From Three Mile Island to the Future

Improving Worker Safety and Health
In the U.S. Nuclear Power Industry

A White Paper
Prepared for the
Blue Ribbon Commission on America's Nuclear Future

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March 14, 2011
First Revision, March 30, 2011

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List of Revisions

No	Date	Description
1	4/4/2011	Incorporates written responses received from NRC. Adds Finding No. 2. Minor edits.

A Note on the Situation in Japan

This report was completed as the nuclear crisis in Japan was unfolding. The relative risks of nuclear energy should be assessed in comparison to the risks of the other energy sources. What has become vividly evident in the past twelve months is that all our major sources of energy -- nuclear, coal and petroleum -- require the most careful management of very high risks. It will be essential in the coming months to determine how well the containment systems and the plant workers in Japan did in protecting not only the general public, but also those workers on the front lines of the crisis. Then we must in a clear-eyed way place that analysis in the context of our overall energy security and climate change goals to chart the nuclear future of the U.S.

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Preface

In January 2010, the Secretary of Energy, acting at the direction of the President, established the Blue Ribbon Commission on America's Nuclear Future to conduct a comprehensive review of policies for managing the back end of the nuclear fuel cycle, including all alternatives for the storage, processing, and disposal of civilian and defense used nuclear fuel, high-level waste, and materials derived from nuclear activities. Criteria for evaluation should include cost, safety, resource utilization and sustainability, and the promotion of nuclear nonproliferation and counter-terrorism goals.

On January 11, staff from the Blue Ribbon Commission asked if we could provide an overview of occupational safety and health risks in the nuclear fuel cycle, from mining to disposal. They also asked that we investigate this risk in terms of the history, current state of, and anticipated future developments in this industry. They asked us to do this in two months, including two weeks for peer review.

The report we have produced reflects the complexity of the subject and the limitations of time that we worked under. The development of the nuclear fuel cycle is surely one of the most fascinating achievements of the industrial age, combining great science, engineering and project management. It is of course also one of the most troubling industries because at every turn we are faced with the prospect of huge risks. We barely had the time to scratch the surface of this topic which deserves much more extensive investigation.

In the time available we were unable to obtain meetings with the Institute of Nuclear Power Operations (INPO), and we did not have time to arrange to visit a nuclear power plant to perform a thorough on-site assessment of safety and health operations. The Nuclear Regulatory Commission provided written responses after we submitted the report to a long list of questions we submitted, and these are included in this revision. Many questions about both the self-regulatory system and the regulatory system have therefore gone unanswered or have been assessed based largely on document review. Also, a number of ancillary issues of interest to the Commission could not be addressed. It is possible that additional work will be performed that could provide new information or cause changes to the existing report. Check the website of the Commission for future updates of this report:

www.brc.gov; then click on "commissioned papers" in the left hand column

The following team worked on this study and there is a brief biography on each at the end of the report:

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ACKNOWLEDGEMENTS

We would like to thank the Blue Ribbon Commission for the opportunity to complete this important study, and for providing us with full support, authority to convene stakeholders, and complete freedom to pursue the available evidence and make our own findings and conclusions based on them. In particular, we would like to recognize the extensive efforts that Commission staff member Dr. Glenn Paulson provided in his capacity as the Commission's liaison with the study team.

At the Commission's request, the following individuals reviewed the draft of this report and provided great insights that were incorporated into the final report:

- Eula Bingham, Ph.D. — Professor of Environmental Health, University of Cincinnati College of Medicine; former Assistant Secretary of Labor for Occupational Safety and Health
- Donald Elisburg, J.D. — Attorney; former Assistant Secretary of Labor for Labor Standards
- James Melius, M.D., Dr.P.H. — Director, New York State Laborers Health and Safety Fund; Chair, Advisory Board on Radiation and Worker Health, National Institute for Occupational Safety and Health
- Sue Wallace — Vice President, Exelon Corporation

Many people provided assistance and insights for which we are grateful. Three significant industry committees gave us time on their agendas: Associated Maintenance Contractors, The Joint AMC-GPA Committee, and the Nuclear Mechanic Apprenticeship Training Committee. The following individuals gave use their time: Ralph Andersen, Nuclear Energy Institute; Ron Ault, Metal Trades Department, AFL-CIO; Mark Ayers, Building and Construction Trades Department, AFL-CIO; Robert Brooks, Shaw Power Group; Scean Cherry, Day Zimmermann NPS; Thomas Cochran, Natural

Resources Defense Council; Sue Dong, CPWR: The Center for Construction Research and Training; Robert D. Daniels, National Institute for Occupational Safety and Health; Larry Elliott, National Institute for Occupational Safety and Health; Richard Fairfax, Occupational Safety and Health Administration; Arthur Frank, Drexel University; Laurence Fuortes, University of Iowa; Derek Hagemeyer, Oak Ridge Associated Universities; Brittain Hill, Nuclear Regulatory Commission; David Hoel, University of South Carolina Medical Center; Tom Houghton, Nuclear Energy Institute; Jocelyn Lian, Nuclear Regulatory Commission; Doris Lewis, Nuclear Regulatory Commission; Giz Kaczorowski, Building and Construction Trades Department, AFL-CIO; David Lochbaum, Union of Concerned Scientists; Lisa Long, Occupational Safety and Health Administration; Sean McGarvey, Building and Construction Trades Department, AFL-CIO; Vernon McDougal, ATL International; Richard Meserve, Carnegie Institution for Science; Arthur Miller, National Institute for Occupational Safety and Health; David Mullen, International Brotherhood of Electrical Workers; Douglas Myers, Duke University Medical Center; Christopher Paine, Natural Resources Defense Council; Charles Pennington, NAC International; Lewis Pepper, Boston University; Reggie Phelps, Bechtel; Robert Pleasure, Building and Construction Trades Department, AFL-CIO; Robert Powers, Nuclear Energy Institute; Natalia Saraeva, Blue Ribbon Commission; Pete Stafford, CPWR: The Center for Construction Research and Training; Alex Thrower, Blue Ribbon Commission; Jim Tomaseki, International Brotherhood of Electrical Workers; Thomas Tansil, Bechtel; James Weeks, Mine Safety and Health Administration; Wayde Werley, Bechtel; and Mary Mendiola and Karen (no last name given), librarians in the NRC Public Document Reading Room.

A final, special thanks to Professor Joseph V. Rees, Virginia Polytechnic Institute, for writing the remarkable little book, *Hostages of Each Other: The Transformation of the Nuclear Industry after Three Mile Island*, which has been cited extensively by the Deepwater Horizon Commission and in this report. He started investigating the industry after he moved near a nuclear power plant, and his book sets a high bar for an active citizenry.

On a final note, we would like to add that the study team members have vivid personal memories of Three Mile Island, are accustomed to the prescriptive regulatory systems that were put in place in the 1970s and have experience with the defense nuclear complex and the damage it did to workers. We approached this assignment with a *questioning attitude*. We found that we had a lot to learn. This study has been a great eye-opener for us. The safety story of the nuclear industry over the past 30 years is worth knowing, and telling.

While recognizing the extensive help and support we have received, I remain solely responsible for the final content of this report, and for any errors or omissions in it.

Seattle, March 14, 2011
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Executive Summary

The Blue Ribbon Commission on America's Nuclear Future (BRC) asked us to study whether occupational safety and health conditions in today's U.S. nuclear industry are reasonably safe, and if those conditions have improved since the Three Mile Island event in 1979. The BRC also asked us to look to the future, to try to anticipate worker safety and health risks that should be addressed by the industry, its government regulators and private watchdogs.

Over the eight weeks allotted, we performed a limited review of the literature and spoke with stakeholder representatives from utilities, contractors, unions, government regulators, and environmental groups. The Nuclear Regulatory Commission (NRC) provided written responses to a long list of question we submitted to it. However, in the time available to us, we were unable to gain access to anyone at the Institute of Nuclear Power Operations (INPO).

We began this study with the knowledge that the defense nuclear operations have exposed workers to risks, and that independent medical evaluations of older DOE workers have found significant rates of a variety of illnesses that are associated with their DOE work. We also knew that Congress had adopted legislation in 2000 to provide former and current DOE workers with compensation for such illnesses. Therefore, we approached our task with vigilance.

Overall, we found that the record of occupational safety and health (OSH) performance for civilian electricity generation is very good, and that this industry's OSH performance has improved in measurable terms since Three Mile Island. The nuclear industry's level of OSH performance is significantly stronger than that of other U.S. energy sectors. However, such comparisons must be viewed in the context of the potentially catastrophic risk inherent to nuclear power generation. Notwithstanding the U.S. industry's strong safety culture, and its very good record in OSH, reportable accidents have continued to occur at American facilities even after improved oversight mechanisms were instituted following Three Mile Island.

The industry's movement to embrace safety culture over the past two decades has been impressive. Safety culture has been increasingly emphasized in the NRC's Reactor Oversight

Process.   It is certain that significant resources must continue to be dedicated by operators, contractors, unions and other stakeholders to training for safe work in the nuclear environment. For its part, we would encourage the industry to take safety culture and self-regulation to an even higher level.

Looking ahead, we identify certain areas of concern that will require industry and regulators to take new actions to ensure that a well-trained workforce operates as safely as possible. In addition, we found that the industry could further improve OSH performance on the front end of the fuel cycle by selectively extending oversight by the NRC and a self-regulatory group similar to INPO, just as it already does in the nuclear power plants. Finally, we found that the once-through fuel cycle does not in itself pose an unmanageable OSH risk to industry workers.

Although the numbers change a little from time to time, the U.S. nuclear fuel cycle is an enterprise with approximately 97 workplaces. Approximately 119,000 workers are employed in power plants, and another 9,000 work in uranium mining, milling, conversion, enrichment, fabrication and waste storage.   For these workers and the American public, a nuclear industry defined by strong oversight, shared responsibility, and a transparent commitment to safe operation and safe workplaces is essential.

Our *Findings* are summarized below. We have ranked them according to importance.

Finding No. 1: On the Whole, Occupational Safety and Health Performance is Very Good

We find that occupational safety and health (OSH) performance is very good in the nuclear power plants and in the back end of the nuclear fuel cycle. Rates of reported occupational injuries and illnesses in nuclear plants have declined greatly since Three Mile Island. The probability of a serious injury or illness resulting from working in a nuclear power plant is very low — at only one-fourth to one-fifth of the rates reported by facilities using fossil fuels.

Of great significance, we note that since TMI, the average radiation dose received by workers in nuclear power plants who recorded any dose has declined by over 90 percent. For many years, not a single worker in nuclear power plants has received a radiation dose over three rem, and in the most recent year with completed reporting (2008) only one facility reported any workers receiving radiation doses above two rem, and then it was only five workers. The NRC's maximum allowable annual dose of five rem is lagging industry practices and scientific consensus and should be reviewed.

The safety culture driving this performance, as described by industry participants, is often credited to the training received by the industry's extensive reliance on managers drawn from America's Nuclear Navy to straighten out operations following Three Mile Island in 1979. While the safety culture is procedure-based and intended to prevent nuclear accidents, it has clearly contributed to the good OSH performance of nuclear facilities.

The industry goes to great lengths to achieve its high level of operational safety and OSH performance. The owners of nuclear power plants acknowledge and embrace their responsibility for the safety of their operations to a much greater extent than we think is the case in other industries. Between seven and eight percent of personnel in nuclear facilities are employed in a safety assurance function. The owners have put in place an impressive system of self regulation by INPO. They are actively regulated by the NRC. Whereas NRC regulates to ensure that operators meet the conditions of their licenses, INPO's intended mission is to help facilities achieve higher standards of excellence in operations. Both NRC and INPO can impose sanctions if they find performance problems.

At least 50 U.S. nuclear plants have unionized workforces, and most of the outage work is performed by contractors using union workers. Union health and safety officers reported to us that labor relations with most nuclear operators are generally good, that joint health and safety committees operate at a number of locations, and that this contributes greatly to their safety.

Despite this overall commitment to safety, the level of safety performance is not uniform throughout the industry. There are still worksites in need of improvement. The general pattern of safe operation has been marred by periodic reportable-level incidents which should have been avoided. Three Mile Island and the near miss at Davis-Besse in 2002 are probably the best known, but there have also been other less well publicized incidents.

We believe that the industry and NRC should continue to strive to improve occupational safety and health throughout the nuclear fuel cycle and ensure that such performance is more uniform throughout the industry. The industry should do more to explain its safety record to the public. In particular, we think the nuclear power plant operators should make public the assessments that INPO conducts of their operations.

Finding No. 2: Significant Adverse Events Mar the Safety Record

NRC maintains records of precursor events and it is required to report annually on all abnormal occurrences to Congress. A significant precursor event is the highest risk rating assigned by NRC. An abnormal occurrence is an unscheduled event that the NRC rates as "significant" in terms of possible effect on public safety and health. According to the NRC, there have been at least a dozen and half significant precursor events and many more significant abnormal occurrences. We were able to obtain documentation on many of these, but not all. So far, as near as we can tell, no workers have experienced adverse health impacts from these events, at least for radiation exposure. However, as the Fukushima Daiichi event demonstrates, this will not necessarily always be the case. Based on the information available to us, we have found it useful to group these events in four different broad categories of risk:

- *Inexperience.* In 1979, the event at Three Mile Island in Pennsylvania revealed that the operator (and the entire industry) was applying a "fossil fuel" mentality that was lacking in understanding of the risks of nuclear power operations or the much greater level of effort required to manage them.

- *Overconfidence*. NRC and the operators rate risks based on probabilistic risk assessments (PRAs). PRAs are performed to allocate prevention resources to where they are most needed, but often they also become interpreted as being indicators of safety, which can result in plant operators and their staff becoming overconfident in the safety of a system or procedure. One good example of this was the hoist at the Waste Isolation Pilot Plant in New Mexico. The designer of the hoist estimated that the probability of a failure was one in 60 million, which plant operators took to mean failsafe. Consequently, neither required maintenance nor training of operating personnel was implemented. Not long after it was placed in operation, the hoist experience two serious failures and the underlying causes were design fault, failure to maintain equipment and failure to implement emergency procedures.
- *Complacency/negligence*. The Davis-Besse event in Ohio in 2002, which is described in detail in this report, revealed that both the operator and the NRC had been aware of a potential risk to a certain type of reactor yet failed to investigate with the result that very severe corrosion of the steel primary containment of the reactor vessel made the reactor highly vulnerable. Operating staff then sought cover up the event and provided falsified information to the NRC.
- *Risk taking*. In 1996, the NRC found that the safety culture at the Millstone nuclear power plant in Connecticut had deteriorated so severely that it shut down the plant for two years. Evaluations of the plant operation found that the operating company had decided to cut corners in order to decrease operating costs in anticipation of having to compete in open electricity wholesale markets.

The excellent safety record of the nuclear power industry must always be balanced against the likelihood of a potentially very significant event occurring in the future, even though it is not possible to quantify the probability or severity of such an event. Consequently, the nation, the industry and the regulators must be fully prepared for a worst-case event. Evidence from the Fukushima Daiichi plant suggests that the U.S. needs to assess whether such readiness is present.

Finding No. 3: Commitment to Safety Culture Must Be Constantly Renewed and Strengthened

Finding ways to maintain high safety performance over time will be NRC's and the industry's biggest challenge. After Three Mile Island, and more so after Davis-Besse, NRC has put a growing emphasis on understanding the safety culture of plants, and the organizational and human factors that control plant operations. There is evidence that this emphasis has had a positive impact on safety performance. Importantly, NRC has worked to identify early warning signs of safety culture degradation.

The emphasis on safety culture recognizes that the people who operate the nuclear fuel cycle are as important to safety as the technologies deployed—and that their behaviors can be hard to predict. The safety culture must aspire to make all personnel in the nuclear cycle, from top executives to crafts workers, equally aware of the need to be vigilant about risk. At this point, safety culture has been defined as a matter of policy by NRC, but only incorporated piecemeal into the NRC Reactor Oversight Process (ROP). The ROP essentially assumes that degradation in culture will be revealed in the reporting of performance indicators by the licensee and through inspections. We have proposed a fundamental change in the ROP in which safety culture is added as a strategic area, with its own cornerstones and performance indicators.

The NRC and the industry are trying to figure out how safety culture fits into the ROP. However, we have found little evidence that a high-performance safety culture can simply be imposed from outside an organization, even by an agency with as much power as the NRC. Safety culture must be built from within, and embraced by managers and workers equally. There is significant evidence to this effect within the nuclear power industry. Plants that NRC has struggled to bring into compliance can be turned into high safety performers when new owners committed to building internal safety culture take them over.

The nuclear power plant operators recognize that they have a general duty and a regulatory responsibility for identifying and resolving safety issues, and that worker involvement in safety processes is essential to this duty. The INPO principles of professionalism includes "a questioning attitude" which is an expectation of all workers. The Safety Conscious Workplace Environment is a cross-cutting issue in NRC's oversight of reactor operations. It allows workers to speak up about potential risks that they observe, without fear of retaliation by management.

As the industry works to strengthen its safety culture process, we believe there may be ways to achieve a higher level of self-regulation. In the wake of huge disasters on off-shore oil rigs in the North Sea, the region's oil industry and its regulators decided that best way to impose the highest level of accountability for rigorous safety processes was to hold both workers and managers responsible both for preparation for any new procedure, and for monitoring of operations. This greatly increased accountability for safety, and has worked well since by all accounts. U.S. nuclear power plants could take similar steps. U.S. plants have emphasized a safety-conscious work environment for many years, and many have adopted joint worker-management safety processes, with different degrees of emphasis. However, in our opinion, the North Sea model's heightened role for workers in the safety process would make sense for the U.S. nuclear industry and should be explored.

We think the NRC should revamp the ROP and replace the cross-cutting areas with safety culture as an added Strategic Area; this would recognize safety culture as a foundation of good safety performance and a fundamental part of the inspection process triggering enhanced regulatory oversight. The industry and NRC should explore creating a safety culture process that gives managers and workers greater parity and accountability in the administration of safety culture, along the lines of programs used by the North Sea offshore oil industry. We believe this approach holds the best hope for assuring safe working conditions.

Finding No. 4: Outage Work Can Be Improved

Periodically, usually every 18-24 months, nuclear plants are shut down for several weeks to undergo maintenance and refueling. In this process the vessel head of the reactor is open, creating inherently higher radiation exposure risks. Specialized contractors bring a thousand or more highly trained workers to perform this operation. Nuclear power plant operators take great care to plan for maintenance work and scheduled outages, and union health and safety representatives told us the industry is a safe place to work.

Occupational safety and health data provided to us by one maintenance contractor showed low occupational injury and illness rates for the nuclear industry compared to the same kind of work in fossil power plants. Even so, maintenance outage workers employed in nuclear plants have occupational injury and illness rates that are twice as high as those of in-plant operations personnel.

NRC does not maintain radiation data that are specific to maintenance work, but it does have data on what it calls "transient workers," who are employed in more than one nuclear plant per year. Most of these workers are engaged in outage work. Although their measured radiation dose is well within regulatory limits, transient workers receive radiation exposures that are 2.5 times greater than permanent in-plant workers. As a result, although transient workers comprise only 24 percent of the workforce that is monitored for radiation exposure in nuclear power plants, they receive 58 percent of the collective radiation dose.

While OSH has improved significantly in maintenance work, the industry's greatest opportunity for continued reduction in industry-wide collective radiation dose lies in reducing radiation exposure during outage work. To measure this, NRC should add two data components to the Radiation Exposure Information Recording System (REIRS) to better classify transient workers: a code for contractor and a code to indicate if the work performed was outage work.

Finding No. 5: Specific and Potential OSH Hazards Warrant Vigilance

We identified a number of areas where because of hazard or risk the industry needs to be especially vigilant.

- ***Aging Facilities*.** Most U.S. nuclear generating facilities are 30 years old or more and most are being given license renewals which will allow them to operate with a life cycle of 60 years, rather than the 40 years for which they were originally approved. There is greater concern about material fatigue and the integrity of aging mechanical systems (including piping, valves and pumps, cables, switches, and auxiliary generators) as they get old, and there is also less empirical evidence to work from to anticipate and prevent failures. The industry and the NRC have recognized this concern and have taken numerous steps to address them. *Nevertheless, we believe that this is an issue that cannot be ignored in any assessment of the future safety of this industry.*
- ***Aging Workforce and Looming Skills Shortage*.** The 20th century build-out of nuclear power plants coincided with the baby boomer generation coming into the work force.

These workers are likely to retire in massive numbers in the next five years. There could be a shortage of experienced nuclear engineers, health physicists, plant operators and particularly skilled crafts workers essential to construction and maintenance. We have heard some in the industry say that the market will take care of this problem--a "build it and they will come" approach, but we also heard others say this is a concern. *In spite of many industry efforts, we do not see evidence that a new U.S. workforce is being developed fast enough, especially in some geographic areas. This may reflect deficiencies in some regional labor markets.*

- ***New Technologies, New Risks.*** While new-generation reactors are expected to reduce safety risks, new materials are being considered to enhance efficiency. Two of these materials pose potential OSH concerns: engineered nano-materials and beryllium. Some forms of engineered nano-fibers have been found to have risks similar to asbestos. Beryllium is highly toxic to susceptible individuals. In workplaces throughout the nuclear weapons complex where workers have been tested, a number of them have been found to have been sensitized to beryllium. Some have developed chronic beryllium disease. *Both of these hazards require utmost care in terms of safe handling practices. For susceptible individuals, there is no threshold of zero risk for beryllium exposure, and therefore it should be managed according to the ALARA ("as low as reasonably achievable") principle. As a precaution, the industry should institute a pilot medical screening study to determine if any workers test positive for beryllium sensitization*.
- ***Working in Underground Salt Formations***. We know of no studies about the occupational health effects of working in salt formations where there is significant exposure to salt dust. *This could be investigated through a pilot medical study of workers in the WIPP facility.*

Finding No. 6: The "Front End" of the Nuclear Fuel Cycle Needs Better OSH Focus

In terms of OSH, the U.S. nuclear fuel cycle appears to function on two levels: at a very high level for nuclear power plant operations and waste management, and at a somewhat lower level in the “front end” — uranium mining, milling and processing.

Mining receives the least OSH focus within the U.S. nuclear fuel cycle. Fewer than 500 U.S. workers are employed in mining operations; however, a number of companies are exploring the possibility of opening new mines. There are now 20 uranium mines in the U.S. The four in-situ leach operations, which produce 90 percent of the total uranium mined, are licensed by NRC. Underground and open pit mines are the only parts of the nuclear fuel cycle that are not licensed by NRC.

Occupational safety and health in underground mining is regulated by the Mine Safety and Health Administration (MSHA). MSHA's regulations are obsolete and it does not have a single radiation expert on staff. Studies of miners by the National Institute for Occupational Safety and Health, show serious health effects among those employed before 1970. There are no independent data in the U.S. on whether underground or in-situ leach mining or milling as practiced today poses a risk to workers.

We believe the industry would benefit by using the same approach to safety in all phases of the nuclear cycle. NRC should seek authority to license all mines. NRC should maintain in-plant inspectors in all large facilities that convert, enrich and fabricate fuel, and at mining sites where it has jurisdiction. A self-regulatory system, with an organization modeled after INPO, should monitor operations in the front end of the cycle. MSHA urgently needs to review its uranium mining program. NIOSH should perform field studies on all types of uranium mining operations to determine if current workers are safe.

Finding No. 7: Construction of New Nuclear Power Plants Could Serve as a Model

The nuclear operators take their responsibilities as owners of new construction seriously. They recognize their responsibility for assuring that this work is done as safely as possible. The handful of construction companies that are capable of constructing a nuclear power plant are equally dedicated to safety. The construction of new nuclear plants could provide a great showcase for demonstrating how construction can be done both safely and efficiently, and this experience could be used to inform construction in other sectors about best practices.

In its review of environmental impact statements in applications to construct and operate new nuclear plants, the NRC seems to accept a risk of one occupational fatality, 100-200 serious occupational injuries and hundreds of recordable occupational injuries per reactor built. If the new reactors that have been proposed are built to this level of risk, the risks to construction workers will be enormous, and in stark contrast to NRC's adherence to ALARA when it comes to nuclear safety, and with no apparent understanding of current construction practices. The NRC has increased its competency in recent years by establishing an Office of New Reactors in its headquarters, and a center to coordinate all construction oversight in its Region II Office, which this evidence suggests was much needed.
We think NRC should examine its policies with regard to construction risks. To do this, NRC needs to continue to add more construction safety and health expertise. NRC should work with the licensees, the contractors and the building and construction trades unions to make new plant construction a model for all U.S. industries.

Finding No. 8: OSH Risks in the Back End Should be Manageable in Diligent Operations

Spent fuel from civilian reactors is increasingly being stored in dry casks within secure facilities. Transfer of spent fuel from wet storage to dry casks includes several difficult work tasks which must be carried out with extreme care. Although there is potential for low level radiation exposure in dry storage facilities, we have found no evidence that this poses an unmanageable OSH hazard to workers. As concrete technology improves, the durability of the casks will be extended as well. Our experience with constructing two permanent deep geologic storage facilities --WIPP and Yucca

Mountain-- demonstrates that in the future safety and health precautions during construction need to be significantly improved over the practices used in the past. Evidence from the operation of WIPP shows a very good level of safety, although potential chronic health effects from working in heavy salt dust has not been explored. We did not examine OSH risks in present-day reprocessing, since there is no reprocessing by the US civilian nuclear industry. The only example of commercial reprocessing we have to draw on is the Nuclear Fuels Services operation in West Valley, New York 40 years ago. Its safety record was not good, and by comparison, waste storage is advantageous from the OSH perspective. *Strictly in terms of OSH concerns for nuclear facility workers, finding permanent storage for nuclear waste is not an urgent issue. This is important in that there appears to be no viable alternative to the once-through fuel cycle in the foreseeable future. We also believe that horizontal deep geological disposal facilities (such as Yucca Mountain) may be advantageous over vertical (deep bore) facilities (such as WIPP) because the latter would require use of hoists that may pose a greater degree of risk to workers. Storage facilities should be subject to the same levels of self-regulation and government regulation as nuclear power plants.*

3

How We Conducted this Study

At the September 22, 2010 meeting of the Blue Ribbon Commission, Commissioner Mark Ayers raised the issue of occupational safety and health:

> "*Much of this Commission's work has and will continue to focus on protecting the environment and surrounding communities, and rightfully so. However, as we consider these issues, I would offer that policies and procedures enacted to protect the workers actually engaged in these processes will help us also protect the environment and the communities along the way. We should consider the worker safety and health track record in the nuclear industry as we proceed. I'm not suggesting it's bad, nor do I have readily available the data to confirm that it's good, but I am suggesting it's an issue to be explored as part of this Commission's work.*"[1]

This is study is the response to his statement. The Commission's charge for this study is in **Annex 1**. It described the overall goals for this study as:

> *"... to understand the history and to provide the BRC a basis for comparison between the OS&H experience of today's once-through fuel cycle and future alternatives that may reduce the need for uranium mining, milling and fuel fabrication*."

In consultation with the Commission staff, we defined this charge as four distinct issues:

[1] BRC. Meeting Transcript, September 22, 2010, pp. 6-7. http://www.brc.gov/pdfFiles/September2010_Meeting/0922musc.pdf [Accessed 1/13/11]

1. Are the occupational safety and health practices and risks in today's nuclear fuel cycle sufficient to assure workers reasonably [as defined in Occupational Safety and Health Act] safe and healthy working conditions at each stage of the nuclear fuel cycle?
2. How do the occupational safety and health practices and risks in today's nuclear power industry compare to other types of electrical power production (hydro, coal, natural gas)?
3. What are the occupational safety and health practices and risks [qualitative and quantitative] at each stage of the nuclear fuel cycle in today's industry compared to 30-40 years ago?
4. What changes can we anticipate in the nuclear fuel cycle over the course of the foreseeable future that will affect occupational safety and health practices and risks in nuclear power generation?

3.1 APPROACH

This study was commissioned on January 11, 2011 with March 14, 2011, as the due date for delivery of the final report, including two weeks for peer review. With only two months to complete this study, we collected as much information as possible from the published literature. In addition, we met with the following groups of stakeholders and asked them to supply information that they thought would be useful to our study:

- Utilities that commission and operate nuclear power plants
- Industry organizations
- Contractors that build and provide maintenance services to the nuclear power plants
- Unions that represent workers who operate, build and maintain nuclear power plants
- Federal regulators
- Environmental organizations that birddog the industry

We reviewed the past history and anticipated future changes and focused on the following factors which we consider to be key conditions for and predictors of safety and health performance:

- Materials used
- Engineering
- Work practices
- Expertise of workforce
- Management systems and oversight
- Reporting
- Regulation

The nuclear fuel cycle encompasses the following stages, which are applicable both to commercial electrical power reactors and the production of nuclear weapons:

- **The "*Front End*":** mining, milling, conversion, enrichment, and fuel fabrication,
- ***Power Generation***: power reactor operations (including fuel loading, spent fuel unloading, and maintenance),
- **The "*Back End*":** Interim storage of spent fuel, recycling or reprocessing, and waste disposal.

For each of these, we considered four cross-cutting issues:

- Construction of facilities
- Maintenance, renovation and repair of facilities
- Closure of facilities (also known as decommissioning and demolition)
- Transportation of wastes

3.2 LIMITATIONS AND EXCLUSIONS

The BRC's charge for this study was to focus foremost on the "back end," and as time permitted, also on the "front end."   For this reason, our study is heavily skewed towards an examination of power generation part of the cycle and its storage of spent fuel. This is also where the bulk of employment in the nuclear fuel cycle is.

There are three subjects that are not covered in this report which could not be addressed because of time limitations. The first has to do terrorist or sabotage threats. These are a risk to our nuclear facilities and therefore to the workers in them. However, we defined this risk as a national security risk and outside the scope of our assignment. Second, we cover only the civilian nuclear industry, and not the defense facilities. This distinction has been blurred in a number of instances and is not so easy to uphold.[2] Third, we focused only on the U.S. industry. We did not attempt to assess safety of nuclear operations abroad, including where re-processing is being performed.

We did not review closure of facilities, including decommissioning and demolition, in any great detail. The reason for this is that this did not appear to be a pressing issue since licenses renewals are leading to no likely new facility closures in this decade.

We started the study with a review of the investigations that followed the accident at the Three Mile Island facility in 1979, because this was a watershed for the industry. The operation of nuclear power industry, including safety and health, has changed continuously since then. The published literature lags behind real time, and while we have tried to account for the latest changes by talking to people in the field, it is possible that not all the latest advances in best practices have made their way into this report.

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[2]We have described findings from occupational medical examinations of DOE workers in Section 7.1 of this Report. Examples of overlap between civilian a defense functions include: enrichment has taken place within the DOE gaseous diffusion plants, which were owned by the government before they were transferred to the US Enrichment Corp. Civilian transuranic waste may be transported to and stored at the Waste Isolation Pilot Plant in New Mexico if it has first been sent to Hanford, Idaho National Laboratory or Savannah River. High level civilian waste is stored at many different DOE facilities, including the remnants of Three Mile Island Reactor No. 2, at the Idaho National Laboratory. Yucca Mountain in Nevada is a DOE facility. We have not addressed the Nuclear Navy facilities at all.

In the time available to us, it has not been possible to review in detail all the available literature, which is vast. We chose to use the Davis-Besse incident of 2002 as a case study because it cuts across many of the issues we were asked to review, and provides a good illustration of the challenges faced by the nuclear power industry and the NRC if they are to assure the nation about the safety of ongoing and future operations. We note, however, that Davis-Besse is not an isolated incident, but rather one of several near-miss incidents that have occurred over the years. Other incidents, we have learned, may in fact have been more serious.

3.3 A NOTE ON THE UNRELIABILITY OF OCCUPATIONAL SAFETY AND HEALTH DATA

This report relies in part on occupational injuries and illnesses data that are reported by employers to the U.S. Department of Labor and on radiation monitoring data that are reported by nuclear operators and other fuel cycle employers licensed by the NRC. We have reported the available data without any attempt to make a determination about their accuracy.

Over the past two decades, the rate of fatal occupational injuries has declined much less than rate of reported non-fatal occupational injuries and illnesses. To be sure, there have been important improvements in occupational safety and health performance over this time period. However, several studies have been published that suggest that employers are not reporting all the non-fatal occupational injuries and illnesses that have occurred, and that the scale of underreporting may be very substantial.[3] In 2010, the Occupational Safety and Health Administration announced an initiative to modernize the injury and illness data collection process with the aim of improving accuracy and availability of these data.[4]

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[3] The Committee on Education and Labor, U.S. House of Representatives. *Hidden Tragedy: Underreporting of Workplace Injuries and Illnesses.* A majority staff report by The Committee on Education and Labor, U.S. House of Representatives, Washington, DC, 2008; Rosenman K, Kalush A, Reilly M, Gardiner J, Reeves M, Luo Z. How much work-related injury and illness is missed by the current national surveillance system? *Journal of Occupational and Environmental Medicine*, 48(4):357-365, 2006; Ruser J. Examining evidence on whether BLS undercounts workplace injuries and illnesses. *Monthly Labor Review*, 131(8):20-32, 2008; Oleinick A, Zaidman B. The law and incomplete database information as confounders in epidemiologic research on occupational injuries and illnesses. *American Journal of Industrial Medicine*, 53(1):23-36, 2010; Boden L, Ozonoff A. Capture-recapture estimates of nonfatal workplace injuries and illnesses. *Annals of Epidemiology*, 18:500-506, 2008; Leigh P, Marcin J, Miller T. An estimate of the U.S. government's undercount of nonfatal occupational injuries. *Journal of Occupational and Environmental Medicine*, 46, 10-18, 2004; Friedman L, Forst L. The impact of OSHA recordkeeping regulation changes on occupational injury and illness trends in the U.S.: a time-series analysis. *Occupational and Environmental Medicine*, 2007;64:454-460; Boden L, Ozonoff A. Researcher judgment and study design: challenges of using administrative data. *American Journal of Industrial Medicine*, 53(1):37-41, 2010; 12.

[4] Occupational Safety and Health Administration, US Department of Labor. Modernization of OSHA's Injury and Illness Data Collection Process. Federal Register 75:24505-24509, May 5, 2010. http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=FEDERAL_REGISTER&p_id=21470 [Accessed 1/29/11]

Many of the people we spoke to from the nuclear industry indicated that the nuclear industry is regulated very strictly and that it is likely that the data that are reported in this industry are more accurate than in general industry. We are not aware of any studies suggesting that there has been systematic underreporting of radiation monitoring data on workers in civilian nuclear facilities to the NRC.

3.4 WHAT WE MEAN BY "SAFETY."

Safety can be defined in different ways. In this report we use three definitions of safety:

- **Occupational safety and health (OSH)** refers to the recognition and prevention of any hazard in the workplace that can be harmful to human health. These including traumatic hazards ("falling from something"); musculoskeletal hazards (such as lifting too heavy loads and getting a back sprain, or working with the hands overhead regularly which can harm the shoulders); and health hazards (such as radiation or chemicals that can cause lung damage or cancer). The nuclear industry often refers to occupational safety as "industrial safety," to differentiate it from "nuclear safety."
- **Nuclear safety** seeks to make sure that facilities that make or use radiation prevent any of the radiation from being released into the environment.
- **Radiation safety** refers to the monitoring of workers or the environment for radiation and estimating whether the amount of radiation released is hazardous.

4

Introduction

On March 25, 1979 America had its first experience with a crisis in the civilian nuclear industry when Reactor No. 2 at the Three Mile Island (TMI) in Pennsylvania experienced a partial meltdown. It caused a public panic and a confused government response. Although TMI was a very serious accident that should never have happened, it could have been much worse. The investigations immediately following the accident found no evidence of significant harm to human health, including to the workers in the plant.[5,6] As the subsequent investigations unfolded, one very disturbing finding became evident: *none* of the nuclear power plants in operation was well prepared for an accident like the one at Three Mile Island. The accident could have happened at *any* of the plants given what the President's Commission on the Accident at Three Mile Island referred to as the "*mindset*"[7] that existed in the industry and in the regulatory agency responsible for oversight of the industry — the U.S. Nuclear Regulatory Commission (NRC). Consequently, the nuclear power industry as a whole could not be considered safe.[8]

The *mindset* that was referred to was this: at the NRC, the focus was on technology and procedures without a concomitant focus on the human factors required to manage, operate and control the technology or implement the procedures; and at the power plants, there was a "fossil fuel mentality" in the industry that failed to appreciate the need for far greater management rigor in a

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[5] *Report of the President's Commission on the Accident at Three Mile Island*, 1979. http://www.threemileisland.org/downloads/188.pdf. [Accessed January 16, 2011]

[6] Subsequent analyses of the population around TMI found increases in some radiation-related cancer rates. Wing S, Richardson D, Armstrong D, Crawford-Brown D. A reevaluation of cancer incidence near the Three Mile Island nuclear plant: the collision of evidence and assumptions. *Environmental Health Perspectives*, 105:52-57, 1997. NRC has asked the National Academies to perform a state-of-the-art study on cancer risk for populations surrounding NRC-licensed nuclear facilities. NRC. *Fact Sheet on Analysis of Cancer Risk in Populations Near Nuclear Facilities—Phase 1 Feasibility Study*. http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-analys-cancer-risk-study.html. [Accessed 3/4/11].

[7] *Report of the President's Commission on the Accident at Three Mile Island*, 1979, p. 8. http://www.threemileisland.org/downloads/188.pdf. [Accessed January 16, 2011]

[8] *Three Mile Island: A Report to the Commissioners and the American People*. Nuclear Regulatory Commission, January 1980. http://www.threemileisland.org/downloads/354.pdf [Accessed January 16, 2010]

nuclear plant.[9] Before Three Mile Island, at both the NRC and in nuclear plants, the risk management concerns had been about the probability of a technology disaster occurring, rather than the probability of an operator not knowing how to implement emergency procedures in the event of an accident. The central recommendations of the President's Commission put it this way:

> "*To prevent nuclear accidents as serious as Three Mile Island, fundamental changes will be necessary in the organization, procedures, and practices -- and above all -- in the attitudes of the Nuclear Regulatory Commission and, to the extent that the institutions we investigated are typical, of the nuclear industry.*"[10]

Thirty-one years following the accident at Three Mile Island, our nation was struck with another industrial disaster that was not dissimilar but had much more severe consequences in terms of human health and the environment. On April 20, 2010, an explosion consumed the Deepwater Horizon drilling rig far offshore in the Gulf of Mexico. The recent report of the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling eerily echoes the reports from Three Mile Island:

> "*The Commission examined in great detail what went wrong on the rig itself. Our investigative staff uncovered a wealth of specific information that greatly enhances our understanding of the factors that led to the explosion.... There are recurring themes of missed warning signals, failure to share information, and a general lack of appreciation for the risks involved. In the view of the Commission, these findings highlight the importance of organizational culture and a consistent commitment to safety by industry, from the highest management levels on down.*"[11]

This history illustrates the first theme that runs through this report. The nuclear fuel cycle is an amazingly complex system, and like any complex system, it consists of a huge number of subsystems. A defect in any of these subsystems can bring down the overall system. TMI started with cooling pumps shutting down, but the operators at first did not know this, and then they did not know how to deal with the crisis. Those basic defects—a technology problem combined with failure in training and preparation—led to a cascade of other problems which in the end brought the whole system down. Had the pump problem been handled correctly, the TMI accident would not have proceeded to the stage of a large fraction of the nuclear fuel rods actually melting. Every detail matters. One comment we heard repeatedly from workers, employers, utility owners and regulators, was expressed in two different ways. *If you take care of the little things, the big things take care of themselves... If you focus on the big things at the expense of the little things, you open yourself up to risk.*

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[9] Rees JV. *Hostages of Each Other: The Transformation of Nuclear Safety Since Three Mile Island*. The University of Chicago Press, 1994, p. 15.

[10] *Report of the President's Commission on the Accident at Three Mile Island*, 1979, p. 7. http://www.threemileisland.org/downloads/188.pdf. [Accessed January 16, 2011]

[11] National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling. *Deep Water: The Gulf Oil Disaster and the Future of Offshore Drilling*, January 2011, p. ix. https://s3.amazonaws.com/pdf_final/DEEPWATER_Report to thePresident_FINAL.pdf [accessed January 16, 2011.]

The second theme in this report is that it is not sufficient to assure safety by simply putting in place procedures and systems. There has to be a mindset —or culture— that embraces safety at every stage and by every participant regardless of occupational status. However, new mindsets and cultures are hard to define or create. Our Constitution calls for us to "*Create a more perfect union…*" but in spite of this admonition and 240 years to achieve it, we still have a ways to go. While commissions, whether TMI or Deep Water, call for cultural change, their specific recommendations invariably revert to procedures: better training, more quality control, improved instrumentation, and other procedures that aim to keep each person involved ever alert when adverse events are rare but potential risks are cataclysmic. We still need to understand *the human factor*. The NRC-commissioned investigation following TMI framed it this way:

> "*The one theme that runs through the conclusions we have reached is that the principal deficiencies in commercial reactor safety today are not hardware problems, they are management problems. These problems cannot be solved by the addition of a few pipes and valves—or, for that matter, by a resident Federal inspector at every reactor....[T]he most serious problems will be solved only by fundamental changes in the industry and the NRC.*"[12]

The third theme has to do with the people who populate the nuclear fuel cycle, the human factor that is critical to the culture of the enterprise. The nuclear fuel cycle is foremost an incredibly complex engineering enterprise. But it still takes people to run them. Figuring out systems is hard. Figuring out people is also hard. It takes very different skills to understand systems and people.

Shortly after TMI, the commercial nuclear power industry established the Institute of Nuclear Power Operations (INPO), and staffed it with veterans of the Nuclear Navy, which had a long-standing appreciation of safety culture. To make sure INPO would be responsive to their needs and that the industry would understand INPO's "take-home message," executives and other staff from the utilities began to rotate through INPO. The group first brought about significant improvements in training, procedures, equipment failures, design problems and inadequate supervision. Then, in the mid to late 1980s it launched the "*Professionalism Project*" to instill the adherence to a safety-first mindset.[13] Following the Davis-Besse incident in 2002, it produced the industry's first formal statement on principles of safety culture.

In February, 2011, after nearly three years of development, including review in at least two public meetings and publishing drafts in the Federal Register, NRC staff finalized this definition and recommended that the Commissioners adopt it:

> "*The Commission defines Nuclear Safety Culture as <u>the core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize</u>*

[12] Rogovin M, Frampton GT. *Three Mile Island: A Report to the Commissioners and the American People*. Nuclear Regulatory Commission, January 1980, p. 89. http://www.threemileisland.org/downloads/354.pdf [Accessed January 16, 2010]

[13] Rees JV. *Hostages of Each Other: The Transformation of Nuclear Safety Since Three Mile Island*. The University of Chicago Press, 1994, p. 152.

safety over competing goals to ensure protection of people and the environment."[14]

Our report to the BRC in many ways documents the journey from Three Mile Island to the finalization of NRC's statement. Hopefully, we have also anticipated future risks with some degree of validity. It was hard enough to define "safety culture." Making it stick will be a whole lot harder — for operators, workers and regulators.

[14] NRC staff finalized the draft policy in December and have recommended that the Commissioners adopt the policy, which is in process. NRC. *Final Safety Culture Policy Statement*, January 5, 2011. NRC–2010–0282. [Emphasis in original]. http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2011/2011-0005scy.pdf. [Accessed 2/13/11]

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The Nuclear Fuel Cycle in the U.S.

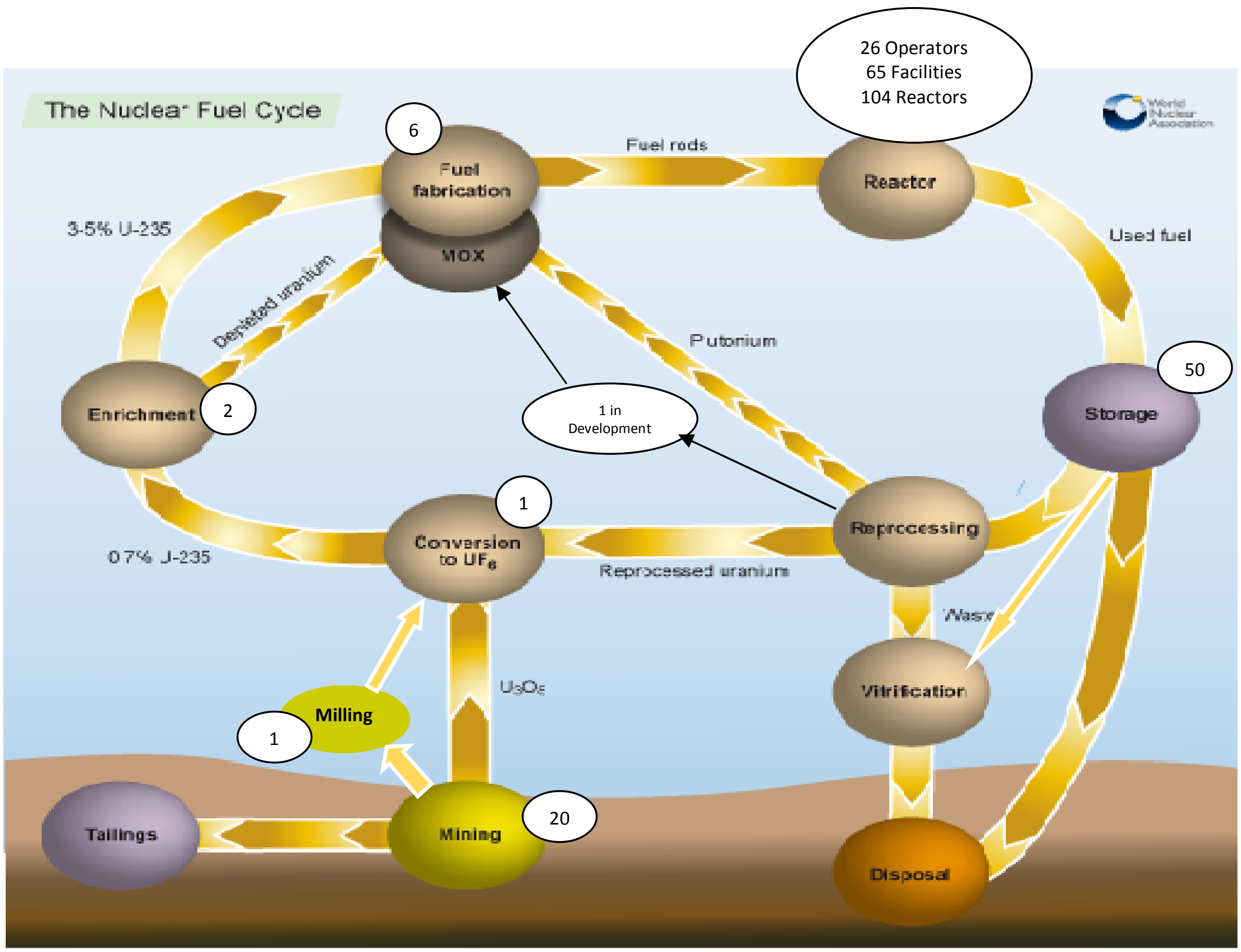

Fig. 5.1: The Nuclear Fuel Cycle and Participants in It

The civilian nuclear power industry in the U.S. is an amazingly compact enterprise. Fig. 5.1 shows the fuel cycle and the entities that participate in it.

Today, the country's nuclear fuel cycle consists of this limited universe:

- **Front end**
  - Twenty mining operations, of which 14 are underground, and four are in-situ leach operations. These four produce 80-90% of all uranium
  - One milling operation
  - One conversion plant
  - One enrichment plant (plus one in start-up)
  - Six fuel fabrication facilities
- **Electricity generation**
  - Four companies design and manufacture reactors
  - Twenty-six operating companies[15] generate electricity using nuclear fuel at 65 facilities with a total of 104 reactors
  - A half dozen companies build, maintain and repair nuclear power plants
- **Waste Disposal**
  - Five companies design and supply interim dry storage systems
  - Fifty interim spent fuel storage sites (all but two are located within operating nuclear power plant sites)
  - No permanent disposal facility for high level civilian waste

There are four principal organizations that protect this community: The NRC sets rules and oversees the safety of operations; the industry, through INPO, provides a self-regulation system; the Nuclear Energy Institute acts as its principal advocate; and the Electric Power Research Institute conducts research and development work. To a lesser extent, the Occupational Safety and Health Administration and the Mine Safety and Health Administration also serve a protective role. The Department of Energy serves an essential but separate role in the form of research, development and promotion of nuclear energy.

Understanding the community is critically important in terms of managing safety and health. Accountability is critical to safety performance, but there are not very many points of accountability in this industry. It is a manageable universe.

5.1 EMPLOYMENT IN THE NUCLEAR FUEL CYCLE

Fewer than 130,000 people work in today's civilian nuclear fuel cycle and that number has not changed much over the past 20 years. About 100,000 of them are employed in operations. The rest are for the most part employed in maintenance, repair, and renovation work, and in other support functions. (Table 5.1)

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[15] Typically public and private utilities.

Table 5.1: Status of Civilian Nuclear Fuel Cycle Facilities and Estimated Employment with Opportunity for Occupational Radiation Exposure in the US, 2010

	Number		Locations
	Facilities	Workers	
Mining (incl. Exploration) [16]	20	1,000	Active and inactive domestic uranium mines are located in: Alaska, Arizona, Colorado, Montana, Nebraska, Nevada, New Mexico, North Dakota, North Dakota, Oregon, South Dakota, Texas, Utah, Virginia, Washington, and Wyoming
Milling[17]	1	200	One operating uranium mill in Utah, three mills in standby status in Colorado, Utah, and Wyoming, and one under development in Colorado.
Conversion[18]	1	700	Illinois (Honeywell UF_6 Plant)
Enrichment[19]	2	3,700	Kentucky; One centrifuge plant in start-up in New Mexico
Fuel Fabrication[20]	6	3,600	Virginia, North Carolina, South Carolina, Tennessee, and Washington.
Reactor Operations[21]	65	119,000	Throughout nation
Interim Spent Fuel Storage[22]	2	100	There are two independent storage facilities, in Illinois and Oregon. In addition 48 ISFS facilities are located in nuclear power plant facilities in 32 states.
Total	97	128,300	

The Bureau of Labor Statistics of the Department of Labor reports that there are approximately 55,000 workers employed in nuclear power plant operations, but that does not include workers who are employed by contractors to do maintenance and repair work. These facilities report that in 2008, 118,692 distinct individuals were issued radiation badges, and most likely about 20% of these, or 20-25,000 work temporarily, mostly for maintenance contractors and possibly at more than one nuclear facility each year. The remaining are operator company support personnel not tied to the individual power plant, visitors and miscellaneous individuals.[23] The difference between the numbers reported to the BLS and to the NRC reflects that the NRC report maintenance workers only if they have been issued a radiation badge, while BLS reports on maintenance work under an industry classification known as "specialty trades,"[24] which does not provide a break-out of workers doing maintenance in nuclear plants.

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[16] U.S. Energy Information Administration. *Annual Domestic Uranium Production Report.* July 15, 2010. http://www.eia.doe.gov/cneaf/nuclear/dupr/dupr.pdf [Accessed 1/17/11]
[17] *Ibid.*
[18] NRC. *Occupational Radiation Exposure At Commercial Nuclear Power Reactors and Other Facilities 2008*, NUREG 0713, Vol. 30, table 3.1 http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0713/v30/sr0713v30.pdf [Accessed 1/13/11]
[19] *Ibid*.
[20] *Ibid*.
[21] *Ibid*.
[22] NRC*. Licensed/Operating Independent Spent Fuel Storage Installations by State*. October 10, 2010. http://www.nrc.gov/waste/spent-fuel-storage/locations.html [Accessed 1/17/2010]
[23] Doris Lewis, NRC REIRS Project Manager, Interview, February 8, 2011.
[24] NAICS 238.

Construction of new nuclear power plants is being planned. Construction of a typical two-unit power plant should take approximately five years, and should employ at its peak about 1,600 workers per unit.[25]

5.2 DESCRIPTION OF WORK IN THE FUEL CYCLE[26]

5.2.1 Mining, Milling and Ore Transport[27]

The purpose of mining and milling is to transform uranium as found in the ground into "yellowcake."

About 90% of all the 25,000 tons of uranium used annually to make nuclear fuel comes from foreign sources. Uranium is recovered from the earth using either underground tunneling and open pit (surface/strip) mining, or in-situ leaching.

Underground or open pit mining produces ore and is not regulated by the NRC. The ore is transported to a uranium mill, where it crushed and ground so that it can be made into a slurry. The slurry is treated with sulfuric acid and alkalis to leach out the uranium and transform it into yellowcake. Uranium milling is licensed by the NRC. The ratio of ore to uranium extract is on the order of 500-5,000:1, so milling produces vast quantities of tailings treated as hazardous waste. Domestic mill tailings sites are located in Arizona, Colorado, Idaho, New Mexico, North Dakota, Oregon, Pennsylvania, South Dakota, Texas, Utah, Washington, and Wyoming.

In-situ recovery of uranium is regulated by states under agreements with the NRC. The process relies on the injection of a solution of water, gaseous oxygen and carbon dioxide into bore holes in ground to separate the uranium from the ore.[28] The uranium slurry is then pumped out of the ground and processed into yellowcake. In-situ mining also produces large volumes of liquid hazardous chemical wastes. In-situ operations are regulated by the NRC, through agreements with agencies in states where operations are located.

About 500 workers are employed in mining operations, and another 500 are involved in uranium exploration. The one active uranium mill in the US employs fewer than 200 workers.

5.2.2 Conversion, Enrichment[29] and Fuel Fabrication[30]

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[25] D'Olier R, Cunningham J, Coward R. *DOE NP2010 Nuclear Power Plant Construction Infrastructure Assessment*. Department of Energy, October 21, 2005. http://www.ne.doe.gov/np2010/reports/mpr2776Rev0102105.pdf. [Accessed 2/13/11].

[26] The fuel cycle is described excellently in a series of articles which were published in *Health Physics News*, and which we will reference throughout this section. An overview can be found in Andersen R. The resurgence of nuclear power. *Health Physics News*, 36(7):1-9, July 2008.

[27] Brown S. The uranium recovery industry. *Health Physics News*, 36, September 2008.

[28] US Energy Information Administration. *Domestic Uranium Production Report*, 2009. http://www.eia.doe.gov/cneaf/nuclear/dupr/dupr.html. [Accessed 1/1/11]

[29] Cypret O. Uranium conversion and isotopic enrichment. *Health Physics News*, November 2008.

[30] Maybry AQM. Fuel Fabrication. *Health Physics News*, January 2009.

Yellowcake is a chemical compound of uranium and impurities. Conversion is used to prepare yellowcake for enrichment. Yellowcake is transported from the mills to a conversion facility where it undergoes a chemical process involving more treatment with sulfuric acid and alkalis to remove impurities. It is then combined with fluorine, and transformed to liquid uranium hexafluoride (UF_6). There is only one conversion plant in the US, the Honeywell plant in Metropolis, Ohio. About 700 workers are engaged in conversion in the Honeywell plant.

The purpose of enrichment is to concentrate the uranium-235 isotope, which is more easily split to produce energy (also known as "*fission*"). The United States Enrichment Corporation (USEC) operates the only U.S.-owned uranium enrichment facility in the United States, a gaseous diffusion plant (GDP) in Paducah, KY. This process, which is inefficient, is being replaced by centrifuge technology. One centrifuge facility is being constructed by USEC in Piketon, OH, and another by URENCO in New Mexico is in the start-up of operations phase. According to the NRC, about 3,700 workers are employed in the USEC plant in Paducah.[31]

The enriched UF_6 is transported to one of six fuel fabrication facilities. There, it is transformed chemically into pellets that can be inserted into fuel rods. A fuel rod is a tube that is about the width of a finger made of zircaloy. The fuel rod is then placed into an assembly which can hold up to 264 fuel rods. According to the NRC radiation monitoring data, about 3,600 workers are employed in fuel fabrication.[32]

5.2.3 Nuclear Power Generating Facilities

The fuel rod assemblies are transported to nuclear power plants where they are placed in the reactors. The U.S. only uses light water (LW) reactors, which use ordinary water for cooling. Two thirds of reactors are pressurized water reactors (PWR) and one third are boiling water reactors (BWR). They both do the same thing using somewhat different processes: they use the heat from the reactor to make water circulating within the reactor core very hot, which in turn heats a separate system that produces steam which is directed into turbines to generate electricity. PWRs use 150-200 fuel assemblies, and BWRs use about 750-800 fuel assemblies.

These reactors can typically run 18-24 months before they have to be shut down for maintenance and refueling, or what is known as an "*outage*." An outage typically involves one or more contractors that specialize in outage work, bringing in between 1,000-2,000 crafts workers[33] and engineers to do the required work. These outages are planned in great detail in advance and the workforce trains extensively for the work that is to be done. In the last 15 years, real-scale mockups of the planned workspaces have been built to enable workers to simulate the work that is to be performed, in part to make sure that workers are shielded from any possible radiation

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[31] See Table 5.2.
[32] *Ibid*.
[33] The principal crafts involved in outage work are: millwrights, iron workers, sheet metal workers, pipefitters, boilermakers and electricians.

sources. One reason that the capacity of the nuclear power plants has increased so much is that the outage process has been made much more efficient. In 1990, a refueling outage averaged 104 days; it is now approximately 40 days.[34]

The 104 reactors in the U.S. are located in 65 facilities. Twelve companies own approximately 70 percent of all the reactors. Many facilities have two reactors and two have three. There are a total of about 55,000 permanent workers in these facilities, and an additional 20,000-25,000 contract workers perform maintenance and repair work.

5.2.4 Interim Spent Fuel Storage

Spent fuel from nuclear reactors has been stored largely on-site at nuclear power facilities in water pools. These pools are becoming crowded, and may also pose a security risk. Therefore, the industry has been transferring this fuel into dry storage "casks." This is a difficult procedure that is done by people with a great deal of experience, using carefully developed procedures. Figure 5.3 gives an overview of the process:

1. A storage canister placed in a transfer cask is sunk into a fuel loading pool.
2. Spent fuel racks are loaded into slots in the canister under water.
3. A steel plug is lowered into the loading opening in the transfer cask and shut tight.
4. The transfer cask is removed from water, the plug is welded shut remotely, then drained, dried and decontaminated.
5. The transfer cask is placed in a steel and concrete storage cask, which is plugged and welded shut.
6. The storage cask can then be stored above or underground.

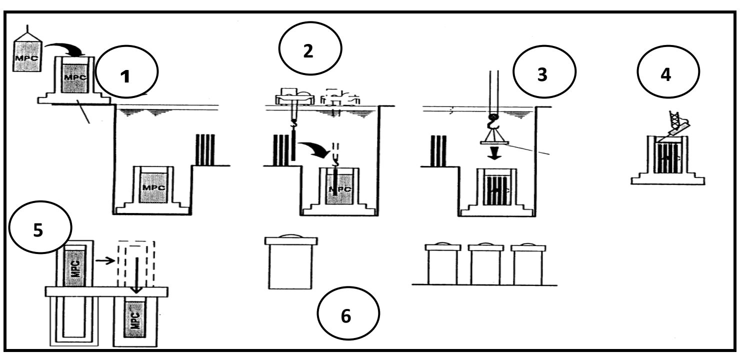

Fig. 5.3. Process for Moving Spent Fuel from Wet to Dry Storage

5.2.5 Closure of Facilities

[34]Nuclear Energy Institute. *U.S. Nuclear Refueling Outage Days (Average, 1990-2009).* http://www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/graphicsandcharts/refuelingoutagedays/. [Accessed 3/11/11].

The end stage of the life cycle of a nuclear facility is known as “closure” or decommissioning and demolition. Fig. 5.4 shows how NRC pans this very difficult task.

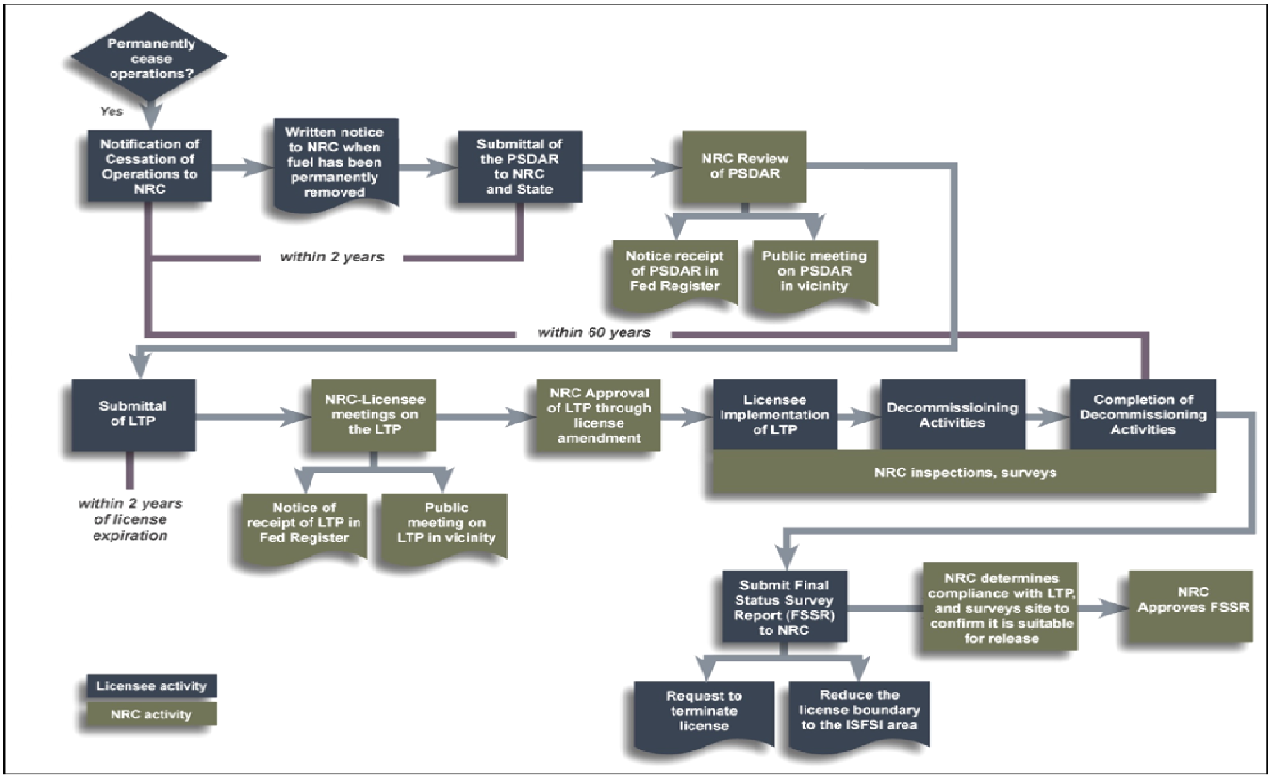

Fig. 5.4 NRC Process Flowchart for D&D

Since the start of the civilian nuclear operations, 28 reactors have shut down, including Shippingport. Of these, 12 have been completely decommissioned; 10 are in SAFSTOR; three are in ENTOMB; and two are in the process of being decommissioned; and one is listed as “other.”[35] Almost all of the currently licensed reactors are projected to operate until at least 2020, and most until after 2030. Therefore closure is, at least for now, a manageable problem.

5.2.6 Waste Facilities

The U.S. nuclear industry does not recycle or reprocess fuel, and it does not yet have facility to permanently dispose of spent fuel from nuclear power plants. There is a need to find ways to get rid of the nuclear waste that is accumulating across the country and there is growing demand for new nuclear fuel.

There are no facilities in the US to reprocess civilian waste at this time. A facility that will convert surplus nuclear materials from the atomic weapons program into mixed oxide (MOX) fuel for use in civilian nuclear reactors is being built at the Savannah River Site in South Carolina.[36] It is

[35] NRC. *Nuclear Reactors*: *2010-2011 Information Digest, Appendix B.* NUREG-1350, Volume 22. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1350/ [Accessed 1/22/11].
[36] http://www.moxproject.com. [Accessed 1/29/11]

scheduled to begin operations in 2016, some nine years behind schedule and 16 years after the US Department of Energy contracted for it. It is only planned to operate for 20 years. Based on this experience, reprocessing does not appear to be economically promising. Also in development is a plant to vitrify nuclear waste at Hanford, but it will probably take 20 years from start to operations, and it is not designed to process civilian waste either.[37]

Only two repository have been designed for permanent disposal of the more difficult types of nuclear waste. The Waste Isolation Pilot Plant (WIPP) in New Mexico has functioned for over ten years, receiving only transuranic waste from nuclear weapons facilities, which does not include the spent fuel from nuclear power production. The other repository that was intended to receive high level wastes and also spent fuel, at Yucca Mountain, Nevada, is in limbo. Regardless of what happens with Yucca Mountain, the disposal problem will not be resolved in the foreseeable future.

5.3 THE END RESULT

In the end, this is what comes from the civilian nuclear fuel cycle: all together the 104 reactors can produce enough electricity to supply approximately 20% of America's electricity demand. This electricity is fed into the nation's electrical power distribution system, or "grid." There, electricity generated by nuclear power plants competes with electricity generated from fossil fuels, hydro and alternative sources. The economics of using nuclear fuel is greatly affected by the economics of coal, oil and natural gas, and wind and solar generation.

The Energy Policy Act of 1992 had the stated objective to “remove impediments to competition in wholesale trade and to bring more efficient, lower cost power to the Nation’s electricity customers.” The Federal Energy Regulatory Commission is responsible for administering it, and provides for open and equal access to jurisdictional utilities’ transmission lines for all electricity producers, thus facilitating the States’ restructuring of the electric power industry to allow customers direct access to retail power generation. However, it is the states that regulate the rates that customers have to pay for electricity. In the second half of the 1990s many states shifted from highly regulated, local monopolies which provided their customers with a total package of all electric services and moved towards a competitive marketplace for electricity (or what is known in the utility industries as a "merchants market").[38] This was also a period of consolidation: in 1995 there were 45 nuclear power plant operating companies; today there are 26.[39]

By one account, Northeast Utilities adopted a competitive strategy in anticipation of deregulated markets which drove down operating costs, but also increased risk, resulting in events that in 1996 led the NRC to shut down all three reactors in the company's Millstone

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[37] http://www.hanfordvitplant.com/ [Accessed 2/12/11]

[38] U.S. Energy Information Administration. *Electric Power Industry Restructuring Fact Sheet*. http://www.eia.doe.gov/cneaf/electricity/page/fact_sheets/restructuring.html. [Accessed 2/2/11].

[39] This source says there are 25. World Nuclear Association. *Nuclear Power in the USA*. December 2010. http://www.world-nuclear.org/info/inf41.html [Accessed 2/25/11].

nuclear power plant in Connecticut and to require many costly changes. This in turn forced the company's financial collapse and in 2000 a transfer of ownership to Dominion.[40] Since then, the plant has had a good record of safety as rated by NRC inspectors, and has obtained license renewals for two of its reactors that could lengthen their operating life to 60 years. There are two sides to the argument about the benefits of competitive markets and ownership consolidation. Northeast Utilities' strategy reflects the potential downside, and Dominion's take-over shows the potential upside.

[40] MacAvoy P, Rosenthal BJ. *Corporate Profit and Nuclear Safety: Strategy at Northeast Utilities in the 1990s*. Princeton University Press, 2004.

6

History:

Thirty Years of Improved Safety and Health Performance

6.1 THE DEVELOPMENT OF THE INDUSTRY

Table 6.1 presents important milestones in the development of the nuclear power industry and its safety.

Table 6.1: Important Milestones in the U.S. Civilian Nuclear Industry and Safety

1957	Shippingport Atomic Power Station becomes the first nuclear power generating plant connected to the Grid. It was created by Admiral Hyman Rickover to demonstrate the feasibility of civilian uses of nuclear power.
1960	First commercial plant (Dresden 1) comes on-line.
1974	The Energy Reorganization Act abolishes the Atomic Energy Commission, which had the dual but conflicting functions of encouraging use of nuclear energy and also regulating its safety. The law divides the functions and creates the Energy Research and Development Administration (which in 1977 is made part of the newly created Department of Energy) to encourage use, and the NRC to regulate its safety.
1979	Three Mile Island event leads to the focus on the "human factor" and the creation by the industry of the Institute of Nuclear Power Operations (INPO), which is formed to raise standards of operation and to fend off looming regulation by the NRC.
Mid-late 1980s	INPO launches the "professionalism project" to turn nuclear power plants into higher performing organizations.
Mid-1990s	The Energy Policy Act of 1992 authorizes deregulation of energy markets. This forces the nuclear power plant owners to become more efficient and leads to a consolidation of ownership into large specialized nuclear operating companies.
2000	NRC modifies its procedures for inspection to identify and direct inspections to higher-risk plants through its Reactor Oversight Process.
2002	Davis-Besse incident forces a reassessment by the NRC, INPO and the industry and leads to a greater focus on safety culture.
2005	Energy Policy Act helps foster a resurgence of interest in nuclear power plant and technology development.
February 2011	NRC staff recommends adoption of final Nuclear Safety Culture Policy

Following Three Mile Island in 1979, new applications for permits to build and operate nuclear power plants dried up, and the ones that were under development and construction became tied up in requirements which frequently led to major re-engineering and modification, even if construction had already been completed. The last currently licensed reactor to begin operations was the Tennessee Valley Authority's Watts Bar No. 1 reactor in Tennessee. Construction was started in 1973 and it began operations in 1996.[41]

The complexity of design and review has permeated all aspects of the nuclear industry. Planning for the Waste Isolation Pilot Project (WIPP) in New Mexico began in 1974. Construction permits were approved in 1980. It took 10 years following completion of initial construction to obtain the operating permits, due to extensive national review of the safety of transportation of waste to the facility and arguments about licensing and jurisdiction.[42]

Beginning in 1989, NRC and the industry began to lay the foundation for what they hoped would become a new period of growth in nuclear energy. NRC did its part by creating a three-pronged licensing framework: (1) Standard Design Certification of reactors; (2) Early Site Permitting; and (3) combined Construction and Operating (CO) License.[43]

As noted in Section 5.3, significant industry consolidation resulted, with the number of operators of nuclear plants dropping from 45 in 1995 to 26 today, creating huge specialized nuclear energy companies.[44] For safety performance, this consolidation can have significant benefits. First, if the parent has a well-developed safety culture, it can instill that in a plant with a troubled history. Second, the parent company can bring expertise and scale of operation. After Entergy bought the troubled Pilgrim nuclear plant, an interviewer spoke to the plant manager, who had stayed on. The manager told him that previously when encountering a problem "*...you feel like you're alone in the desert".* As part of Entergy, *..."he had a wide network to tap into during a crisis.*"[45]

The Energy Policy Act of 2005 made it possible for investors to take a chance on developing new plants by providing for loan guarantees and other benefits.[46] As a result, construction has

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[41] Browns Ferry no 1 in Alabama was restarted in 2007. It had been shut down in 1985.

[42]Kidder L. The Good and Bad of WIPP. *New Mexico Business Journal*, March 1999, http://findarticles.com/p/articles/mi_m5092/is_2_23/ai_54369783/. [Accessed 2/25/11].

[43] While this process was intended to streamline nuclear power plant development, and in spite of NRC's expressed desire for transparency, some say it has made it hard for community stakeholders to participate in a very cumbersome, three-track process. Lochbaum D., Union of Concerned Scientists. *Personal Communication*, 25 February 2011.

[44] World Nuclear Association. *Nuclear Power in the USA*. December 2010. http://www.world-nuclear.org/info/inf41.html [Accessed 2/25/11].

[45] Zachary GP. Entergy has figured out a way to make aging atomic power plants pay--and is fueling the industry's unlikely resurgence. *CNN Money*, May 1, 2005. http://money.cnn.com/magazines/business2/business2_archive/2005/05/01/8259698/index.htm. [Accessed 2/20/11]

[46] Public Citizen characterized the Act as follows: *"The Energy Policy Act of 2005...contains more than **$13 billion in cradle-to-grave subsidies and tax breaks**, as well as unlimited taxpayer-backed loan guarantees, limited liability in the case of an accident, and other incentives to the mature nuclear industry to build new nuclear reactors."*

started to finish plants that were mothballed years ago. Construction of Watts Bar No. 2 was resumed in 2007, and it is expected to come online in 2013.[47] It will be first new nuclear power plant to begin operations in the U.S. in 20 years. Site preparations for two new ones have been started, and license applications for about 30 new reactors in various stages of development are being reviewed at NRC. There could be a "*resurgence of nuclear power*."[48]

6.2 THE CAPACITY FACTOR

In order for nuclear power to be competitive economically with other forms of electricity generation, it has to maximize efficiency, by minimizing downtime of reactors and making sure they produce the maximum amount of electricity. This is known as "capacity," and operating at 100% is known as "peak capacity." Fig. 6.1 shows the average efficiency of all the operating nuclear reactors in the US. The efficiency over the past decade has been very high, at 90% or higher, which compares to 65% for coal fired plants and 40% for hydro plants.[49] The industry is running at nearly peak capacity.

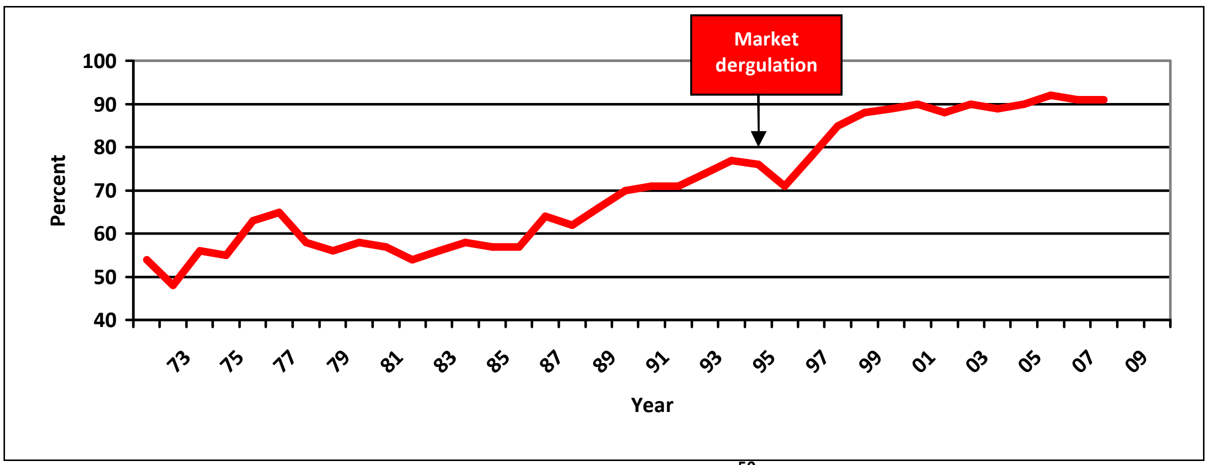

Fig. 6.1: Average Operating Capacity, All Nuclear Power Plants, US[50]

6.3 IMPROVEMENTS IN RADIATION SAFETY PERFORMANCE

If the time, complexity and cost of developing the nuclear fuel cycle grew drastically following TMI, so too did the development of safety precautions. Fig 6.2 shows the decline in average

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Nuclear Giveaways in the Energy Policy Act of 2005. [Emphasis in original]. *http://www.citizen.org/documents/NuclearEnergyBillFinal.pdf. [Accessed 2/25/11]*

47 http://www.tva.gov/power/nuclear/wattsbar.htm [Accessed 1/19/11]

48 Anderson R. The resurgence of nuclear power. *Health Physics News*, 36(7):1-9, July 2008.

49U.S. Energy Information Administration. *Electric Power Industry 2009: Year in Review*. January 4, 2011. http://www.eia.doe.gov/cneaf/electricity/epa/epaxlfile5_2.pdf

50Nuclear Energy Institute. U.S. Nuclear Generating Statistics (1971 - 2009). http://www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/graphicsandcharts/usnucleargeneratingstatistics/. [Accessed 2/21/11].

annual measurable dose of radiation per worker over a 36-year period. Between 1973 and 2009 there was a 90% decline.[51] Reflecting on this trend, the NRC concluded, *"The overall decreasing trend in average reactor collective doses since 1983 indicates that licensees are continuing to successfully implement ALARA dose reduction processes at their facilities."*[52] Radiation data, including distribution of dose among workers, is described in Section 9 of this report.

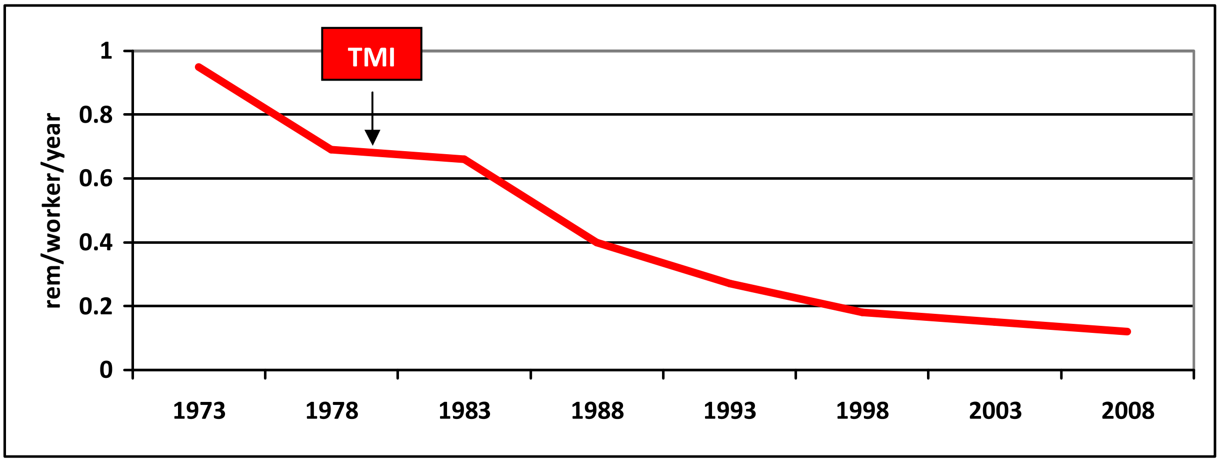

Fig 6.2: Average Annual Radiation Dose per Worker with Measured Dose

The National Council on Radiation Protection noted in its national review of radiation risks:

> *"The annual collective dose for nuclear-power operation peaked in the early 1980s…. Since then, there has been a steady decrease in both the number of individuals with recordable doses and the annual collective dose…. The decrease in annual collective effective dose for U.S. power plant workers occurred during a period in which the electricity generated by this industry increased. This can be accounted for because the efficiency of reactor operation increased with fewer and shorter outages, improved reactor coolant chemistries and materials, careful planning for outages, increased emphasis on the as low as reasonably achievable principle and radiation safety, improved tools and procedures, and a renewed emphasis on cleanliness of the work environment."*[53]

Between 1983 and 2008, the amount of occupational radiation exposure per unit of electricity produced declined by 94% for all nuclear power plants combined.[54] During that same time period, capacity increased by an equally impressive 60%.[55]

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[51]NRC. *Occupational Radiation Exposure At Commercial Nuclear Power Reactors and Other Facilities 2008*, NUREG 0713, Vol. 30, Table 4.1. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0713/v30/sr0713v30.pdf [Accessed 1/13/11]

[52] Ibid, p. 4-6.

[53]*Ionizing Radiation Exposure of the Population of the United States: Recommendations of the National Council on Radiation Protection and Measurements*. NCRP Report No. 160, March 3, 2009, pp. 221-222.

[54]Improved performance in the first seven of the performance indicators is shown in decreases in industry averages. Improvements in the last two are demonstrated by increasing average. NRC. *Occupational Radiation*

The trend in safety performance can also be tracked in the nine performance indicators that the NRC requires power plant licensees to monitor and report to the NRC.   The indicators and the average performance for all the nuclear power plants combined are shown in Table 6.2.[56] Most of them have shown declines, although for many of them there is little room for further decline.

Table 6.2: Industry Performance Indicators, Annual Industry Averages, FY 2000-2009

Performance Indicator	Year									
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Automatic Scrams	0.52	0.57	0.44	0.75	0.56	0.47	0.32	0.48	0.29	0.36
Safety System Actuation	0.29	0.19	0.18	0.41	0.24	0.38	0.22	0.34	0.14	0.23
Significant Events	0.04	0.07	0.05	0.07	0.04	0.05	0.03	0.02	0.02	0
Safety System Failure	1.4	0.82	0.88	0.96	0.78	0.99	0.59	0.68	0.69	0.67
Forced Outage Rate	4.23	3	1.7	3.04	1.88	2.44	1.47	1.43	1.34	2.21
Equipment-Forced Outage	0.13	0.11	0.12	0.16	0.15	0.13	0.1	0.11	0.08	0.09
Collective Radiation Exposure	115	123	111	125	100	117	93	110	96	88
Drill/Exercise Performance	96	95	95	96	96	96	96	98	96	97
ERO Drill Participation	98	99	99	99	99	99	99	99	100	100

Of particular importance are the first two performance indicators in Table 6.2. According to Joseph Rees,[57]

> *"Two indicators--on scrams and safety system actuations... are generally regarded as the leading proxies for measuring the overall safety of nuclear reactors operations. A scram refers to the rapid shutdown of a nuclear reactor in an emergency [like slamming your car's brakes to avoid an accident], and from 1980 to 1990 the annual industry average dropped from 7.6 to 1.6 scrams per unit--an 80 percent drop. As for safety actuations, picture (say) a nuclear plant's emergency core cooling system activated in response to an emergency. Because this ordinarily occurs when the limits of safe reactor operation have been reached, fewer actuations are a sign of greater care in plant operation, according to INPO and the NRC, and greater care contributes to a higher margin of safety. In 1985 (the first year this was measured by the NRC) the average number of actuations per unit was 2.74, while the average for 1990 was 1.5--a 60 percent drop."*

This is a significant achievement.

Exposure At Commercial Nuclear Power Reactors and Other Facilities 2008, NUREG 0713, Vol. 30, Figure 4.3. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0713/v30/sr0713v30.pdf [Accessed 1/13/11]

[55] See Table 6.1.

[56] NRC. *Nuclear Reactors*: *2010-2011 Information Digest, Appendix G.* NUREG-1350, Volume 22. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1350/ [Accessed 1/22/11].

[57] Rees JV. *Hostages of Each Other: The Transformation of Nuclear Safety Since Three Mile Island*. University of Chicago Press, 1995, p. 183. For more detail see NRC. *Organization and Safety in Nuclear Power Plants*. NUREG-5437, May 1990, pp. 135-154.

- **Scrams**: A "scram" is a rapid shutdown of a reactor in an emergency. According to Rees' analysis, the average number of scrams per licensed reactor was 7.6 in 1980, and 1.6 in 1990. As Table 6.2 shows, by 2000, it was 0.52 and 2009 it was 0.36. The decline from 1980 to 2009 was 95%. (See Fig. 6.3)
- **Safety System Actuations**: A "safety system actuation" is the deployment of a system to mitigate an emergency. According to Rees, the average number of actuations per licensed reactor was 2.74 in 1985, and 1.05 in 1990. As Table 6.2 shows, by 2000, it was 0.29 and 2009 it was 0.23. The decline from 1985 to 2009 was 92%. (See Fig 6.4)

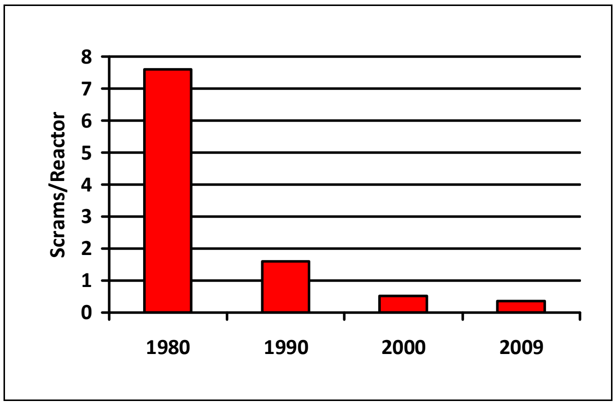

Fig 6.3: Decline in the Average Annual Number of Scrams Per Licensed Reactor, 1980-2009

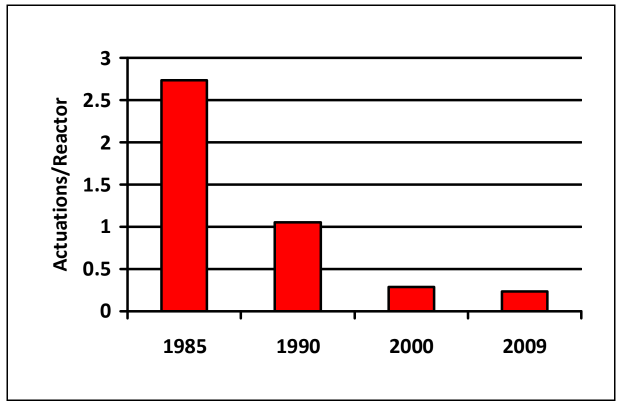

Fig 6.4: Decline in the Average Annual Number of Actuations Per Licensed Reactor, 1985-2009

As these figures show, massive improvements in safety performance took place between 1980 and 1990, and again between 1990 and 2000.

Based on these data, since TMI the nuclear power plants lowered their most serious risk indicators on average by over 90%

6.4 PERIODIC ADVERSE EVENTS MAR THE SAFETY RECORD

The problem about looking at averages is that they do not tell us anything about outliers. We found three listings of significant events at nuclear power plants: two official listings by NRC and one unofficial.[58] The first is a 2002 NRC press release. It states that since 1979, 18 events have

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[58] A more extensive list, which does not overlap much with the NRC list, and which we have not attempted to verify, is provided by Sovacool BJ. Nuclear power plant accidents in the U.S. with multiple fatalities or more than US$100 million in property damage, 1952-2010. *Wikipedia*. http://en.wikipedia.org/wiki/Nuclear_safety_in_the_United_States#cite_note-bksaccident-14 [Accessed 2/28/11]. See also Murphy GA, et. al. *Survey and Evaluation of System Interaction Events and Sources.* NUREG/CR-3922, Januray 1985. It analyzes 235 adverse events occurring prior to December, 1984. http://en.wikipedia.org/wiki/Nuclear_safety_in_the_United_States#cite_note-bksaccident-14 [Accessed 2/28/11].

been rated as significant, and several of them have been rated more severe than the 2002 Davis-Besse event. (See Table 6.3)[59]

Table 6.3 The Seven Highest Ranked Nuclear Power Plant Significant Precursor Events Since 1979

Rank	Nuclear Power Plant	Year	Event
1	Three Mile Island	1979	Partial core meltdown
2	Davis-Besse	1985	Feedwater loss
3	Brunswick	1981	Heat exchanger damage
4	Shearon Harris	1991	Unavailability of high pressure injection pump
4	Wolf Creek	1994	Drainage of reactor cooling water during outage
4	Catawba	1996	Loss of off-site electrical power feed
4	Davis-Besse[60]	2002	Cracking and corrosion of reactor vessel head

The latter four are roughly tied in terms of risk at approximately 6 in 1,000.

The second source about problematic events is the NRC annual report to Congress on "*abnormal occurrences*." Congress defines an abnormal occurrence as an unscheduled incident or event that the NRC determines is significant from the standpoint of public health or safety. These reports cover all licensees in the nuclear fuel cycle.[61] The reports that we have been able to access since 1989 are summarized in Table 6.4. This table contains our assessment of the causes of each incident.

Table 6.4: NRC Abnormal Occurrence Reports to Congress
Concerning Risks in the Nuclear Fuel Cycle Licensees, 1989, 1996-2010

Year	Facility	Process	"Abnormal"	Occurrence	Finding(s)
1989	Nine Mile Point, NY	Reactor	No	Radioactive spill	A 1981 flooding incident caused a radioactive spill in the sub-basement of the Radwaste Processing Building (RPB), which had never been decontaminated. The licensee was using the room as a liquid radwaste holding area although it had been designed as a solid radwaste drumming and storage facility. An NRC inspection team found about 150 55-gallon drums of radwaste in the room with estimated dose rates on the drums as high as 500 rem/hour and the total estimated inventory in the room to be about 7,500 curies.[62]
1989	Trojan, OR	Reactor	Yes	Damaged/missing	A July 1989 inspection of the sump, which

[59] NRC. *NRC issues preliminary risk analysis of the combined safety issues at Davis-Besse*. *NRC News,* September 20, 2004.
http://adamswebsearch2.nrc.gov/idmws/DocContent.dll?library=PU_ADAMS^pbntad01&LogonID=98e38de21dbe62f4dc4eb1321a727b25&id=042640204. [Accessed 1/20/11]. We, as well as the NRC pubic documents librarians, were unable, were unable to assemble the entire list of 18 "significant events" to which the press release refers. Some may have been in the early years for which the reports to Congress are not available on line at NRC.
[60] This event is described in detail in Section 6.5 of this Report.
[61] Section 208 of the Energy Reorganization Act of 1974 (Public Law 93-438)
[62] NRC. *Memorandum S89-387, SECY-89-387-Section 208: Report to the Congress on Abnormal Occurrences for July-September 1989,* January 19, 1990

				screens in emergency cooling system	contained a large amount of debris, found that a 3/16-inch wire mesh screen had not been installed as required by the approved design. The screen is required to keep debris from entering the pumps needed for emergency cooling. Other screens for the sump were found to be damaged or missing. The condition had existed for at least one year and possibly since initial plant operation in 1975.[63]
1996	Maine Yankee, ME	Reactor	No	Failure of safety culture	NRC received information in late 1995 alleging that inadequate analyses were knowingly performed in support of license amendments to increase the rated thermal power of the plant which NRC subsequently granted. An NRC investigation confirmed the validity of the allegations and ordered the licensee to return the plant to the originally licensed power limit.[64]
1996	Millstone No. 1, No. 2, No. 3, CT	Reactor	No	Failure of safety culture	The NRC Office of Inspector General found that certain activities at Millstone Unit 1 related to operation of the spent fuel cooling systems may have been conducted in violation of license requirements and refueling activities may not have been consistent with the Updated Final Safety Analysis Report (UFSAR). Investigators for the licensee determined that: • the original 1986-87 UFSAR contained errors and omissions, • administrative control programs did not fully address regulatory requirements and were not fully implemented • the UFSAR was not seen as requiring accurate information. • internal communications showed that licensee management received information as early as 1985 identifying risks and weaknesses associated with the design bases and UFSAR, • licensee management made commitments to correct these deficiencies that were either ineffective, partially implemented, or not implemented, and • licensee oversight did not identify the

[63] *Ibid*.
[64] NRC. *Report to Congress on Abnormal Occurrences—Fiscal Year 1996,* NUREG-0090, Vol. 19, February 1997.

					information communicated to management, its significance, or the effectiveness of the corrective actions. The report also stated that similar management conditions likely existed at Millstone Units 2 and 3 and at Haddam Neck. NRC subsequently determined that all of these units had similar deficiencies. Millstone 3 and Haddam Neck were shutdown until critical system modifications were made to meet NRC regulations.[65]
1996	Braidwood No. 1 and No. 2, IL	Reactor	Yes	Containment bypass leakage due to human error	During a testing procedure in November 1994 hydrogen sensing lines were disconnected inside a monitor cabinet. Following the test, operators observed the lines outside the cabinet and assumed the lines had been reconnected inside the cabinet without verifying the situation. The lines remained disconnected for approximately three months until discovered and re-connected. The hydrogen monitoring system is a critical system used to determine containment hydrogen concentrations during a loss of coolant accident. NRC implemented escalated enforcement and assessed a $100,000 civil penalty.[66]
1996	Wolf Creek, KS	Reactor	Yes	Deficient design of essential service water system	In the early morning hours of January 30, 1996, plant operators received alarms and reports indicating that screens for the circulating water system were becoming blocked by ice adversely affecting the system that provides cooling during emergency conditions. The root cause of this event was found to be deficiencies in the design of the essential service water system warming line. NRC issued a civil penalty of $300,000 because of violations as a result of this event.[67]
1997	Oconee No. 3, FL	Reactor	Yes	Loss of high pressure injection pump	During the post-shutdown cooling period prior to a piping inspection in May 1997 insufficient water was available to supply high pressure coolant system pumps. A subsequent investigation showed the potential for a more serious situation if a small break loss-of-coolant accident had occurred because all three HPI pumps

[65] *Ibid*.
[66] *Ibid*.
[67] *Ibid*.

					would have been inoperable. The cause was traced to faulty water level instruments that showed a higher water level than existed. The NRC implemented escalated enforcement and assessed a $330,000 civil penalty.[68]
1998	Big Rock Point, MI	Reactor	No	Loss of liquid poison system	The Big Rock Point plant was permanently shut down in August 1997. The LPS tank contains a concentrated solution of sodium pentaborate. In April, 1998 an inspection revealed that the LPS discharge pipe was completely severed due to corrosion about six inches above the bottom of the tank due to the inadequate curing of a phenolic coating on the inside of the pipe during manufacture in 1961. Metallurgical analysis estimated that the pipe had failed due to corrosion between 1979 and 1984 rendering the LPS system inoperable during the last 14 years of plant operation.[69]
1998	Quad Cities, IL	Reactor	No	Deficient fire program	The licensee for the Quad Cities plant submitted an analysis of fire risks to the NRC in February 1997 that showed the turbine building to be at risk of severe fire-related accidents. Units 1 and 2 both share the facilities in the same turbine building. The licensee shut down both units in the 4th quarter of 1997 to implement corrective actions. The licensee was subsequently allowed to re-start the reactors; additional improvements are planned for future refueling outages in 2000 and 2001.[70]
1998	St. Lucie No. 1, FL	Reactor	No	Recirculation actuation signal/engineering miscalculation	In October 1997, St. Lucie Unit 1 was defueled for an outage to replace obsolete plant components. During the outage, an engineering calculation adversely affected instrumentation showing the water level in the refueling water tank which could have caused damage to pumps. The licensee implemented corrective actions including training for engineering and maintenance staff.[71]
1999	Indian Point No. 2, NY	Reactor	No	Scram and partial loss of power;	The automatic shut down of Reactor 2 in August 1999 was followed by a cascade of

[68] NRC. *Report to Congress on Abnormal Occurrences—Fiscal Year 1997,* NUREG-0090, Vol. 20 March 1998.
[69] NRC. *Report to Congress on Abnormal Occurrences—Fiscal Year 1998,* NUREG-0090, Vol. 21. March 1987.
[70] *Ibid.*
[71] *Ibid*

				Failure of safety culture	electrical system failures which revealed lapses in configuration control and management oversight. As a result, NRC increased its attention to the licensee's overall safety program. An inspection team found that a significant contributor to the event was inadequate upkeep of electrical components and station management missed a number of opportunities to recognize degrading plant conditions and implement corrective actions.[72]
1999	Fitzpatrick, NY	Reactor	No	Hydrogen storage facility valve failures	The failure of three separate valves in January 1999 led to a fire in the hydrogen storage facility located about a hundred yards from main structures of the plant. Licensee and local fire brigades responded and put out the fire in about an hour then sprayed water on the storage cylinders to ensure the remaining hydrogen would escape without restarting a fire.[73]
2000	Indian Point No. 2, NY	Reactor	Yes	Steam generation tube failure	In February 2000, a steam generator tube failed causing a leak of 146 gallons per minute of radioactive water and a release to the environment within regulatory limits. There are four steam generators at Indian Point Unit 2 and each one has 3,300 tubes. A subsequent NRC inspection determined that the licensee performed an inadequate examination of the steam generator tubes during the last outage in 1997 which allowed degraded tubes to remain in service leading to the failure. The licensee had opportunities to replace the affected tubes and had failed to do so.[74]
2001	Oconee No. 3, SC	Reactor	No	Cracked welds	During a shutdown period, a visual examination of the reactor pressure vessel head found small amounts of boric acid residue at 9 of the 69 control rod drive mechanism (CDRM) penetration nozzles and indications of recordable cracks at all 9 locations. Circumferential cracking of CDRM nozzles and welds is a degradation of the reactor cooling system pressure boundary and raises concerns

[72]NRC. *Report to Congress on Abnormal Occurrences—Fiscal Year 1998,* U.S. Nuclear Regulatory Commission, NUREG-0090, Vol. 21.

[73] *Ibid*.

[74] NRC. *Report to Congress on Abnormal Occurrences—Fiscal Year 2000,* NUREG-0090, Vol. 23.

					about a potentially risk-significant generic condition affecting all pressurized water reactors (PWRs).[75]
2001	Point Beach , WI	Reactor	No	Auxiliary pumps	Under certain conditions all four auxiliary feedwater pumps could fail because of overheating. If the pumps had failed in this way, the probability of damage to the reactor core would have increased significantly. The potential for failure existed since the early 1970s when the two reactors began commercial operations.[76]
2002	Davis-Besse, Oak Harbor, OH	Reactor	Yes	Cracked vessel head Failure of safety culture	During a refueling outage beginning in February 2002, repairs were initiated on cracks near control rod drive mechanisms and the removal of boric acid deposits at the top of the pressure vessel head. A "pineapple sized" cavity caused by corrosion was found in the low alloy steel head. The entire damaged head of the reactor was replaced.[77]
2002	Salem Unit No. 1, DE	Reactor	No	Spent Fuel Pool Leak	Personnel exiting a radiologically controlled area, were found to have low-level radioactive contamination on their shoes. The contamination was traced to a leak containing radioactive contaminated water due to blocked drains under the spent fuel pool. In November 2002, tritium activity was detected in the ground adjacent to the Fuel Handling Building which enclosed the spent fuel pool. Corrective actions and remediation were implemented.[78]
2003	Honeywell Specialty Chemicals, Metropolis, IL	Chemical process	Yes	Radioactive release Failure of safety culture	A 70-pound uranium hexafluoride (UF6) release lasting approximately 40 minutes occurred in one of the plant's chemical process lines. Four members of the public were taken to the hospital. Three were examined and released, but one showed skin reddening on portions of his face and arm indicating a hydrogen fluoride (HF) acid burn. NRC's Notice of Violation issued in May 2004 noted that a

[75] NRC, *Report to Congress on Abnormal Occurrences—Fiscal Year 2001.* NUREG-0090, Vol. 24, April 2002. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0090/v24/. [Accessed 1/17/2010]
[76] U.S. Nuclear Regulatory Commission, *Report to Congress on Abnormal Occurrences—Fiscal Year 2002.* NUREG-0090, Vol. 25, April 2003. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0090/v25/ [Accessed 1/17/2010]
[77] U.S. Nuclear Regulatory Commission, *Report to Congress on Abnormal Occurrences—Fiscal Year 2002.* NUREG-0090, Vol. 25, April 2003. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0090/v25/ [Accessed 1/17/2010]
[78] U.S. Nuclear Regulatory Commission, *Report to Congress on Abnormal Occurrences—Fiscal Year 2003.* NUREG-0090, Vol. 26, April 2004. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0090/v26/ [Accessed 1/17/2010]

					reconfiguration of the fluorination system allowed the leak to occur and that there was a failure to execute various emergency response plan measures. A follow-up inspection in December 2004 found that Honeywell personnel failed to properly inspect UF6 cylinders before filling them and had shipped 14 full cylinders with prohibited valves attached.[79]
2003	Westinghouse Columbia Fuel Fabrication Facility, SC	Fuel Fabrication	Yes	Contaminated ash	271 kilograms of ash were found in the secondary combustion chamber of an incinerator used to reduce uranium-contaminated process waste volume and facilitate uranium recovery from the waste at a maximum uranium concentration of approximately 30 wt%. No criticality safety controls were in place to prevent the accumulation of fly-ash containing excessive uranium concentrations.[80]
2005	Kewaunee, WI	Reactor	No		Failed to conduct adequate engineering analysis and to provide adequate design control to ensure that the design of KPS prevented turbine building flooding and safe shutdown of the plant. Contributing causes included a lack of complete understanding of the risk associated with internal flooding events; the failure to adequately evaluate and implement actions to address industry operating experience; and the failure to adequately resolve known deficiencies.[81]
2006 2008	Nuclear Fuel Services, Erwin, TN	Fuel Fabrication	Yes	HEU spill	A transfer of high enriched uranium (HEU) solution through a transfer line resulted in a spill of approximately 35 liters, first into a glovebox where a criticality was possible and then to the floor where a criticality was also possible due to the presence of an elevator pit. If a criticality accident had occurred at either place, at least one worker likely would have received a high

[79] U.S. Nuclear Regulatory Commission, *Report to Congress on Abnormal Occurrences—Fiscal Year 2004.* NUREG-0090, Vol. 27, April 2005. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0090/v27/ [Accessed 1/17/2010]
[80] U.S. Nuclear Regulatory Commission, *Report to Congress on Abnormal Occurrences—Fiscal Year 2004.* NUREG-0090, Vol. 27, April 2005. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0090/v27/ [Accessed 1/17/2010]
[81] U.S. Nuclear Regulatory Commission, *Report to Congress on Abnormal Occurrences—Fiscal Year 2005.* NUREG-0090, Vol. 28, April 2006. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0090/v28/ [Accessed 1/17/2010]

					enough exposure to cause acute health effects or death.[82] There were two root causes: 1) the facility's failure to manage the configuration of its processing system, and 2) safety culture deficiencies at the facility.[83]

6.5 DAVIS-BESSE: A CASE STUDY

It seems everyone in the nuclear industry knows what happened in 2002 at Davis-Besse plant. However, few people outside the industry know much about it even though it has been subject of Congressional hearings and has been written up in the popular press.[84]

6.5.1 Background

By the middle of 2001, the NRC had concluded that certain PWRs made by one manufacturer were subject to a corrosion risk from leaks around the vessel head. The NRC had been examining this risk for many years and decided that all plants using this particular reactor would be shut down before the end of 2001 for a careful evaluation of possible corrosion. One of those reactors was at the Davis-Besse facility in Ohio. Its owner, FirstEnergy Nuclear Operating Company (FENOC), requested an extension of the deadline since it already had a refueling outage scheduled for March 31, 2002. NRC prepared a shutdown order, but after subsequent discussions with FENOC the NRC concluded that FENOC's responses, including information and video tape of earlier inspections of the reactor vessel head in 1996, 1998 and (to a lesser extent 2000) indicated that Davis-Besse could be granted an extension. Based on this information, NRC agreed to a February 16, 2002 shutdown, subject to the plant making a number of “compensatory” adjustments to operations to protect against possible risk.[85]

The leaks of concern involved water containing boron leaking out from inside the reactor. Boron is a highly corrosive acid. The investigation following the shutdown revealed extensive corrosion on the reactor vessel head, especially around the control rod nozzles. Moreover, the investigators discovered a large hole in the 6.6 inch (20 cm.) thick carbon steel vessel head caused by corrosion. The only thing containing the pressure inside the reactor, and preventing control rods from possibly ejecting, was a stainless steel reactor liner that was only 1/8 inch (0.5 cm.) thick. This lining was not designed for the purpose of containment of this kind of pressure

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[82] U.S. Nuclear Regulatory Commission, *Report to Congress on Abnormal Occurrences—Fiscal Year 2006.* NUREG-0090, Vol. 29, April 2007. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0090/v29/ [Accessed 1/17/2010]

[83] U.S. Nuclear Regulatory Commission, *Report to Congress on Abnormal Occurrences—Fiscal Year 2008.* NUREG-0090, Vol. 31, May 2009. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0090/v31/ [Accessed 1/17/2010]

[84] Biello D. Atomic weight: balancing the risks and rewards of a power source. *Scientific American*, January 29, 2009.

[85] NRC. *Nuclear Regulatory Commission (NRC) Staff Evaluation Related to NRC Bulletin 2001-01 response. FirstEnergy Nuclear Operating Company, Davis-Besse Nuclear Power Station, Unit 1*. Docket No. 50-346. http://www.nrc.gov/reactors/operating/ops-experience/pressure-boundary-integrity/upper-head-issues/upper-head-files/davisbesse-closeout-bl2001-01.pdf. [Accessed 2/14/11].

and was showing signs of distress. Had it burst, the reactor would be seriously compromised. Subsequent modeling concluded that it could have burst in as short a period of time as two weeks, or it could have help up for approximately a year. The investigation also found many other problems at the facility.

Fig. 6.5. The corroded part of vessel head after it was cut out from the rest of the vessel head.

The findings of this investigation resulted in the reactor being shut down for two years, a record fine being levied on FENOC by the NRC, two criminal convictions involving fraud in reporting information to the NRC, and FENOC incurring repair costs estimated at $600 million.

There had been many warning signs of this problem at Davis-Bessie for several years. The plant was aware of boron buildup and some corrosion. It had found filters in radiation detection devices inside the reactor containment that were clogged with boron dust, and the rates that filters had to be changed out had gone up dramatically and had no relationship to established norms.[86] Nevertheless, in the inspection cycle just prior to the event, the NRC had given the plant a Green (or safe) rating, which meant that no additional inspection resources needed to be allocated to the plant.

6.5.2 NRC Assessment

The NRC established a "Lessons Learned" Task Force to review this incident. It found a host of technical problems at Davis-Besse as well as in the design of the reactor and the Davis-Besse plant as a whole, but it honed in what it characterized as safety culture problems as root causes. The plant personnel failed to perform hazard recognition and correction assessments and quality assurance procedures. It faulted management oversight and monetary incentives

[86] Andersen R. Nuclear Energy Institute. Personal Communication, February 18, 2010.

to managers that favored production over safety. It concluded, (referring to Davis-Besse as DBNPS):[87]

> *"About 10 years ago, the NRC and industry recognized the potential for an event such as the one that occurred at DBNPS. In spite of the wealth of information...[but] that the likelihood of such an event was low...*
> *The task force concluded that the event was not prevented because: (1) the NRC, DBNPS, and the nuclear industry failed to adequately review, assess, and follow-up on relevant operating experience; (2) DBNPS failed to assure that plant safety issues would receive appropriate attention; and (3) the NRC failed to integrate known or available information into its assessments of DBNPS's safety performance.*
>
> *"The task force identified multiple DBNPS performance problems that indicated DBNPS's failure to assure that plant safety issues would receive appropriate attention. Specifically, the licensee failed to: (1) resolve long-standing or recurring primary system component leaks; (2) establish and effectively implement a boric acid corrosion control program; and (3) adequately implement industry guidance and NRC recommendations intended to identify VHP nozzle leakage. Collectively, these and other performance issues involved: (1) strained engineering resources; (2) an approach of addressing the symptoms of problems as a means of minimizing production impacts; (3) a long-standing acceptance of degraded equipment; (4) a lack of management involvement in important safety significant work activities and decisions, including a lack of a questioning attitude by managers; (5) a lack of engineering rigor in the approach to problem resolution; (6) a lack of awareness of internal and external operating experience, including the inability to implement effective actions to address the lessons-learned from past events; (7) ineffective and untimely corrective actions, including the inability to recognize or address repetitive or recurring problems; (8) ineffective self-assessments of safety performance; (9) weaknesses in the implementation of the employee concerns program; and (10) a lack of compliance with procedures."*

6.5.3 FENOC Assessment

On August 15, 2002 FENOC presented the results from its root cause evaluation of management failures at Davis-Besse to the NRC in a public meeting. FENOC defined the root cause as: *"There was a focus on production, established by management, combined with taking minimum actions to meet regulatory requirements that resulted in the acceptance of degraded conditions."* [88]

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[87] NRC. *Davis-Besse Reactor Vessel Head Degradation: Lessons-learned Task Force Report*. http://www.nrc.gov/reactors/operating/ops-experience/vessel-head-degradation/lessons-learned/lessons-learned-files/lltf-rpt-ml022760172.pdf. [Accessed 2/21/11].

[88] FirstEnergy, 2002. Management of human performance root causes. Presentation slides, August 15

As part of NRC's requirements, Davis-Besse agreed to undergo an independent safety culture evaluation to determine whether it had made improvements in its safety programs. The survey was conducted a year after the plant had been shut down. While it found significant improvements in the safety programs, there were still many deficiencies. Specifically: safety, and accountability and ownership for safety were not consistently accepted or integrated throughout the organization, or aligned with a common set of values.[89] On October 1, as part of the "*Quest to Get Our Plant Back, Better and Beyond*," FENOC reported that it had developed a safety culture that was "*built to last*."[90]

6.5.4 The NRC Inspector General's Assessment

The Office of Inspector General is NRC's independent in-house watchdog. It reviewed the NRC's actions in the Davis-Besse incident and reported in December 2002.[91] It found that the NRC had issued a bulletin on August 3, 2001 to all licensees having the particular nozzles in question asking them to assess the problem. The plants found to have the highest susceptibility would have to shut down to perform the recommended inspections, so to save the industry money and to prevent competition for maintenance teams, they allowed a five month window, until December 31, 2001 to conduct the inspections. Davis-Besse was unwilling to shut down before December 31, wanting to wait until its next outage on March 30, 2002 to perform the inspections. Thus, the NRC began to draft a shut down order. At the same time, NRC and FENOC began to discuss compensatory measures that could be taken to avoid a shutdown. The staff discussed the matter as a group, and concluded that the nozzle was unlikely to fail before a February inspection date. They agreed to an inspection date in February and the order was never issued.

The Inspector General found that the NRC actions had been influenced by the financial impact on the industry in general and Davis-Besse in particular (though it was rationalized as a means of reducing regulatory burden). Further, the NRC staff had set the original December 31 due date as a practical matter not grounded in any scientific basis. When questioned internally and challenged by FENOC, the staff was unable to justify that date on any sound foundation. When they considered the issue internally, they agreed that the nozzle was unlikely to fail before a February inspection. Finally, the NRC had "informally" set an unreasonably high burden of requiring absolute proof of a safety problem to shut down the plant, even though all staff offices including the General Counsel's office had signed off on the shutdown order. Finally,

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[89]Performance, Safety, and Health Associates, Inc. *Safety Culture Evaluation of the Davis-Besse Nuclear Power Station*, April 2003. http://www.hss.doe.gov/deprep/archive/oversight/DavisBesseCultureEvaRpt042303.pdf. [Accessed 2/21/11].

[90] FENOC. *Davis-Besse Nuclear Power Station: Organizational Effectiveness*. October 1, 2003. http://www.nrc.gov/reactors/operating/ops-experience/vessel-head-degradation/vessel-head-degradation-files/safety-culture-10-1-03.pdf. [Accessed October 1, 2003].

[91]NRC. Office of Inspector General. *NRC's Regulation of Davis-Besse Regarding Damage to the Reactor Vessel Head.* (Case No. 02-035). December 30, 2002, p. 23 http://www.nrc.gov/reading-rm/doc-collections/insp-gen/2003/02-03s.pdf. [Accessed 2/25/11].

they never expected to find the hole in the reactor containment.

Perhaps most importantly, the OIG reported: *"OIG found that Federal regulations authorize NRC to initiate enforcement action whenever it lacks 'reasonable assurance' that the licensee can operate safely. However, many NRC staff expressed to OIG their unwillingness to pursue enforcement action against a licensee without absolute proof of a regulatory violation."*[92]

6.5.5 GAO Assessment

The GAO did its own assessment of the Davis-Besse incident and concluded,

> *"NRC should have but did not identify or prevent the vessel head corrosion at Davis-Besse because both its inspections at the plant and its assessments of the operator's performance yielded inaccurate and incomplete information on plant safety conditions.... NRC's process for deciding whether Davis-Besse could delay its shutdown to inspect for nozzle cracking lacks credibility because the guidance NRC used was not intended for making such a decision and the basis for the decision was not fully documented."*[93]

6.5.6 Third Party Assessments

There is a significant community of people who are concerned about the risks of nuclear energy. The case study prepared by the Union of Concerned Scientists seems to reflect a broad consensus in this community. The USC concluded:

> *"The gaping hole in the reactor head symbolized the gap between perception and reality. The perception that Davis-Besse was a top performer prevented the NRC from looking for evidence to the contrary and to dismiss evidence that it did see. While the lessons learned by the NRC may make it harder for them not to look for problems, and harder to overlook those problems that are found, there will almost undoubtedly be another event like that at Davis-Besse. Davis-Besse was not caused by a lack of data or an inaccurate assessment of available data; it was caused by an underlying belief system that Davis-Besse was safe and no data could show otherwise. Until that belief system is exorcised from the regulatory process, the names and circumstances will change but extended outages will continue to produce nuclear power at higher costs and lower safety levels than is necessary."*[94]

For many in the nuclear industry it might be tempting to dismiss this finding, but they should consider this: industry insiders also told us essentially the same thing. The industry has improved enormously, but not uniformly. The safety culture has not been uniformly embraced

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[92] *Ibid*.

[93] US General Accounting Office, 2004. *Nuclear Regulation: NRC Needs to More Aggressively and Comprehensively Resolve Issues Related to the Davis-Besse Nuclear Power Plant's Shutdown*. GAO-04-415.

[94] Union of Concerned Scientists. *Davis-Bessie (Outage Dates: February 16, 2002-February 16, 2004).* http://www.ucsusa.org/assets/documents/nuclear_power/davis-besse-ii.pdf [Accessed 1/23/11]

by all decision-makers. Monetary incentives still are in play. Unless things continue to improve, there will almost certainly be another serious event.

6.5.7 Concluding Observation

There is an interesting detail about the NRC and FENOC handling of the delay in shutting down Davis-Besse. NRC wanted it shut down on Dec. 31, 2001. FENOC wanted to operate until its planned outage on March 31. In the end, NRC settled on February 16, 2002. NRC has given a tortuous explanation of its reasons for allowing the extension, but it has not given an explanation for how it arrived at that particular date.[95] It simply seems like they split the difference between their date and FENOC's date. That might not be an unreasonable solution except for this: the NRC and the utilities spend enormous effort at making precise probabilistic calculations of risk. Yet, in this decision, that could not have been the case. Why was February 16 an acceptable risk beyond December 31, when March 31 was not acceptable? We have not been able to find an answer to this question.

Our analysis of these findings is that the NRC had an undue appreciation for the financial impact on Davis-Besse; had normalized a deviation by setting too high a bar for issuing a shutdown order; and had failed to conduct a full "what if" analysis that would have revealed the seriousness of the potential for risk. The agency had become-risk averse to shutting down a facility. In short, the safety culture of the NRC itself was found wanting.[96]

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[95] NRC. *Nuclear Regulatory Commission (NRC) Staff Evaluation Related to NRC Bulletin 2001-01 response. FirstEnergy Nuclear Operating Company, Davis-Besse Nuclear Power Station, Unit 1*. Docket No. 50-346. http://www.nrc.gov/reactors/operating/ops-experience/pressure-boundary-integrity/upper-head-issues/upper-head-files/davisbesse-closeout-bl2001-01.pdf. [Accessed 2/14/11].

[96] We discuss "safety culture" in detail in Section 12 of this Report. The NRC Inspector General confirmed this with reference to a 2002 survey of NRC's employees, which found insignificant improvements (over an earlier survey) in the category of the survey reflecting views on NRC's commitment to safety and whether they were encouraged to communicate ideas to improve safety or requirements of operations. In fact, NRC was found to rate well below the norm for this category in similar surveys of other government agencies and the broader U.S. labor force. Additionally, only 53% of the employees felt that it was "*safe to speak up in the NRC*." NRC. Office of Inspector General. *OIG 2002 Survey of NRC's Safety Culture and Climate*. OIG-03-A-03, December 11, 2002, pp. 34, 36. http://www.nrc.gov/reading-rm/doc-collections/insp-gen/2003/03a-03.pdf. [Accessed 2/28/11]

7

The Safety and Health of Nuclear Work

Many in the nuclear industry like to say, *"No member of the public has ever been injured or killed in the entire ... history of commercial nuclear power in the U.S."*[97] That is not quite accurate. For while there have been no deaths in the general public from radiation in the civilian nuclear industry, there have been workplace deaths in civilian nuclear plants, and all of them related to the production of electricity using nuclear fuel. Workers are of course also members of the general public when they are not at work. The worst such incident was in 1986 at the Surry power plant in Virginia, when four workers were killed because a high pressure pipe broke and sprayed workers with scalding water and steam. But the accident happened in a non-nuclear portion of the plant and was therefore not counted by the NRC or the plant as a nuclear accident.[98] It could just as well have happened in a fossil fuel plant, and if it did it would be counted as a fatality associated with fossil fuel electricity production.

Those who say this also forget about the workers in defense facilities who pioneered this technology. It is well established that workers in defense nuclear weapons facilities have experienced both occupational injuries and illnesses, including fatalities from radiation poisoning. The defense program was pursued with great urgency, which at times led to exposure of workers to hazardous conditions. This was recognized in 2001 when Congress adopted the Energy Employees Occupational Illness Compensation Program Act, which found that, "*Since World War II, Federal nuclear activities have been explicitly recognized under Federal law as activities that are ultra-hazardous....."*[99]

7.1 FINDINGS FROM THE DEFENSE NUCLEAR COMPLEX

While there is a clear separation between defense and civilian nuclear programs, there is also a very clear link. The civilian technologies derived from the defense experience, including the calculated risks built into the technology. Having said that, there is no parallel in the civilian

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[97]American Nuclear Society. *Top 10 Myths about Nuclear Energy*. http://www.ans.org/pi/resources/myths/. [Accessed 2/21/11].

[98]This even though the NRC characterized it as a "Catastrophic failure" in Unit 2 of the Surry Power Station. See NRC. *NRC Bulletin 87-01*, July 9, 1987. http://www.nrc.gov/reading-rm/doc-collections/gen-comm/bulletins/1987/bl87001.html. [Accessed /12/11].

[99]42 CFR 84 §7384. http://www.dol.gov/esa/owcp/energy/regs/compliance/law/EEOICPAALL.htm [Accessed 7/14/09]

industry for the first 17 years of the defense program, or the expediency surrounding defense work during the Cold War, and data from the defense program should be viewed with caution before drawing conclusions about their relevance to current civilian workplaces. However, they do point to significant issues, such as the difference in risk between construction workers and in-plant workers.

7.1.1 Mortality Studies

A number of studies have examined mortality risk among workers who have been employed in DOE facilities. Gilbert and Marks found that operators and skilled craft workers (e.g. millwrights, steamfitters) had higher cumulative external radiation doses compared to other Hanford workers.[100] Multiple myeloma has been reported to be in excess among Hanford workers.[101] In a study of four DOE sites, Wing et al. observed an association between the risk of multiple myeloma and low-level whole body penetrating ionizing radiation dose at older ages.[102] A specific association between cancer mortality and radiation doses accrued at older ages has been reported in studies of Hanford workers,[103] and this association appears particularly strong for lung cancer.[104]

Frome et. al. studied mortality patterns among workers employed at Oak Ridge between 1943 and 1985. Excess mortality was observed for lung cancer (SMR=1.18) and non-malignant lung diseases (SMR=1.12) for all Oak Ridge sites combined. Internal analyses found that non-salaried workers experienced higher lung cancer risk compared to salaried workers.[105] Richardson and Wing observed increased cancer mortality among Oak Ridge workers to be associated with low-level external exposures to ionizing radiation with potentially greater effects after age 45.[106] Richardson et. al. reported that Savannah River workers hired between 1950 and 1986 had significant excess risk for leukemia and cancer of the pleura was observed among hourly-paid men, and female workers had a significant excess risk for kidney cancer.[107] Dement et. al., in a study of construction trades workers who had been employed at Hanford, Oak Ridge and Savannah River reported significant excess mortality for all cancers, lung cancer, mesothelioma,

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100 Gilbert ES, Marks S. An updated analysis of mortality of workers in a nuclear facility. *Radiation Research*, 83: 740–1, 1980

101 Gilbert ES, Omohundro E, Buchanan JA, Holter NA. Mortality of workers at the Hanford Site. *Health Physics*, 64: 577-590, 1993

102 Wing S, Richardson D, Wolf S, Mihlan G, Crawford-Brown D, Wood J. A Case Control Study of Multiple Myeloma at Four Nuclear Facilities. *Annals of Epidemiology*, 10: 144-153, 2000.

103 Kneale GW, Stewart AM. Reanalysis of Hanford Data: 1944–1986 Deaths. *American Journal of Industrial Medicine*, 23: 371–389, 1993.

104 Wing S, Richardson DB Age at Exposure to Ionising Radiation and Cancer Mortality among Hanford Workers: Follow Up Through 1994. *Occupational and Environmental Medicine*, 62: 465–472, 2005.

105 Frome EL, Cragle DL, Watkins JP, Wing S, Shy CM, Tankersley WG, West CM. A mortality study of employees of the nuclear industry in Oak Ridge, Tennessee. *Radiation Ressearch*. 148: 64–80, 1997)

106 Richardson DB, Wing S. Radiation and mortality at Oak Ridge National Laboratory: Positive associations for doses received at older ages. *Environmental Health Perspectives* 107(8): 649-656, 1999.

107 Richardson DB, Wing S, Wolf S. Mortality among workers at the Savannah River Site.
American Journal of Industrial Medicine. 50(12): 881-891, 2007.

and asbestosis; non-hodgkin's lymphoma was in excess at Oak Ridge, multiple myeloma was in excess at Hanford and COPD was significantly elevated among workers at the Savannah River Site.[108]

7.1.2 Findings from the DOE Former Worker Program

In 1992, Congress directed the Department of Energy to determine if workers are at significant risk for occupational illnesses from DOE work, and if so provide them with notification about such risk(s) and ongoing medical evaluation.[109] In 1996, DOE established the Former Worker Medical Screening Program (FWP) by funding pilot medical screening programs performed by independent organizations under cooperative agreements. As of October 2009, over 60,000 workers had been screened. Because the lungs are the main target for occupational exposures from dusts, fumes and vapors, lung diseases have been a major focus of the program. Table 7.1 summarizes findings in the program to date:[110]

Table 7.1 Findings of Occupational Illness in DOE Former Worker Program as of Oct 2009

Health Risk	Medical Test	No. Examined	No. Abnormal	Prevalence (%)
Asbestos Disease	X-Ray	53,489	6,588	12.3
Silicosis	X-Ray	53,489	185	0.3
Other Dust	X-Ray	53,489	1,059	2.0
Lung Nodules, Nodes or Lesions	X-Ray	53,489	1,753	3.3
Beryllium (≥ 1 abnormal test)	BeLPT	45,977	1,054	2.3
COPD	PFT	52,177	11,274	21.6

7.1.3 Workers engaged in Fuel Fabrication, Enrichment, Fuel Use, and Fuel Storage.

The Burlington Atomic Energy Commission Plant (BAECP) and Ames Lab Former Worker Programs at the University of Iowa have performed approximately 2,600 medical exams on former workers from two DOE facilities, one in southeast and the other one in northwest Iowa. There were some characteristics in that work similar to conversion and fuel fabrication. The Ames lab site in the northwest part of the state has been operational since the early 1940s as a Research and Development Laboratory, having processed several hundred tons of uranium and thorium in the early years of operation. The BAECP site assembled and disassembled nuclear weapons between 1949 and 1975 when it was moved to the Pantex site in Amarillo, Texas. The BAECP and Ames Lab programs have documented these former workers as being at increased risk for beryllium sensitization[111] and work related lung disease. Workers at Pantex started work there making high

[108] Dement J, Ringen K, Welch L, Bingham E, Quinn P. Mortality among older construction and craft workers employed at Department of Energy (DOE) sites. *American Journal of Industrial Medicine*, 52:671-682, 2009.

[109] Defense Authorization Act of 1993, Section 3162. Public Law 102-484, Oct. 23, 1992 Emphasis added.

[110] http://www.hss.energy.gov/healthsafety/fwsp/formerworkermed/. [Accessed 2/4/11]

[111] Mikulski MA, Leonard SA, Sanderson WT, Hartley PG, Sprince NL, Fuortes LJ. Risk of beryllium sensitization in a low-exposed former nuclear weapons cohort from the cold war era. *American Journal of Industrial Medicine*, 54(3):194-204, 2011; Mikulski MA, Clottey V, Hoeger N, Nichols C, Welch J, Tryzna M, Lozier L, Fuortes L. Beryllium sensitization

explosive weapons during World War II. After the war it was turned into a facility that to this day constructs, refurbishes and dismantles nuclear weapons. The Pantex Former Worker Medical Surveillance Program was started in 2003, with exams starting two years later. Over the years about 800 examinations have been carried out, and a smaller number of repeat exams. The main focus has been on production technicians, who worked on the weapons. About 150-200 have been referred for possible workers compensation. Among the disease entities found were asbestos-related non-malignant and malignant disease, thyroid disease (especially among material handlers), and smaller number of other diseases such as beryllium disease. Hearing loss has been found in some workers as well.[112]

Over the past 15 years, medical examinations have been offered to workers who have been employed in the gaseous diffusion enrichment plants in Portsmouth, Paducah and Oak Ridge K-25. These studies have examined workers for lung diseases as indicators for a larger occupational problem. Their findings are summarized in Table 7.2

Table 7.2: Prevalence of Occupational Illnesses, DOE Gaseous Diffusion Plants[113]

Health Risk	Prevalence of Health Risk by Facility (Percent)				
	Portsmouth		Paducah		Oak Ridge K-25
	Production	Construction	Production	Construction	(Production only)
Asbestos Disease	5.7	20.2	6.2	18.6	6.0
Silicosis	0.3	0.7	0.9	0.7	0.2
Other Dust	0.4	0.4	0.5	1.5	0.5
Lung Nodules, Nodes or Lesions	1.6	4.5	1.7	6.2	1.3
Beryllium (≥ 1 abnormal test)	0.9	0	1.4	0	1.7

7.1.4 Workers Engaged in Construction, Maintenance, Renovation, Repair and Demolition.

Most construction trades workers in defense nuclear facilities have been employed intermittently by subcontractors. The Building Trades National Medical Screening Program[114] has performed approximately 25,000 medical exams on older workers with employment in DOE facilities. It has reported that these workers have increased risk for lung cancer and other

associated with low exposure in the manufacture of nuclear weapons. *Proceedings of 137th APHA Annual Meeting & Exposition*. Philadelphia, PA. November 7-11, 2009

[112] Mikulski MA, Lourens S, Buhrow J, Welch J, Clottey V, Hoeger N, Nichols C, Wang Z, Hartley P, Sprince N, Fuortes L. Association between ILO abnormalities and exposures among former nuclear weapons workers. *Proceedings of 138th APHA Annual Meeting & Exposition*. Denver, CO. November 6-10, 2010; Worden N, Mikulski M, Brown CK, Fuortes L. Association of beryllium exposure and ILO profusion score with declined in FVC*. Proceedings of 137th APHA Annual Meeting & Exposition*. Philadelphia, PA. November 7-11, 2009; Welch J, Czeczok T, Mikulski M, Brown CK, Clottey V, Nichols C, Hoeger N, Wang Z, Hartley P, Fuortes L. Risk factors for lung disease in former atomic energy workers from the Ames laboratory. *Proceedings of 138th APHA Annual Meeting & Exposition*. Denver, CO. November 6-10, 2010

[113] DOE, Former Worker Medical Screening Program. *2009 Annual Report*, Tables 7-9. http://www.hss.doe.gov/healthsafety/fwsp/formerworkermed/2009_FWP_Annual_Report.pdf. [Accessed 2/7/11]

[114] www.btmed.org.

radiation-association cancers,[115] lung disease,[116] pulmonary disease,[117] beryllium sensitization,[118] and hearing loss.[119] The program has also reported that radiation exposure monitoring for construction trades workers has been deficient.[120]

7.2 POTENTIAL OCCUPATIONAL HAZARDS IN THE NUCLEAR FUEL CYCLE

The main occupational safety and health hazards at each stage of the nuclear fuel cycle are described in ***Annex 3***. Here we provide an overview.

7.2.1 Mining, Milling and Ore Transport

We know of no occupational health data on workers in in-situ mining operations. Underground uranium miners and millers have been studied for work-related health effects.

Miners: Miners have experienced work-related illnesses, including pulmonary diseases and cancers as a result of exposures to different hazards including silica dust, diesel exhaust and radon. The health of uranium miners in the U.S. has been studied since the late 1950s when a cohort of 4,137 miners who had been employed in different mines on the Colorado Plateau, primarily in Arizona, Colorado and to a lesser extent New Mexico. These miners were either white (n=3,358), American Indian (n=774) and other (n=5). The miners had worked for at least one month in a uranium mine and had participated in at least one health screening during the period January 1, 1950-December 31, 1960. The investigators followed up on the vital status and causes of death for the miners through 2005, and they did a special study of end-stage renal disease which started in 1977 when Medicare established a registry of all Americans being treated for this disease. The most recent follow-up this population found that as of December 31, 2005.[121] The miners had overall mortality rates that were 50% higher compared to the general population of the Colorado Plateau, meaning that the miners died at significantly

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[115] Dement JM, Ringen K, Welch LS, Bingham E, Quinn P. Mortality of older construction and craft workers employed at department of energy (DOE) nuclear sites. *American Journal of Industrial Medicine*, 2009; 52(9):671-682

[116] Dement J, Welch L, Bingham E, Cameron B, Rice C, Quinn P, Ringen K. Surveillance of respiratory diseases among construction and trade workers at department of energy nuclear sites. *American Journal of Industrial Medicine*, 43:559-573, 2003.

[117] Dement J, Welch L, Ringen K, Bingham E, Quinn P. Airways obstructive diseases among older construction and craft workers at Department of Energy nuclear sites. *American Journal of Industrial Medicine*, 53: 224-240, 2010

[118] Welch L, Ringen K, Bingham E, Dement J, Takaro T, McGowan W, Chen A, Quinn P. Screening for beryllium disease among construction trade workers at Department of Energy nuclear sites. *American Journal of Industrial Medicine*, 46: 207-218, 2004.

[119] Dement J, Ringen K, Welch L, Bingham E, Quinn P. Surveillance of hearing loss among construction and trade workers at department of energy nuclear sites. *American Journal of Industrial Medicine*, 48:348-358, 2005

[120] Bingham, E., Ringen, K., Dement, J., Cameron, W., McGowan, W., Welch, L. and Quinn, P. Frequency and Quality of radiation monitoring at two gaseous diffusion plants. *Annals of the New York Academy of Sciences*, 1076:394-404, 2006

[121] Schubauer-Berigan MK, Daniels RD, Pinkerton LE. Radon Exposure and Mortality Among White and American Indian Uranium Miners: An Update of the Colorado Plateau Cohort. *American Journal of Epidemiology*, 169:713-730, 2009

younger age than they would have had they not been miners. High rates of death were found for radiation cancers, pulmonary diseases that are linked to exposure to silica and other dusts, and several traumatic injury categories (see Fig. 7.1)

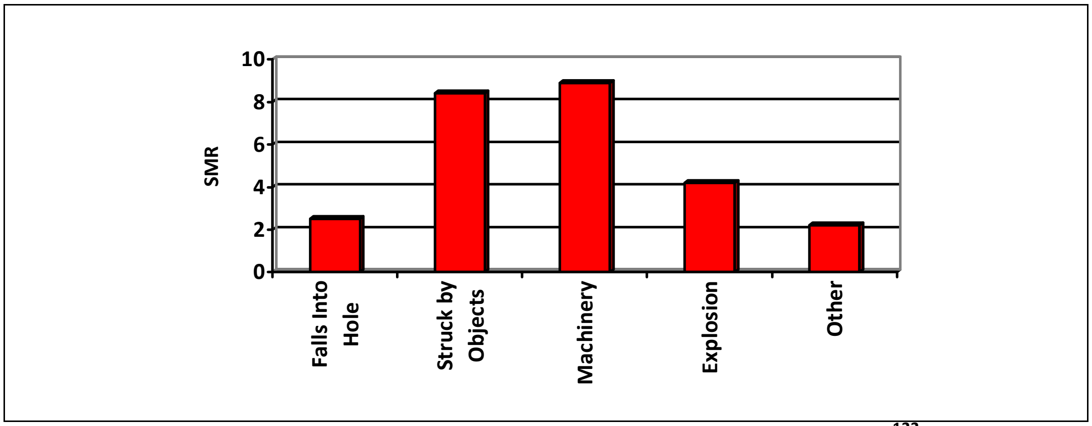

Fig. 7.1: Standardized Mortality Ratios (SMR) for Select Causes, Uranium Miners[122]

Millers: Workers performing milling and initial purification of uranium containing ore into yellowcake have not been studied extensively. However, NIOSH has established a cohort of 1,485 male workers employed for at least one year in seven uranium mills on the Colorado Plateau between 1940 and 1971. None of the workers included in the cohort had any work experience from underground or surface uranium mining. These workers were followed through 1998 and their mortality was recorded. Analysis of causes of death found:[123]

- 810 workers had died
- The mill workers had no increase in overall mortality.
- The mill workers had a high risk for lung disease and some radiation-related cancers.
- These risks were higher among workers employed before 1960.

Based on the available evidence, in 1990 Congress concluded that radon exposures experienced by workers in underground mining, and transport and milling of ore, had been hazardous and included workers Radiation Exposure Compensation Act of 1990. [124]

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[122]*Ibid.*, Appendix Table 1, p. 730.

[123]Pinkerton LE, Bloom TF, Hein MJ, Ward EM. Mortality among a cohort of uranium mill workers: an update. *Occupational and Environmental Medicine*, 61:57–64, 2004.

[124]The Act provides compensation to individuals who contracted one of 27 medical conditions associated with nuclear fall-out, and covers individuals residing as specified counties where fallout from the nuclear testing was significantly measured, as well as the following categories for nuclear fuel cycle occupational exposures:

> **Mining**. Workers employed for at least 40 months in aboveground or underground uranium mines located in Colorado, New Mexico, Arizona, Wyoming, South Dakota, Washington, Utah, Idaho, North Dakota, Oregon, and Texas at any time during the period beginning on January 1, 1942, and ending on December 31, 1971.
>
> **Millers**. Workers employed for at least one year in uranium mills located in Colorado, New Mexico, Arizona, Wyoming, South Dakota, Washington, Utah, Idaho, North Dakota, Oregon, and Texas at any time during the period beginning on January 1, 1942, and ending on December 31, 1971.
>
> **Ore Transporters**. Workers employed for at least one year in the transport of uranium ore or vanadium-uranium ore from mines or mills located in Colorado, New Mexico, Arizona, Wyoming, South Dakota,

Another study of one mining and milling operation in New Mexico found an excess risk of death for miners, but not for mill workers. It included 2,745 workers who were employed for at least six months between 1955-1990, and followed them up for vital status through 2005. The miners had elevated risk for all causes of death, cancer and trauma. The workers employed in milling did not experience excess risk.[125]

Since the 1970s, there has been little underground mining in the US. In 2009, there were 16 underground mining operations which delivered ore to a single operating mill -- the White Mesa mill in Blanding, Utah. All of these operations are very small. There were four in-situ mining operations in the US which produced 80-90% of uranium mined, and seven operational in-situ mines on stand-by. In-situ leaching is a technique which has been developed over the past couple of decades.

One application for a permit to mine uranium in Virginia is being reviewed by a committee of the National Academies.[126] This operation is considering all extraction operations: underground mining, pit mining and in-situ mining, and the review will hopefully examine all of these options. We expect that the report of this committee (which is scheduled for December 1, 2011), will provide better insight into the future risks from new types of mining.

7.2.2 Conversion, Enrichment and Fuel Fabrication

Enrichment is the U.S. has been done by gaseous diffusion. A study conducted by NIOSH of workers at the Portsmouth, Ohio gaseous diffusion plant did not find statistical significant increases in risk, but did find suggestions of associations with some radiation-related cancers. However, the study had significant design limitations.[127] A more recent study of the Paducah, Kentucky gaseous diffusion plant produced similar findings.[128] In medical evaluation studies of beryllium exposure, 5% of workers at the Oak Ridge GDP tested positive on at least one test, as did 2.8% at Paducah

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Washington, Utah, Idaho, North Dakota, Oregon, and Texas at any time during the period beginning on January 1, 1942, and ending on December 31, 1971.

42 U.S.C. 2210 *et seq*, November 5, 1960. http://www.justice.gov/civil/torts/const/reca/about.htm [Accessed 2/4/11]. Congress made additional amendments to the program in 2000 when it included RECA in the Energy Employees Occupational Illness Compensation Act (Public Law 106-398, July 31, 2001 (42 U.S.C. 7384 *et seq.*)); and in an amendment to that Act (Public Law 108-375, October 28, 2004(42 U.S.C. 7385 et. seq.))2004 which increased the amount of compensation and medical conditions covered. http://www.id.doe.gov/eeoicpa.htm [Accessed 2/4/11]

[125]Boice JD, Cohen SS, Mumma MT, et al A cohort study of uranium millers and miners of Grants, New Mexico, 1979-2005, *Journal of Radiological Protection*; 28:303-325 2008.

[126]National Academies, Board on Earth Sciences & Resources. *Uranium Mining in Virginia*. DELS-BESR-09-06. http://www8.nationalacademies.org/cp/projectview.aspx?key=49253. [Accessed 2/10/11]

[127]National Institute for Occupational Safety and Health. *Mortality Patterns Among Uranium Enrichment Workers at the Portsmouth Gaseous Diffusion Plant, Piketon, Ohio*. July 2001. http://www.cdc.gov/niosh/oerp/pdfs/2001-133g5-2.pdf. [Accessed 2/7/11].

[128]Chan C, Hughes T, Muldoon S, Aldrich T, Rice C, Hornung R, Brion G, Tollerud D. Mortality patterns among Paducah Gaseous Diffusion Plant workers. *Journal of Occupational and Environmental Medicine*. July 2010 - 52: 725-732, 2010

and 1.6% at Portsmouth, and 1-2% of construction workers at these facilities tested positive. [129] This test is a particularly sensitive indicator for occupational risks, because some individuals have a predisposition to its effects and therefore require very little exposure to trigger sensitization.

NIOSH received a request in 1996 for a Health Hazard Evaluation to evaluate worker exposures to neutron radiation at the Portsmouth Gaseous Diffusion Plant operated by Lockheed Martin Utility Services. The request described the hazard as a chronic exposure to neutron radiation during various production, maintenance, and security activities and that noted neutron doses had not been recorded in the workers' dose histories. The management of the plant had reviewed neutron exposures at the plant and concluded that they were "*considered insignificant in comparison with DOE radiation protection standards.*" Based on this they decided not to monitor for neutron exposure since the expected occupational dose would be too low to justify it. In 1981, the plant switched from radiation film badges to thermo-luminescent dosimeters (TLDs), and after 1990 the TLDs were calibrated to allow for measurement of neutron exposures. NIOSH obtained the TLDs data for 1992-1995. Its evaluation found that "*under certain conditions an acute exposure to neutron radiation can occur. Therefore, a potential health hazard to neutron radiation exists at this site*." It noted that a potential, chronic low-level neutron radiation exposure existed at the site where uranium was stored, handled, or solidified within the cascade. Areas where neutron exposures most likely occurred included the feed and withdrawal areas, UF_6 cylinder storage areas, and places where uranium deposits formed within the cascade. Historical health physics programs (1954—1992) neither calibrated nor monitored for neutron exposures.[130]

In the Energy Employees Occupational Illness Compensation Act, all three gaseous diffusion enrichment plants -- Portsmouth, Paducah and Oak Ridge K-25 facilities-- were included in a "Special Exposure Cohort" because Congress found that the facilities did not have a reliably documented radiation protection program and that workers who had been employed in them for more than 250 days had to be considered at significant risk for radiation cancer as a result.[131] To date, 4018 Paducah workers have received compensation, as have 6,136 K-25 workers and 2,903 Portsmouth workers.[132]

7.2.3 Nuclear Power Generating Facilities and Interim Spent Fuel Storage

Safety and health in the nuclear power generating facilities is discussed extensively in subsequent sections. Spent fuel storage involves transferring spent fuel from wet storage pools to dry casks. Occupational health risks have been identified at three stages of this process:[133]

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[129]DOE, Former Worker Medical Screening Program. *2009 Annual Report*, Table 6. http://www.hss.doe.gov/healthsafety/fwsp/formerworkermed/2009_FWP_Annual_Report.pdf. [Accessed 2/7/11]
[130]NIOSH . Health Hazard Evaluation Report HETA-96-0198-2651, 1996. http://www2a.cdc.gov/hhe/select.asp?PjtName=16887&bFlag=0&ID=41 . [Accessed 1/21/11]
[131]42 CFR 84 §7384. http://www.dol.gov/esa/owcp/energy/regs/compliance/law/EEOICPAALL.htm [Accessed July 14, 2009]
[132]http://www.dol.gov/owcp/energy/regs/compliance/statistics/Statistics.htm. [Accessed 3/6/11]
[133]Pennington C. NAC Corporation. Personal Communication, January 26, 2011.

- The welding of the plug on the transfer cask.
- The draining and drying during which the transfer cask is filled with helium and welds are checked for leaks.
- Moving the transfer cask into the storage cask.

We are not aware of any studies of health risks from working in interim spent fuel storage facilities, which are monitored carefully for radiation leaks.

7.2.4 Waste Facilities

In the US, we now have experience with constructing two deep geological disposal facilities--the Waste Isolation Pilot Plant (WIPP) in the 1980s and the Yucca Mountain Exploratory Studies Facility, in the 1990s. We also have over a decade of operational experience from receiving and storing waste at WIPP.

The construction of facilities deep underground is a huge undertaking with great risks that are manageable but difficult. The major risks are traumatic injuries from working around heavy equipment and explosives, lung disease from both silica dust and diesel exhaust fumes, and noise induced hearing loss. Construction of the two nuclear waste depositories has not been without risk to workers.

During construction of WIPP, in July 1984 one construction worker fell 1,000 feet down a 6 foot diameter borehole. A DOE investigation attributed the fatality to failure to comply with safety measures by the worker and the company as causative factors in his death.[134] It is estimated that the construction of WIPP consumed approximately 17,000 person years of work, so the traumatic fatality rate was 1 in 17,000 working years during the years of facility construction.[135]

During the excavation of Yucca Mountain, industrial hygiene procedures to measure and prevent silica exposures were unacceptable at times and placed workers at risk.[136] As a result, the DOE's Office of Environment, Safety and Health asked the University of Cincinnati to conduct a medical screening program to determine if any workers who were employed in the tunneling operations for the Exploratory Studies Facility (ESF) between 1993-2002 had developed silicosis as a result. This medical program was performed between 2003 and 2005. Of almost 3,000 individuals who had been known to have worked in some capacity at Yucca Mountain during that period, 413 completed the medical screening. Three of the workers were found to have silicosis. Two of these workers reported that they had been miners and their

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[134]"Safety Violations Led to WIPP Worker's Death", *Albuquerque Journal*, July 4, 1984, p. D-2.

[135]This translates to an annual occupational fatality rate of roughly 6 per 100,000 working years. By comparison, in 1996, the fatality rate in mining was 26.8 and in construction it was 13.9. CPWR. *The Construction Chart Book*, 2nd Ed., Chart 31. April 1998.

[136]*An Investigation into the Silica Exposure of Yucca Mountain Project Workers*. Special Hearing before a Subcommittee of the Committee on Appropriations, US Senate, Las Vegas, March 15. 2004. http://www.gpo.gov/fdsys/pkg/CHRG-108shrg94749/pdf/CHRG-108shrg94749.pdf f the. [Accessed 2/17/11]

disease had been diagnosed before they started work at Yucca Mountain. One case was a new diagnosis, but since he reported that had also worked in mining before it is not possible to solely attribute his disease to Yucca mountain exposures. Based on this evidence, if the same procedures that were used at Yucca Mountain are deployed again, we estimate that it is possible that workers will face a risk of developing silicosis of 1 in 4,000 working years.

These and similar risks are preventable. It is possible to perform construction without traumatic risk and we have good technologies for suppressing respiratory silica dust and other forms of respirator protection and hearing protection. But this was also known before the WIPP or Yucca projects started, so while the likelihood that such risks will be lower in the future as a result of improvements in construction and mining safety practices in general, they cannot be discounted, and regulatory and management oversight should be prepared for this.

WIPP was being prepared for operation in 1997-98, and received its first shipment of waste on March 26, 1999. Table 7.3 summarizes occupational injury and illness data reported by the WIPP facility to the Department of Labor[137] and DOE since 1997. These rates are roughly comparable to what nuclear operators report, and one-tenth of what is reported for the waste collection industry as a whole.[138]

Table 7.3: Reported Occupational Injuries and Illnesses (I&I), WIPP, 1997-2010

Data Field	**Year**													
	97	**99**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09#**	**10**
Rep. form*	200	200	200	200	200	300	300	300	300	300	300	300	300	300
No. workers	-	-	-	-	-	661	632	590	609	644	669	658	-	744
Hours **	-	-	-	-	-	1130	1060	1100	1122	1211	1239	1266	-	1405
Total I&I	11	9	9	7	19	10	10	5	4	6	1	1	5	2
-Lost-time	5	7	6	2	8	3	1	4	0	3	0	0	2	1
Cause														
-Trauma	2	6	4	2	5	5	10	4	4	6	1	1	5	2
-WMSD	5	3	5	11	5	-	-	-	-	-	-	-	-	-
-Health	4	-	-	1	2	-	-	-	-	-	-	-	-	-
-Other	-	-	-	-	-	5	-	1	1	-	-	-	-	-
Rate***														
--Total	-	-	-	-	-	1.5	1.6	0.9	0.6	.9	0.2	0.2	-	0.3
--Lost-time						.5	.2	.6	0	.5	0	0	-	0.2

*OSHA Reporting form changed in 2002.** The number of hours for all workers at WIPP, in 000s, rounded. ***Number of injuries and illnesses per 100 FTEs or 200,000 hours. #Report did not include no. of workers or hours worked.

The WIPP facility involves continuous mining in halite (NaCl / sodium choride / salt) deposits to create new storage space, and workers in the facility are exposed to a great deal of salt dust. It is possible that future waste depositories could be sited in similar formation. Salt dust is a potential

[137] Employers are required to make reports of all occupational injuries and illnesses annually in accordance with procedures set out in 29 CFR 1904.8 through 1904.12.

[138] NAICS 562211. Bureau of Labor Statistics. *Table 1: Incidence rates of nonfatal occupational injuries and illnesses by industry and case type, 2009.* http://www.bls.gov/iif/oshwc/osh/os/ostb2435.pdf. [Accessed 3/6/11].

risk with an unknown potential magnitude, particularly for cardiovascular, gastric and kidney diseases. There have been no studies performed of the health effects of occupational exposure to salt. It would be useful to perform a pilot medical evaluation of the workers in the WIPP facility to determine if they experience any health effects, if they are adequately protected, and to inform assessment of risk for future waste depositories.

The Blue Ribbon Commission may want to consider whether from a workplace safety point of view it may be desirable to consider horizontally constructed deep geological disposal facilities (such as Yucca Mountain) over vertical (deep bore) facilities (such as WIPP) because the latter would require use of hoists that may pose a greater degree of risk, especially as casks used in interim spent storage become larger or heavier. WIPP has experienced at least two unanticipated serious hoist failures. The probabilistic estimate of the hoist in the WIPP facility failing was originally 1 in 60 million. Nevertheless, in 1987 the hoist experienced two serious failures, in the same day. This experience reduced the probability estimate to 1 in 27,000.[139] Regardless of approach, any deep geological disposal facility should be constructed with great vigilance for the safety and health of workers, including those in construction and those in later operations.

7.2.5 Transportation of Nuclear Fuels and Waste

We did not have time to review whether workers who are engaged in transport of nuclear fuel cycle material are at risk as a result. We note, however, that this subject has been reviewed in great detail, including several times by the National Academies, and based on their reviews there is little evidence of significant risk.[140]

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[139] Greenfield MA. *Probabilities of a Catastrophic Waste Hoist Accident at the Waste Isolation Pilot Plant*. Environmental Evaluation Group, EEG-44, DOE/AL/58309-44, January 1990. http://homepages.nyu.edu/~ts43/research/EEG-44.pdf. [Accessed 2/17/11]

[140]National Academies. *Committee on Transportation of Radioactive Waste. Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States, 2006.* http://www.nap.edu/catalog/11538.html. National Academies. Committee on the Characterization of Remote-Handled Transuranic Waste for the Waste Isolation Pilot Plant. Characterization of Remote-Handled Transuranic Waste for the Waste Isolation Pilot Plant, Board on Radioactive Waste Management, National Research Council, National Academy Press, 2001. [http://www.nap.edu/catalog.php?record_id=10244]

8

Relative Risks:

The Nuclear Industry's Safety and Health Record Compared to Other Industries and Utility Sectors

Last year was hard on the workers in America's energy industries:

- On February 2, 2010, a Kleen Energy gas fired plant generating electricity in Connecticut was ripped by an explosion which killed six workers and injured 50 others.[141]
- On April 2, 2010, an explosion at the Tesoro oil refinery in Washington State left six workers dead.[142]
- On April 11, 2010, Massey Energy's Big Branch coal mine exploded, with 29 workers killed.[143]
- On April 20, 2010, the Deepwater Horizon drilling rig blew up, killing 11 workers and injuring another dozen and a half.

There has been no shortage of risk to workers in the energy industry, but none of this risk was exhibited in the nuclear energy sector.

8.1 OCCUPATIONAL SAFETY AND HEALTH DATA

The Bureau of Labor Statistics, U.S. Department of Labor, has a program called the Occupational Safety and Health Statistics (OSHS) program.[144] OSHS collects two types of occupational safety and health data:

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[141] Occupational Safety and Health Administration, US Department of Labor. US Labor Department's OSHA proposes $16.6 million in fines in connection with fatal Connecticut natural gas explosion: Federal agency warns natural gas power plant operators against deadly practice. August 5, 2010. http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=18117 [Accessed 1/29/11]

[142] http://www.lni.wa.gov/news/2010/pr101004a.asp. [Accessed 1/29/11]

[143] http://www.msha.gov/performancecoal/performancecoal.asp. [Accessed 1/29/11]

[144] http://www.bls.gov/iif/

- **Fatal occupational injuries**. The Census of Fatal Occupational Injuries (CFOI) compiles a count of all fatal work injuries occurring in the U.S. during the calendar year. The CFOI program uses diverse state, federal, and independent data sources to identify, verify, and describe fatal work injuries. The multiplicity of sources assures counts that are as complete and accurate as possible.
- **Occupational injuries and illnesses.** The Occupational Safety and Health (OSH) Act of 1970 requires certain employers to prepare and maintain records of work-related injury and illness cases. The specific requirements are established by the U.S. Occupational Safety and Health Administration in its recordkeeping regulation. The reported data are maintained by the Bureau of Labor Statistics. In this section we use two types of data:
  - ***TRC****—Total Recordable Cases*[145]
  - ***DAR****T—Days Away from Work, Restricted Duty or Transferred*[146]

These data are presented as the number of injuries and illnesses per 200,000 hours worked (i.e., 100 full-time employees in a 12 month period). A TRC rate of one is equal to an average of one percent of all FTEs having a recordable injury or illness in one calendar year.

We have discussed the unreliability of these data in section 3.3. Nevertheless, they are the best data we have and the nation relies extensively on them, including for such things as precertification of contractors based on reported safety and health performance, and awarding special status in Voluntary Protection Programs by both DOE and OSHA. We have assumed that patterns of underreporting are similar for all the entities compared in this analysis, while noting that there has never been an effort by OSHA or anyone else to verify the accuracy of the data.

8.2 NUCLEAR POWER COMPARED TO OTHER INDUSTRIES

Table 8.1 shows occupational injury and illness rates reported by nuclear power generation facilities compared to a spectrum of other industries.

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[145]***Total recordable cases*** include all of the following: death; loss of consciousness; days away from work; restricted work activity or job transfer; medical treatment (beyond first aid); significant work related injuries or illnesses that are diagnosed by a physician or other licensed health care professional, including any work related case involving cancer, chronic irreversible disease, a fractured or cracked bone, or a punctured eardrum; additional criteria that can result in a recordable case include: any needlestick injury or cut from a sharp object that is contaminated with another person's blood or other potentially infectious material; any case requiring an employee to be medically removed under the requirements of an osha health standard; tuberculosis infection as evidenced by a positive skin test or diagnosis by a physician or other licensed health care professional after exposure to a known case of active tuberculosis; hearing loss based on specific testing requirements. http://www.bls.gov/iif/oshdef.htm. [Accessed 3/9/11].

[146]*Ibid*. ***Dart cases*** involve days away from work (defined as requiring at least one day away from work with or without days of job transfer or restriction), or days of restricted work activity or job transfer, or both; and cases where an employer or health care professional keeps, or recommends keeping an employee from doing the routine functions of his or her job or from working the full workday that the employee would have been scheduled to work before the injury or illness occurred.

The rates for nuclear generating facilities are 0.6 and 0.3 respectively for TRC cases and for DART cases. The average rates for all private industries are six times higher than for nuclear facilities. Manufacturing in industries such as computer storage devices and pharmaceuticals, have rates comparable to nuclear facilities, and most industries, including hospitals, have much higher rates. Nuclear facilities report rates as low as do finance and insurance.

Table 8.1. Rates of Reportable Injuries and Illnesses for Select Industries,2009

Industry	**NAICS**	**Injury and Illness Rates****	
		Recordable	**Lost-time**
Nuclear Facilities	221113	0.6	0.3
Computer Storage Device Mfg	334112	0.8	0.2
Finance and Insurance	52	0.8	0.2
Pharmaceutical Manufacturing	3254	2.0	1.1
Chemical Manufacturing	325	2.3	1.4
Aerospace Manufacturing	3364	3.3	1.8
All Manufacturing	31-32	4.3	2.3
Hospitals	6221	7.3	2.8
Steel Products Manufacturing	3312	7.6	3.5
Average for All Private Industry	-	***3.6***	***1.8***

**Number per 100 FTE workers in industry

8.3 NUCLEAR POWER COMPARED TO HYDRO, FOSSIL FUEL AND OTHER SOURCES OF ELECTRICITY

Electricity in the U.S. is provided by utilities which generate and deliver electricity to transmission systems or to electric power distribution systems. The US Census Bureau classifies electrical power generation into four sub-categories according to the energy sources used to generate the electricity:[147]

- Hydroelectric power generation
- Fossil fuel electricity power generation
- Nuclear electricity generation
- Other electricity power generation

Table 8.2 shows employment in each of these sectors. Fossil fuel is the predominant source of electricity, followed by nuclear power, hydroelectric power and "other" sources. Other sources include renewable sources and employment in this sector has been growing rapidly, which makes for greater variability from year to year than the other sources.

[147] US Census Bureau. *2007 Economic Census*. http://factfinder.census.gov/servlet/IBQTable?_bm=y&-ds_name=EC0700A1 [Accessed 1/27/11]

Table 8.2: Employment By Electricity Generating Sector, 2009

Sector	NAICS	No of workers Employed*[148]
All Electric	22111	241,000
Hydro	221111	38,000
Fossil	221112	137,000
Nuclear	221113	55,000
Other	221119	11,000

*Rounded to nearest thousand. These are production workers employed in plants.

8.3.1 Fatal Occupational Injuries

Before 2003, CFOI did not break out data by different utility sectors. Since 2003, data are presented for hydroelectric power generation, fossil fuel electric power generation, and nuclear electric power generation. Table 8.3 shows the number of fatal injuries in utility facilities between 2003 and 2008, which is the most recent year for which detailed *fatality* data are available.[149] The hydro sector, with about 38,000 workers, recorded 20 fatalities in total and the fossil fuel sector, with approximately 140,000 workers, recorded 32 fatalities in total. The nuclear sector, with approximately 55,000 workers, recorded zero fatalities during this period.

Table 8.3: Annual Number of Fatal Occupational Injuries by Utility Sector, 2003-2008[150]

Year	Number of Fatal Injuries Reported				
	Hydro	Fossil	Nuclear	Other	Total
2003	1	5	0	2	8
2004	2	9	0	1	12
2005	5	4	0	2	11
2006	8	6	0	0	14
2007	2	5	0	0	7
2008	2	3	0	0	5
Total	***20***	***32***	***0***	***5***	***57***

Based on this, we estimate that had the nuclear plants operated at the same risk level as hydro plants they would have experienced a total of 29 fatalities during the period 2003-2008, and if they had operated at the same level of risk as fossil fuel plants, they would have experienced 13 fatalities.

8.3.2 Occupational Injuries and Illnesses

[148] Bureau of Labor Statistics. Incidence rates of nonfatal occupational injuries and illnesses by industry and case types, 2009. December 14, 2010, Table 1, pp. 24-25. http://www.bls.gov/iif/oshwc/osh/os/ostb2435.pdf [Accessed 1/18/11]
[149] Bureau of Labor Statistics. *Census of Fatal Occupational Injuries (CFOI) - Current and Revised Data*. http://www.bls.gov/iif/oshcfoi1.htm#19922002 [Accessed 1/18/11] As of this writing, occupational fatality data were available through 2008, while data for occupational injuries and illnesses were available through 2009 (see below).
[150] *Ibid.*

Figure 8.1 shows TRC and DART rates (as defined above) reported by utility operators for their in-plant employees in 2009, which is the most recent year for which data are available at the time of this study. Nuclear power plants reported 0.6 TRC and 0.3 DART cases per 100 full-time equivalent workers. This means that across the U.S. nuclear industry, the employers reported that 0.6% of their employees experienced any work-related injury or illness and fewer than 0.3% experienced a loss-time injury or illness. The rates of injuries and illnesses reported by nuclear operators were about 80% below those reported by fossil fuels plants, and also substantially below other sources of electricity generating power plants. Thus, based on the reported injuries and illnesses, safety and health performance in nuclear power plants appears to be very sound.

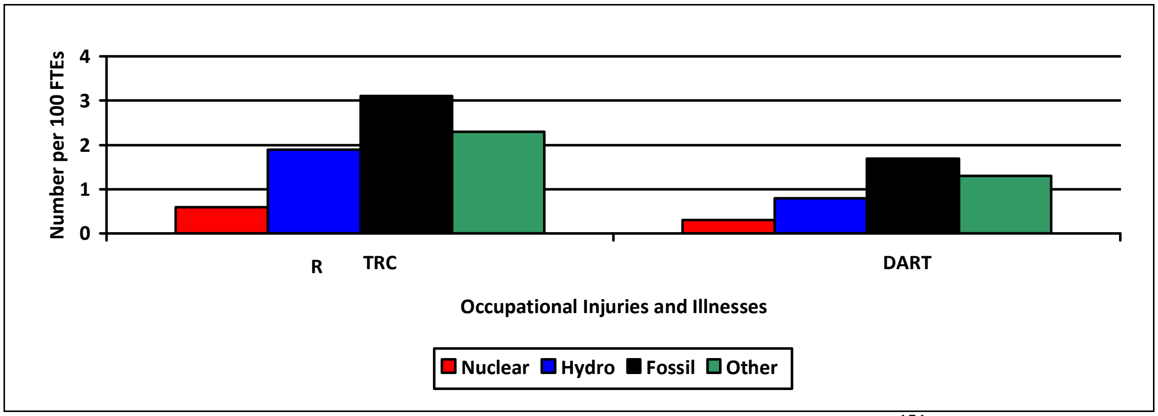

Fig 8.1: Occupational Injury and Illness Rates Reported by Utility Operators, 2009[151]

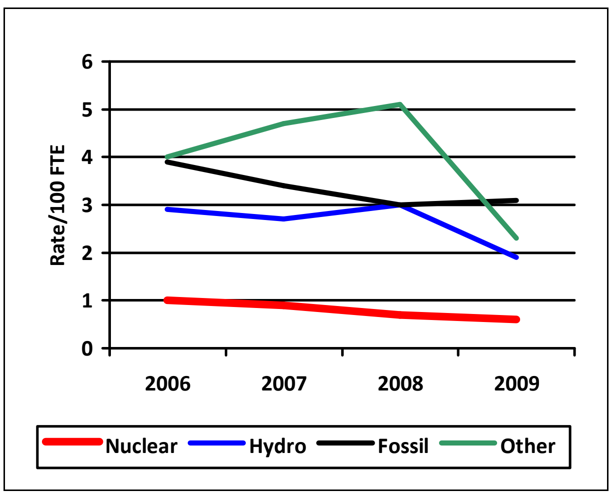

Fig 8.2: TRC Rates by Type of Electricity Generation 2006-2009

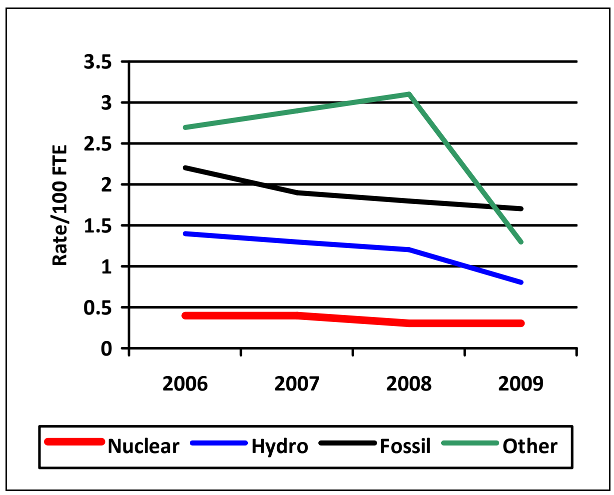

Fig 8.2: DART Rates by Type of Electricity Generation 2006-2009

Figures 8.2 and 8.3 show changes in TRC and DART rates for the years 2006-2009. BLS did not break out data by type of electricity generation before 2006. The trends show a decline in all

[151] Bureau of Labor Statistics. Incidence rates of nonfatal occupational injuries and illnesses by industry and case types, 2009. December 14, 2010, Table 1, pp. 24-25. http://www.bls.gov/iif/oshwc/osh/os/ostb2435.pdf [Accessed 1/18/11]

sectors, although "other" (renewable sources) had a less predictable trend as a result of rapid employment changes.

8.4 SAFETY AND HEALTH IN OUTAGE WORK IN NUCLEAR AND FOSSIL FUEL PLANTS

One contractor that does a great deal of maintenance work in different utilities provided us with data on its reported occupational injuries and illnesses with days away from work, transfer or restricted duty (DART) for both work performed in nuclear power plants and in fossil power plants.[152] This contractor is a leading safety performer in the U.S. construction and industrial maintenance industries. Fig. 8.2 shows that over the past decade, the rates in nuclear plants were below the rates in fossil plants. For instance, in 2010, 0.05 percent of the workers employed by this contractor in nuclear work experienced a DART injury, and 0.12 percent working in fossil fuel facilities experienced DART injuries.

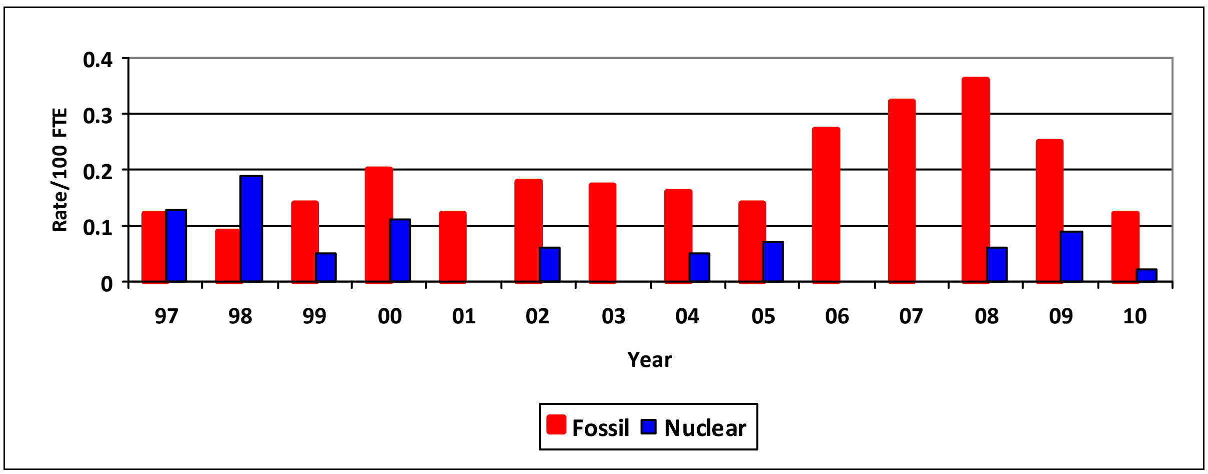

Fig 8.2: One Maintenance Contractor's Experience, DART Cases/200,000 Hours/Year, 1997-2010.

Compared to in-plant workers in nuclear power plants (see Fig. 8.1), the rate of reported DART injuries and illnesses is about twice as high in outage work. In 2009, the nuclear plants reported DART rates of 0.3, while this contractor reported rates of 0. 9. (See Fig. 8.3).

The injury rates reported by this contractor are very low compared to rates in general construction. The most recent year that the Bureau of Labor Statistics has produced a report for is 2009. In the U.S. construction industry as a whole, the DART rate for the industrial classification that most closely resembles this work, specialty trades construction (NAICS 238) was 2.5 or some two and one-half times greater than what this contractor reported for work in the nuclear industry in 2009.[153] (See Fig. 8.4.)

[152] These data were provide on condition that the source would not be identified.
[153] Bureau of Labor Statistics, workplace Injuries and Illnesses – 2009, Table 1, http://www.bls.gov/news.release/archives/osh_10212010.pdf. [Accessed

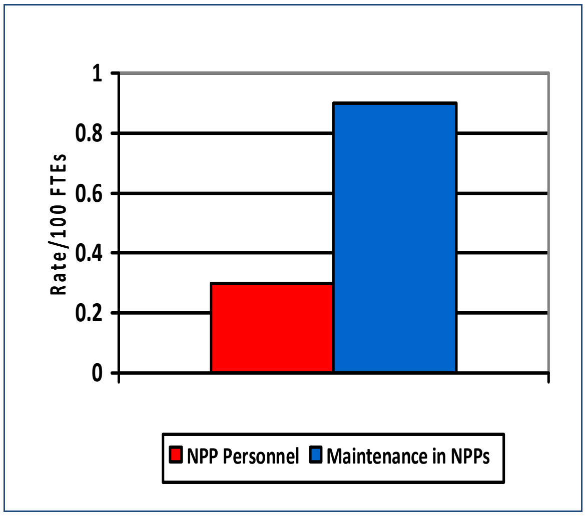

Fig 8.3: DART Rates Reported by all Nuclear Plants and by One Nuclear Maintenance Contractor, 2009

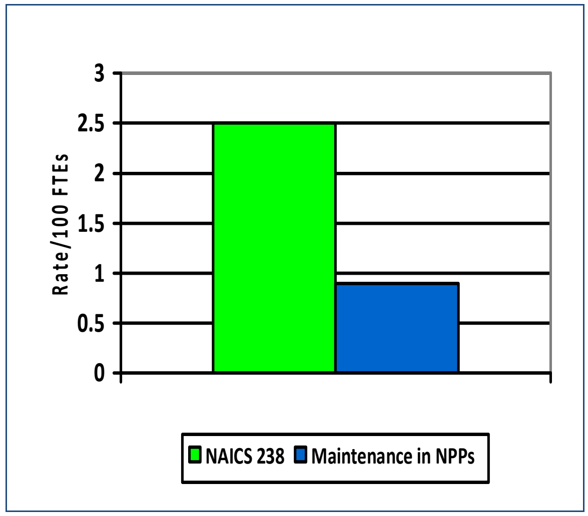

Fig 8.4: DART Rates Reported for all NAICS 238 and by one nuclear maintenance contractor, 2009

9

Radiation Risks in Today's Nuclear Industry

The occupational safety and health risks in the nuclear fuel cycle are qualitatively similar to risks in other complex industrial systems except for the presence of radiation. Any worker who is employed in a nuclear facility is required to have continuous monitoring for radiation exposure by a device which records the dose of any radiation to which a worker is exposed.

9.1 NCRP ESTIMATE

In 2008 the National Council on Radiation Protection and Measurements (NCRP) undertook a review of sources of radiation in the United States with the aim of estimating the contribution of each significant source to two measures of radiation risk:[154]

- **Collective effective dose,** which is the cumulative dose to a population of individuals exposed to a given radiation source or group of sources; and
- **Effective dose per individual** in the U.S. population, computed by dividing the collective effective dose by the total number of individuals in the U.S. population whether exposed to the specific source or not.

Using data from 2006, the NCRP considered the risk posed by five broad source categories:

- Exposure from ubiquitous background radiation, including radon in homes;
- Exposure to patients from medical procedures;
- Exposure from consumer products or activities involving radiation sources;
- Exposure from industrial, security, medical, educational and research radiation sources;
- Exposure of workers that results from their occupations.

The NCRP concluded that in 2006, occupational exposures contributed less than 0.1% of total radiation exposure to the American population. This occupational exposure added 0.05 rem to

[154] *Ionizing Radiation Exposure of the Population of the United States: Recommendations of the National Council on Radiation Protection and Measurements*. NCRP Report No. 160, March 3, 2009

average effective dose per US resident. It estimated that 1.15 million American workers were occupationally exposed to radiation, and that the average annual dose per worker exposed was 0.11 rem per year and that this was distributed by industrial sources as shown in Table 9.1. It found that commercial nuclear power contributed 8% of total occupational radiation exposures and that the average exposure per worker in the nuclear industry was the second highest among the industrial sectors, behind aviation.[155]

Table 9.1 Estimated Average Annual Radiation Exposure Caused by Occupational Exposures, US, 2006

Industry Sector	Number of Radiation Monitored Workers ('000s)	No. of Workers With Recorded Radiation Dose('000s)	% of total Occupational Exposure to Radiation	Average Exposure per Worker (rem/Year)
Commercial nuclear power	110	56	8	0.19
Medical	1,958	690.6	39	0.08
Aviation*	177	177	38	0.31
Industry and commerce	360	112.6	8	0.08
Education and research	357	79.9	4	0.07
Government, DOE and military	266	36.6	3	0.06
Total	3,228	1,152.7	100%	0.11 rem

*The aviation industry does not monitor for radiation exposure. This estimate is based on an assigned dose applied to each employed person who flies.

The NCRP concluded that occupational exposures in commercial nuclear power contributes 8% of 0.1% --that is, 0.008%-- of the total burden of radiation exposures in the U.S. The average exposure per worker employed in the commercial nuclear industry was less than 1/20th of the maximum allowable exposures of 5 rem per year. NCRP produced detailed estimates of exposure for workers in the commercial nuclear energy industry for the years 2003-2006, and concluded that the number of workers potentially exposed to radiation above 5 rem per year was about 0.1% of all workers who could have such exposures. (See Table 9.2)

Table 9.2 NCRP Estimate of Potential Number of Workers with Annual Radiation Dose over 5 rem

Year	Number of workers Employed ('000s)	Dose >5 rem	
		No. of Workers	% of All Workers
2003	90.3	81	0.09%
2004	108.8	88	0.08
2005	102.0	114	0.1
2006	110.0	128	0.1

9.2 OCCUPATIONAL RADIATION EXPOSURES REPORTED TO THE NRC BY NUCLEAR LICENSEES

[155] NCRP also concluded that environmental fall-out from commercial nuclear power production contributes up to 0.1% of the total radiation exposure to the American people, but this contribution is outside the scope of this report.

In 10 CFR 20.2206, the NRC requires licensees to report annually the data from their radiation monitoring program for each individual who is issued a radiation badge. Some monitored individuals have dose records from more than one licensee. They are classified as "transient," and include contractor workers who perform temporary work such as maintenance, repair or fuel handling. Table 9.3 summarizes the radiation monitoring data for 2008 for all fuel cycle licensees.

Table 9.3: Average Radiation Exposure for Permanent and Transient Reactor Workers, 2008[156]

License Category (Category Number)	No. of Licensees	Total Number Monitored	Workers with Measurable Exposure		Measured DOSE (TEDE)	
			Number	Percent	Collective (person-rem)	Average
Enrichment (21200)	3	3,649	380	10.4	15.627	0.04
Fuel Fabrication (21210)	6	3,535	2,390	67.6	40.527	0.17
Nuclear Power Reactors	104	118,692	57,356	48.3	9,195.940	0.16
Independent Fuel Storage Installation (23200)*	2	53	21	39.6	1.248	0.056
Uranium Hexafluoride (UF_6) Production Plants (11400)	1	683	654	95.8	117.303	0.18

*There are 50 Storage Facilities, but 48 are located in nuclear power plants and are included in the dose reports from these Plants.**Honeywell Specialty Chemicals, an enrichment facility, in Metropolis, ILL.

Fig. 9.1 shows the average dose per individual who was monitored in 2008. In 2008, over half of all monitored individuals had zero dose, and among those who had a dose, the average dose was 0.16 rem when adjusted for transient individuals. In the last decade, average dose declined by almost 40%. For detailed 2008 data, see **Annex 2**.

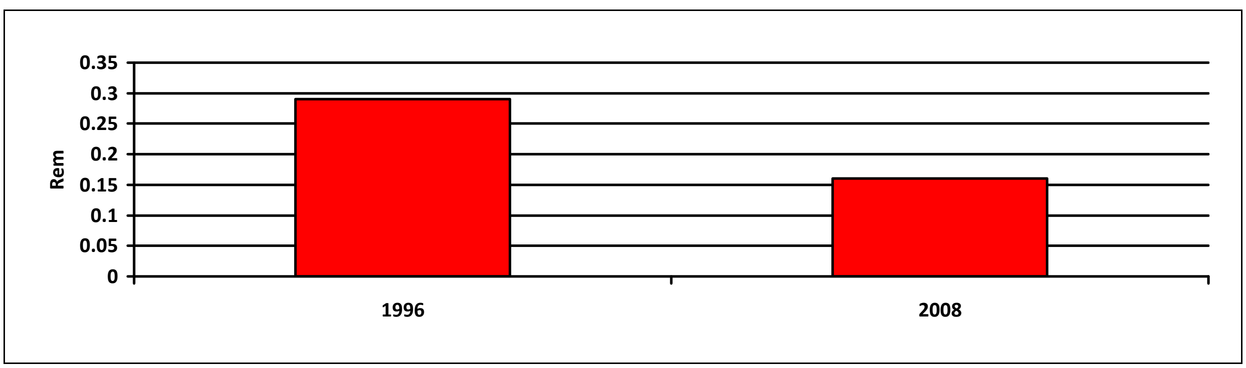

Fig 9.1: Average Annual Radiation Exposure (Rem) per Person with Whole Body Dose, Corrected for Transient Reporting, 1996,[157] 2008[158]

[156]NRC. Occupational Radiation Exposure At Commercial Nuclear Power Reactors and Other Facilities 2008, NUREG 0713, Vol. 30, Table 5.1, p. 5-2.. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0713/v30/sr0713v30.pdf [Accessed 1/13/11]

[157]NRC. *Occupational Radiation Exposure At Commercial Nuclear Power Reactors and Other Facilities 1994*, Vol. 18. http://www.reirs.com/nureg96/nureg96.pdf [Accessed 1/13/11]

[158]NRC. Occupational Radiation Exposure At Commercial Nuclear Power Reactors and Other Facilities 2008, NUREG 0713, Vol. 30. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0713/v30/sr0713v30.pdf [Accessed 1/13/11]

The NRC defines maximum allowable annual dose to be less than 5 rem, and the ICRP recommends a maximum dose of 2 rem per year.[159] However, the average annual dose across the complex tells us nothing about how it is distributed among the 65 nuclear facilities. Fig. 9.2 shows This distribution. The lowest average dose was 0.01 rem, and the highest dose was 0.217 (see Annex 2), so there is a significant range of performance in terms of worker exposures. The average also tells us nothing about how many workers were most heavily exposed. In 2008, there was not a single report of an individual in a nuclear power facility with a cumulative dose for the entire year exceeding three rem, and only five workers had exposures above 2 rem.[160] In fact, in the last three years there have not been any reports of exposures above the regulatory limit.

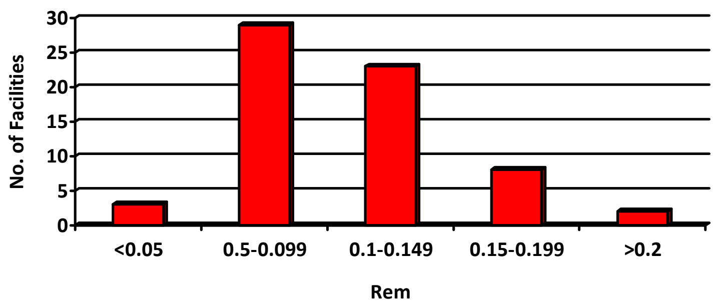

Fig. 9.2: Nuclear Facilities by Average Annual Radiation dose per Person Monitored who had a Measured Dose, 2009, Not Corrected for Transients.

9.3 OCCUPATIONAL RADIATION EXPOSURES FOR TRANSIENT WORKERS

Although the radiation safety performance of the industry is very good, this does not mean that there is no room for improvement. Table 9.4 compares radiation monitoring results for permanent and transient workers. NRC only reports data on transient workers for the nuclear power reactor classification, since it contains the bulk of such individuals. In 2008 the monitoring reports submitted by nuclear reactor operators to the NRC show that 118,692 individuals were monitored at some point during 2008, and that of these, 28,682 were transient and 90,010 were "permanent;" that is, they were monitored in only one reactor location.

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[159]ICRP recommends a maximum dose of 2 rem averaged over five years and no more than 5 rem in any single year (i.e., maximum dose over 5 years should be no more than 10 rem, and if a worker has a dose of 3-5 rem, then the worker has to have a dose in the remaining four years of no more than a total of 5-7 rem). International Commission on Radiological Protection. *The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103*. http://www.icrp.org/docs/ICRP_Publication_103-Annals_of_the_ICRP_37(2-4)-Free_extract.pdf. [Accessed 2/10/11]

[160]The five workers with dose above 2 rem were all recorded at the Cooper Station nuclear power plant in Nebraska.

Table 9.4: Average Radiation Exposure for Permanent and Transient Reactor Workers, 2008[161]

Category	Total Number Monitored	Workers with Measurable Exposure		Measured DOSE (TEDE)	
		Number	Percent	Collective (person-rem)	Average
Permanent Workers	90,010	36,578	40.6	3,833.083	0.105
Transient Workers	28,682	20,778	72.4	5,362.857	0.26
Total	118,692	57,356	48.3	9,195.940	0.16

Fig 9.3 shows transient workers are almost twice as likely to have been exposed to radiation compared to permanent workers. Fig. 9.4 shows the average radiation dose for permanent and transient workers in 2008. For permanent workers, the average dose was 0.1 rem, however, for transient workers, the annual average dose was 0.26 rem. In other words, the dose for transient workers is 2.5 times higher than for permanent workers. The average dose for transient workers in 2008 is approximately the same average dose that reported by all nuclear power plants for all persons monitored twenty years ago.[162]

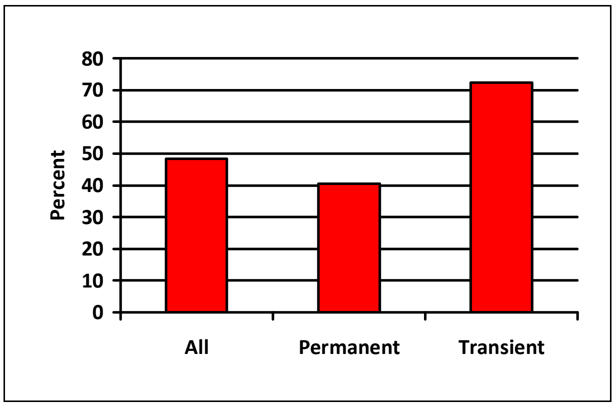

Fig 9.3: Percent of Workers Monitored with Measurable Dose[163]

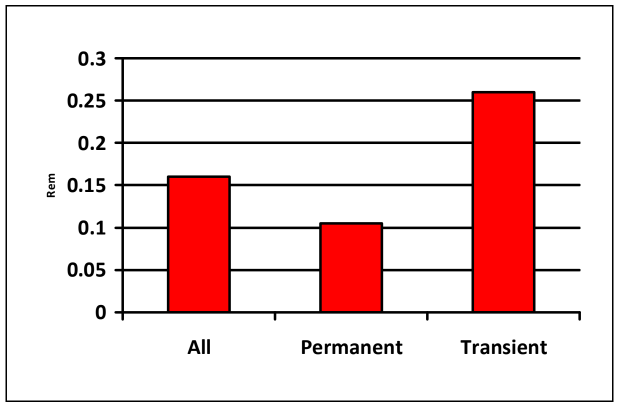

Fig 9.4: Average Annual Radiation Exposure (Rem) per Person with Whole Body Dose, 2008[164]

9.4 RADIATION DOSE BY OCCUPATION

It is not easy to find radiation data according to occupation. In table 9.4 are data from the environmental impact statement submitted to NRC as part of a nuclear license application. The highest reported average doses are for maintenance.

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[161] NRC. *Occupational Radiation Exposure At Commercial Nuclear Power Reactors and Other Facilities 2008*, NUREG 0713, Vol. 30, Table 5.1, p. 5-2. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0713/v30/sr0713v30.pdf [Accessed 1/13/11]

[162] For comparison, See Fig. 6.2 of this report. Rotating workers through radiation areas has been used to keep personal dose below regulatory limits. This practice was used in the West Valley reprocessing facility. (See Section 14 of this report.) We were not able to ascertain whether any transient workers fell into this category.

[163] Source: See Table 9.3.

[164] Source: See Table 9.3.

Table 9.4: Average Individual Dose 1991-2000[165]

Category	Rem/Person
Routine Operations and Surveillance	0.139
Routine Plant Maintenance	0.243
In-Service Inspection	0.173
Special Maintenance	0.156
Waste Processing	0.130
Refueling	0.134
All Categories	0.193

9.5 RADIATION EXPOSURE IN INTERIM SPENT FUEL STORAGE

Only the two Independent Fuel Storage Installation facilities report radiation monitoring data for workers who are employed in interim fuel storage operations. One of these has 30 workers who are monitored, and the other 23, so this is a very limited sample. In 2008, the facility with 30 workers reported no measured dose. In the other one, 21 of 23 monitored workers recorded exposure, but all had less than 0.5 rem and only one recorded a dose above 0.25 rem.[166]

[165] *BFN SEIS Analysis NUREG 1437 Vol. 1 Section 4.6.3 Occupational Radiation Dose*. http://pbadupws.nrc.gov/docs/ML0427/ML042790351.pdf [Accessed 1/21/11].
[166] NRC. *Occupational Radiation Exposure At Commercial Nuclear Power Reactors and Other Facilities 2008*, NUREG 0713, Vol. 30, Appendix A, Table A1, p. A-6. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0713/v30/sr0713v30.pdf [Accessed 1/13/11]

10

The Regulatory System and the ROP

The regulatory system covering occupational safety and health in the nuclear fuel cycle is divided between three principal agencies:

- NRC has primary responsibility for any part of the civilian nuclear fuel cycle that involves potential for exposure to radiation, including in-situ leach mining (or recovery or extraction) and uranium milling.
- OSHA, in the Department of Labor, has primary responsibility for any non-radiation hazards, except for mining and milling.
- MSHA, in the Department of Labor, has primary responsibility for underground and open pit (surface or "strip") mining, as well as responsibility for non-radiation hazards in underground waste storage that involves mining.

Beyond these primary agencies, other agencies have lesser roles. The Environmental Protection Agency shares the duty of regulating waste disposal and in-situ mining with both the NRC and the DOE. The US Department of Transportation regulates many aspects of the transportation as do the DOE and NRC. Adding to this complexity is the fact that state agencies function on behalf of or in addition to the Federal agencies. Section 274 of the Atomic Energy Act allows states to enter into agreements with the NRC to perform some lesser oversight duties.[167] OSHA and MSHA also have agreements with states and territories which administer their own OSH plans, and most of them work with NRC to regulate non-radiation hazards in NRC licensed facilities.[168] State transportation and highway law enforcement authorities have a substantial role in transportation issues.

10.1 REGULATION OF UNDERGROUND AND OPEN PIT MINING

The Mine Safety and Health Administration does not at present have a focused uranium mining program. Its regulations governing exposure to radon are out of date,[169] and it does not have

[167] NRC has Agreements with 38 states at this time. Except for in-situ leach mining, they do not have a role in the nuclear fuel cycle. They regulate such things as nuclear materials health care and industrial processes, low level waste or waste incidental to reprocessing.
[168] See Table 10.4 for states OSHA plans that regulate nuclear power plants.
[169] Elliot L. *Occupational Health and Safety of Uranium Mining*; Weeks J. *Structure & Function of the Mine Safety and Health Administration (MSHA): Emphasis on Occupational Health Hazards at Uranium Mines*. Presentation to the

single radiation health physicist on its staff.[170] It is likely, at least in major mining states, that State agencies are more effective in regulating mining. Countries from which the U.S. imports most of its uranium (Canada and Australia) have up-to-date regulations.[171]

10.2 THE NRC AND NUCLEAR SAFETY

The mission of NRC is to protect the American people and the environment from exposure to radiation being emitted from the nuclear fuel cycle. The NRC has a very substantial set of strengths that it can use to accomplish this. These include:

- The duty to approve, revoke or deny renewal of operating licenses for fuel cycle facilities.
- A very large budget of approximately $1 billion, of which approximately $800 million is devoted to reactor safety.
- Full-time resident inspectors in all nuclear power plants.
- A high degree of respect from its licensees.

In the civilian nuclear fuel cycle, NRC regulates 120 licensees for occupational exposures to radiation: 1 uranium mill, 4 in-situ mining sites, 1 conversion facility, 2 enrichment plants, 6 fuel fabrication plants, 104 reactors located in 65 nuclear power plant facilities, and 2 independent fuel storage facilities. It also licenses nuclear reactor designs and other radiation uses not directly associated with the nuclear fuel cycle. Fig. 10.1 shows the intensity of inspection effort that the NRC devotes to its nuclear power plant licensees.

Fig. 10.1: Number of Annual Inspection Hours Per Nuclear Power Plant Facility, 2009[172]

National Academies' Committee on Uranium Mining in Virginia, November 15, 2010. http://www8.nationalacademies.org/cp/meetingview.aspx?MeetingID=4645&MeetingNo=2 [Accessed 1/17/11]

[170]Weeks J, Min Safety and Health Administration. Personal Communication, February 15, 2011.

[171]World Nuclear Association. *Occupational Safety in Uranium Mining*, September 2009.

[172]NRC. *Nuclear Reactors: 2010–2011 Information Digest*, NUREG 1350, Vol 22., p. 37. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1350/ [Accessed 2/25/11].

Most nuclear power plants get the equivalent attention of three or more full-time inspectors. That compares to OSHA, which has about 2,200 compliance officers to cover 8 million worksites, or about 4,000 workplaces per inspector.[173]

10.3 THE NRC REGULATORY SYSTEM

Fig. 10.2 is a schematic of the NRC regulatory system. It starts with the development of regulations and guidance for use by the industry and by the NRC's staff. The regulatory functions are licensing and oversight of licensed facilities. Based on its oversight, NRC gains knowledge and experience, which together with regulatory research are used to improve the regulatory systems. In theory (and hopefully practice), the system is based on continuous improvement.

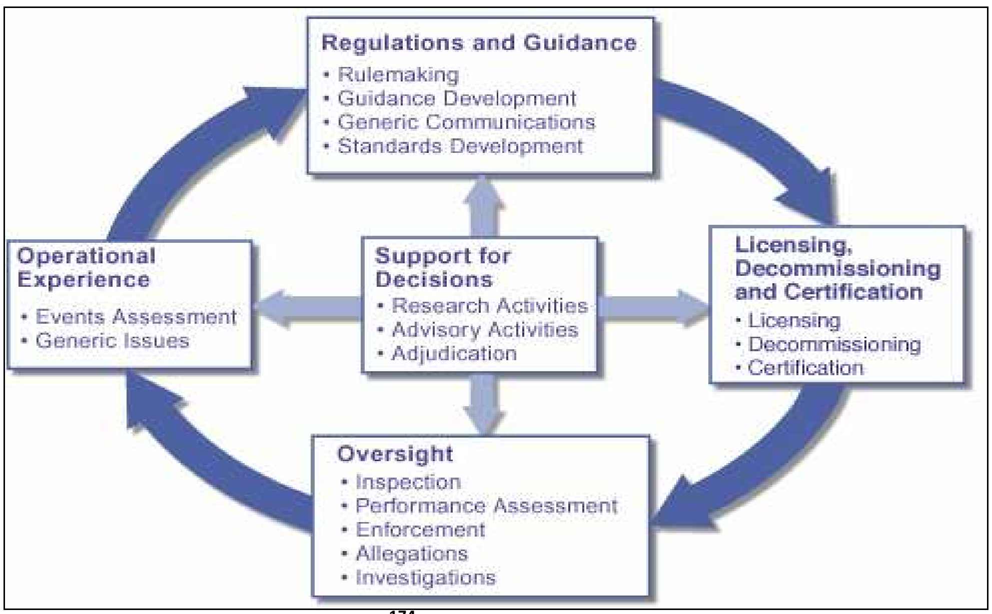

Fig. 10.2: The NRC Regulatory Flow[174]

NRC's regulatory functions have not been without flaws, which has been pointed out by the President's Commission after Three Mile Island[175] and an NRC-commissioned study after the Davis-Besse event in 2002.[176]

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[173]Fairfax R., Deputy Assistant Secretary for Occupational Safety and Health, U.S. Department of Labor. *Personal communication*. February 27, 2011.
[174]NRC *Enforcement Policy*.
http://adamswebsearch2.nrc.gov/idmws/DocContent.dll?library=PU_ADAMS^pbntad01&LogonID=a8ef1ebf1a3e6e9c6fa0498a0142a11c&id=082590709. [Accessed 1/21/11]
[175]Rogovin M, Frampton GT. *Three Mile Island: A Report to the Commissioners and the American People.* Nuclear Regulatory Commission, January 1980, p. 89. http://www.threemileisland.org/downloads/354.pdf [Accessed January 16, 2010]
[176] See section 6.5 of this report.

10.4 THE NRC REACTOR OVERSIGHT PROCESS (ROP)

The heart of NRC's program to assure safety in the nuclear industry is the Reactor Oversight Process (ROP). NRC has a very basic and very good overview which is readily available on the web.[177] The structure of the ROP is shown as it operates today is shown in Fig. 10.3.

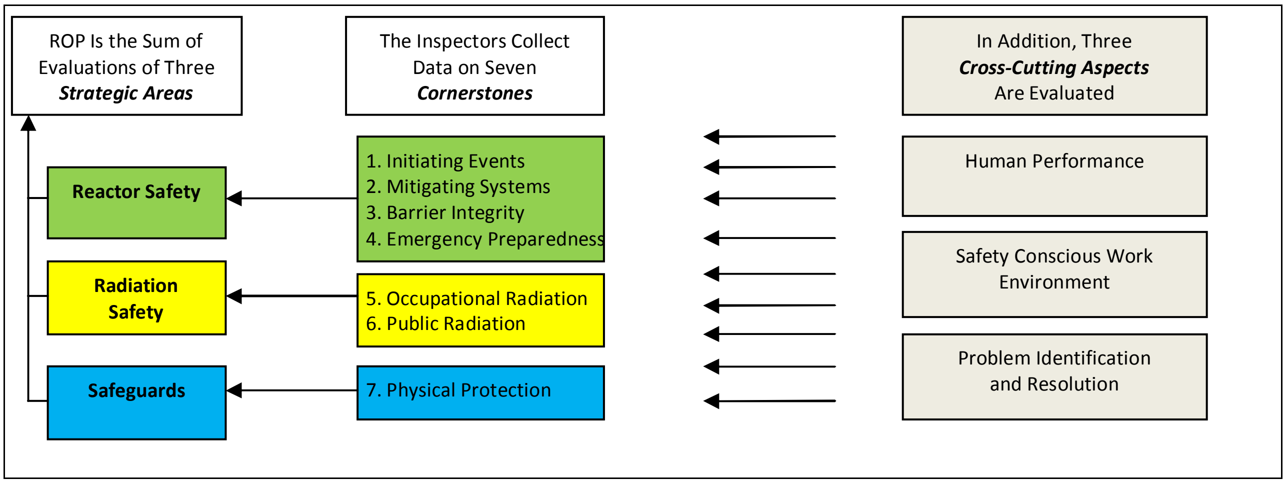

Fig 10.3: ROP Flowchart

The strategic goals of the process are to assess the following:

- Is the reactor integrity good? If something goes wrong, is the plant well prepared to deal with it, by minimizing severity through containment and emergency procedures?
- Is any radiation being released, and if so, are the levels released hazardous to humans?
- Is the plant secure from outside intrusion?

To make this determination, the ROP relies on performance indicators and inspection findings:

- Performance indicators (PIs) are operational data which the plant operator collects quarterly and uses to assess the plant's performance. The NEI defines the PIs in a guideline that is updated periodically. The operators are not required to follow the guideline or supply the PI data to the NRC, but in practice all do. The NRC is not required to use the PI data in its plant evaluations, but in practice the NRC inspectors verify that the PI data are accurate and then use them in their assessments. There are specific performance indicators associated with each of the seven cornerstones of the ROP. They are described in Table 10.1.
- Ongoing inspection of the plant (known as a "*base-line inspection*"), includes interviews with workers and managers, and review of documentation.

The Core of the ROP
Inspection Findings + Performance Indicators = Plant Assessment

[177]NRC. *The Reactor Oversight Process*. NUREG-1649_Rev, December 2006. 4(1)http://adamswebsearch2.nrc.gov/idmws/DocContent.dll?library=PU_ADAMS%5epbntad01&LogonID=c2a29fa0ed76717784fe70767d90bf78&id=070920047 [Accessed 1/29/11]

Table 10.1: The NEI Performance Indicators, 2009[178]

Cornerstone	Code	Performance Indicator
#1 Initiating Events	IE01	Unplanned Scrams per 7,000 Critical Hours
	IE03	Unplanned Power Changes per 7,000 Critical Hours
	IE04	Unplanned Scrams with Complications
#2 Mitigating Systems	MS05	Safety System Functional Failures
	MS06	Mitigating System Performance Index, Emergency AC Power Systems
	MS07	Mitigating System Performance Index, High Pressure Injection Systems
	MS08	Mitigating System Performance Index, Heat Removal Systems
	MS09	Mitigating System Performance Index, Residual Heat Removal System
	MS10	Mitigating System Performance Index, Cooling Water System
#3 Barrier Integrity	BI01	Reactor Coolant System Specific Activity
	BI02	Reactor Coolant System Leak Rate
#4 Emergency Preparedness	EP01	Drill/Exercise Performance
	EP02	Emergency Response Organization Drill Participation
	EP03	Alert and Notification System Reliability
#5 Occupational Radiation Safety	OR01	Occupational Exposure Control Effectiveness
#6 Public Radiation Safety	PR01	Radiological Effluent Occurrence
#7 Physical Protection	PP01	Protected Area Security Equipment Performance Index

Both the Performance Indicators data and the plant inspection reports are entered into a "*Significance Determination Process"* and those violations exceeding acceptable margins are rated "*Greater than Green*", with White, Yellow and Red attached to the assessment. White is the least significant finding and Red is the most serious. NRC oversight increases depending on the severity of the assessment. (See Table 10.2).[179]

Table 10.2: How NRC Rates Safety Performance Based on Inspections

Rating	Inspection Finding
	Green indicates a finding of very low safety significance
	White indicates a finding of low to moderate safety significance
	Yellow indicates a finding of substantial safety significance
	Red indicates a finding of high safety significance

[178]Nuclear Energy Institute. *Regulatory Assessment Performance Indicator Guideline.* NEI 99-02, Revision 6, 2009. http://adamswebsearch2.nrc.gov/idmws/DocContent.dll?library=PU_ADAMS^pbntad01&LogonID=c3bb983ce0a034a6e26633b16dd0afe8&id=092950210 [Accessed 3/26/11]. The reporting of PIIs to NRC is "voluntary," but all operators do so.

[179] NRC. *The Reactor Oversight Process*. NUREG-1649_Rev, December 20064(1), p. 5. http://adamswebsearch2.nrc.gov/idmws/DocContent.dll?library=PU_ADAMS%5epbntad01&LogonID=c2a29fa0ed76717784fe70767d90bf78&id=070920047 [Accessed 1/29/11].

Table 10.3 shows how "*Significance*" is rated and how the NRC's resources are then devoted to bringing the plant into compliance accordingly. The more significant the findings, the more inspection resources are devoted to the plant.[180]

Table 10.3: NRC Inspection Action Matrix

Significance	Assessment of Plant Performance	NRC Response
I	All performance indicators and cornerstone inspection findings GREEN • ***Cornerstone objectives fully met***	**Normal Regional Oversight** • Routine inspector and staff Interaction • Baseline inspection program • Annual assessment public meeting
II	No more than two WHITE inputs in different cornerstones • ***Cornerstone objectives fully met***	**Response at Regional Level** • Public meeting with NRC and plant management • Plant operator corrective actions to address WHITE inputs • NRC inspection follow up on WHITE inputs and corrective action
III	One degraded cornerstone (two WHITE inputs or One YELLOW input or three WHITE inputs in any strategic area) • ***Cornerstone objectives met with minimal reduction in safety margin***	**Response at Regional Level** • Public meeting with NRC and senior regional management and plant management • Plant operator self-assessment with NRC oversight • Additional NRC inspections focused on cause of degraded performance
IV	IV. Repetitive degraded cornerstone, multiple degraded corner stones, or Multiple YELLOW inputs, or one RED input • ***Cornerstone objectives met with longstanding issues or significant reduction in safety margin***	**Response at Agency Level** • Public meeting with NRC Executive Director for Operations and senior plant management • Plant operator improvement plan with NRC oversight • NRC team inspection focused on cause of degraded performance • Demand for Information, Confirmatory Action Letter, or Order
V	V. Unacceptable Performance	**Response at Agency Level**

10.4.1 Safety Culture Inspection Objectives and The Cross-cutting Issues

The ROP recognizes three areas which the ROP calls "crosscutting" because they can affect performance in ANY of the cornerstone activities. These are:[181]

- Human Performance (HP), which is an error in carrying out a required duty
- Problem Identification and Resolution (PIR), defined as a failure to identify problems and correct them

[180] *Ibid.*, p. 6. Amore detailed overview of the Regulatory Action Matrix can be found in NRC. *Operating Reactor Assessment Program, NRC Inspection Manual, Chapter 305, Exhibit 4.* December 24, 2009. http://pbadupws.nrc.gov/docs/ML0934/ML093421300.pdf. [Accessed 4/4/11].
[181] *Ibid*.

- Safety Conscious Work Environment, which is equated with violation of an employee's right to complain about safety.

Protected activities, or the right of an employee to complain about safety problems is embedded in the 1974 statute creating NRC and in its regulations, and a review of NRC's enforcement actions reveals periodic imposition of penalties for violation of the regulations. These violations are graded for severity depending on the status of the person violating the activity: violations by the higher level managers merit the higher penalties. However, NRC does not introduce any of the identified problems in the crosscutting issues into the *Significant Determination Process*, and as a result the cross-cutting issues do not enter into the allocation of inspection follow-up resources.[182] Rather, NRC includes the assessments in reports to the plant, asks for corrective action, and monitors implementation. Plants can also be placed under orders to correct problems with their safety cultures.[183]

The inspection procedure that relates to safety culture and these crosscutting areas is described in an inspection policy called *Identification and Resolution of Problems* which states that it applies to all cornerstones in the ROP.[184] The related inspection objectives are stated as:

> *"01.01 To provide for early warning of potential performance issues that could result in crossing thresholds in the action matrix.*
> *01.02 To help the NRC gauge supplemental response should future action matrix thresholds be crossed.*
> *01.03 To provide insights into whether licensees have established a safety conscious work environment.*
> *01.04 To allow for follow-up of previously identified compliance issues (e.g., NCVs).*
> *01.05 To provide additional information related to the crosscutting areas that can be used in the assessment process.*
> *01.06 To determine whether licensees are complying with NRC regulations regarding corrective action programs.*
> *01.07 To verify that the licensee is identifying operator workarounds at an appropriate threshold and entering them in the corrective action program."*

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[182] http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/actionmatrix_summary.html. [Accessed 2/27/11].
[183] http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/scci_summary.html. [Accessed 2/27/11].
[184] NRC. *NRC Inspection Manual: Identification and Resolution of Problems. Inspection Procedure 71152*. http://pbadupws.nrc.gov/docs/ML0204/ML020400008.pdf. [Accessed 3/5/11]. It states: "*A fundamental goal of the NRC's reactor oversight process is to establish confidence that each licensee is detecting and correcting problems in a manner that limits the risk to members of the public. A key premise of the revised oversight process is that weaknesses in licensee's problem identification and resolution (PI & R) programs will manifest themselves as performance issues which will be identified during the baseline inspection program or by crossing predetermined performance indicator thresholds. However, several aspects of PI & R are not specifically addressed by either the individual cornerstone performance indicators or other baseline inspections. These are detailed in the following objectives. Completion of the inspection objectives is accomplished by sampling issues during each inspectable area inspection, by performing focused reviews of three to six samples per year, and by performing a biennial focused PI & R inspection*".

10.4.2 GAO 2006 Assessment of the ROP

A 2006 GAO report found that fewer than 1% of the reported Performance Indicators are assessed at a "*Greater than Green*" level and that for three indicators there had never been an exceedence of the acceptable performance level.[185] The GAO report also found that although the ROP had been improved, it needed to be refined by developing safety culture metrics which could more effectively identify early signs of safety culture degradation.

We agree. The Performance Indicators and inspection violations are all *lagging* indicators. By failing to incorporate detailed metrics of safety culture, the ROP fails to optimally predict or identify early signs of declines in safety and to institutionalize it at the heart of the safety evaluation. As noted elsewhere, NRC has at least one and usually two or more resident inspectors at each of the plants it oversees. Those inspectors told the GAO that declines in plant performance are often a result of an ineffective corrective action (or PIR), human performance problems, or complacent management.[186] In other words, problems in safety culture are the root cause of declines in plant performance. If that is the case, identified problems in safety culture should be put into the *Significant Determination Process*.

GAO has also found an association between poorer performing plants and the cross-cutting issues indicating safety culture problems.[187] In other words, plants with violations are also more likely to have safety culture problems. Our analysis of the GAO's data (See **Annex 4**) shows that some plants operate with no with no (or only one) "*Greater than Green*" inspection finding and frequently had no problem in safety culture, while other plants, especially those with more significant ROP findings, have safety culture problems year after year.

The GAO report recommended use of the Problem Identification and Resolution cross-cutting issue (See Fig. 10.3) as the metric for safety culture. This recommendation deserves consideration (see Section 10.4.6).

Finally, the GAO report found that it is very difficult for the public to gain access to information about problems in a facility's safety culture. It recommended that NRC make the information more readily available.[188] We agree. We tried to update the table in Annex 4 to show safety culture problems since 2005, but found that the only way to do so is to review the assessment letters sent to plants twice a year. This was impossible to do within the time and resources available to us. NRC can do a better job of providing a simple, searchable data base of the findings.

10.4.3 NRC 2007 Annual Assessment of the ROP

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[185] Government Accountability Office. *Nuclear Regulatory Commission Oversight of Nuclear power Plants Has Improved but Refinements are Needed.* GAO-06-129. http://www.gao.gov/new/items/d061029.pdf [Accessed 1/20/11].
[186] *Ibid.*, p. 27
[187] *Ibid.*, p. 21.
[188] *Ibid.*, pp. 20, 39-40.

The NRC conducts an annual self-assessment of the ROP. A review for Calendar Year 2007 noted that the program was continuing to look for leading performance indicators.[189] It stated that the ROP was failing to provide timely indications of declining safety performance in three distinct sites. It concluded that the Performance Indicators provide insufficient assessment of safety culture. [190] It noted on the positive side that a single new Performance Indicator, Mitigating System Performance Index, had identified 10 of the 16 greater than green findings in CY 2007.[191]

A review of the assessment for CY 2008 made note of "*substantial internal criticisms*" from within the program that the Performance Indicator program does not provide meaningful insight into plant performance and does not predict declining performance.[192]

10.4.4 Focal Point Assessment of the ROP

NRC commissioned an independent evaluation of the ROP from a consulting firm called Focal Point, which reported its findings in 2008.[193] Focal Point concluded that "*The Program...needs to continue efforts to improve monitoring of safety culture within the licensee organizations*,"[194] and that the performance indicators, as currently established, provide limited insight into to variations in plant performance.[195] Focal Point found that unlike the performance indicators, baseline inspectors are able to identify variability in plant performance, that they always find problems in performance indicators not identified by the plant, and that they are effective in identifying degrading performance,[196] although safety culture assessments are challenging for the inspections staff.[197]

Focal Point observed that the fact that so few performance indicators are green may be a reflection of success in the ROP. However, they stated that NRC should further assess the issue. They thought that there might be alternative explanations for the fact that so few PIs are *Greater than Green*. One possibility was that the thresholds between the severity categories were too high. Another might be that there were issues with data collection and analysis of the PIs. Finally, they suggested that licensees had learned how to get the green ratings -- that there was "fatigue" in the performance indicators.[198] They suggested adding a performance metric to

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[189]NRC. *Reactor Oversight Process Self-Assessment For Calendar Year 2007*. SECY-08-0046 April 2, 2008, p. 2. http://pbadupws.nrc.gov/docs/ML0804/ML080460120.pdf. [Accessed 3/311].

[190]Ibid., 4

[191]Ibid, P. 3 The Mitigating Systems Performance Index was developed by NRC and the industry to evaluate risk associated with changes in the availability and unreliability of important safety systems. It consists of five indicators. NRC. *Inspection Procedures & Performance Indicators by ROP Cornerstone*. http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/cornerstone.html)(Viewed March 3,2011)

[192]NRC SECY-09-0054 (April 6,2009)(http://pbadupws.nrc.gov/docs/ML0905/ML090540575.pdf._[Accessed 3/3/11].

[193]Focal Point, *Independent Evaluation of the Reactor Oversight and Incident Response Program*, December 31, 2008. http:adamswebsearch2nrc.gov/idmws/DocContent. [Accessed 3/3/11].

[194]*Ibid*, p. 2

[195]*Ibid*, p.2-3

[196]*Ibid.*, pp. 24, 33.

[197]*Ibid.*, p. 33

[198]*Ibid*, p. 25

show the plant's speed in correcting safety deficiencies.[199]

Finally, Focal Point found that the Significance Determination Process was slow, sometimes subjective or influenced by licensees.[200] We cannot evaluate Focal Point's claim about subjectivity or the degree to which it can be influenced by licensees, but we can attest to the slowness of the process. At the time of writing this report in March 2011 the final reports for 2010 had not yet been posted in publicly available data bases and based on past performance, had probably not yet been sent to licensees.

10.4.5 Stakeholder Assessment of the ROP

On September 25, 2009, NRC published a Federal Register notice asking for comments on 21 questions relating to implementation of the ROP. Three nuclear operating companies, one industry association and one consulting firm responded.[201] All said the ROP and other NRC inspection activities help assure safety[202] and prompt corrective action.[203] They also agreed that the fact that 99% of inspections result in a finding of "Green" reflects the success of the NRC and industry.[204]

However, they were critical of the way the ROP incorporates safety culture into its implementation of the ROP. One respondent said that the safety culture additions to the ROP were not valid measures of safety culture, and that the cross-cutting areas (CCA) do not identify weaknesses in safety culture and do not focus attention on appropriate corrective actions.[205] They also agreed that inspection findings based on the CCAs should not be treated equally. As currently practiced, if four or more cumulative negative inspection findings for safety culture are found in a year in a single plant, the ROP treats it as a "significant" CCA. According to one responder, there are two problems with that: first, the number "four" is not based on any objective research, and, since a thousand or more procedures related to safety culture are performed each day,[206] to conclude that four negative findings among them in a year adds up to a significant finding is "*arbitrary*." Second, it does not take into account the risk significance associated with the finding, i.e., all findings are treated the same regardless of the severity.[207]

In 2009, the Union of Concerned Scientists published a 10-year review of the ROP. It concluded that "*The ROP's first decade had more good than bad. Obviously, that Davis-Besse happened on*

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[199] *Ibid.*, p. 35
[200] *Ibid*, pp. 25-26
[201] NRC. *Consolidated Response to the 2009 Reactor Oversight Process External Survey*, May 7, 2010. http://adamswebsearch2.nrc.gov/idmws/DocContent.dll?library=PU_ADAMS^pbntad01&LogonID=b057ddde73b27056b40520cebe1c510c&id=101370042. [Accessed 3/4/11].
[202] *Ibid.*, p. 32.
[203] *Ibid.*, p. 13.
[204] *Ibid.*, p. 11.
[205] *Ibid.*, pp. 24-25.
[206] *Ibid.*, p. 23. "*The thousand people at a station likely perform more than one procedure per person per day, for 365 days a year, which would be hundreds of thousands of opportunities, with only four failures.*"
[207] *Ibid.*, pp. 22-23.

the ROP's watch is bad. But the ROP functioned well at Palo Verde....The NRC needs to resolve known safety performance problems in a more timely and effective way. It is simply unacceptable that a reactor operate for 67 percent of the decade with identified performance deficiencies." The review also recommended that NRC perform an evaluation of the extent to which inspectors' findings "*result from considerations other than expert judgment based,*" that ROP performance indicators need to be "*more meaningful*" and that the results of the ROP should result in an allocation of inspection resources that better reflect risks.[208]

10.4.6 Our Assessment of the ROP

Just prior to the Davis-Besse event, the plant had been rated by NRC as being in the top performer category (Green). This shows that despite massive efforts at designing and refining the ROP, there are still incidents that happen that should have been detected in the ROP process. As described above, some critics have focused on the performance indicators, stating that they are "too green" -- that is, they are evaluated as being satisfactory 99 percent of the time. However, since the performance indicators are benchmarked to NRC safety margins, others conclude that the high green rate is a measure of NRC and industry success in achieving safety.[209] We observe that the Mitigating Systems Performance Index has been effective in detecting problems (See Section 10.4.3). Many of the other PIs may not discriminate sufficiently at the very high level of safety performance that is currently reported by the licensees. Scrams and safety system actuations are of course important risks that need to be monitored carefully, but given a probability of 0.36 and 0.32 events respectively per reactor per year,[210] they are not very useful as risk predictors to drive safety performance.

The review by the Union of Concerned Scientists points out that some plants have operated for years at levels not in the licensee response (or Green) category.[211] Measured by another index, **Annex 5** shows that some plants receive "*Greater than Green*" inspection findings years on end. It is not clear to us how much the NRC takes such past patterns of poorer performance into account when it performs its plant assessments. We had a hard time trying to use NRC records to identify patterns of problems in safety culture,[212] and it does not appear to us that the NRC is strongly engaged in collecting data and assessing patterns in plant problems when it comes to safety culture. We note that NRC seeks continuous feed-back on how well the ROP works, and provides for the true experts in the field to address such concerns and make changes in the PIs. Further, while the performance indicators have been criticized we have not identified

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[208]Union of Concerned Scientists. *The NRC's Reactor Oversight Process: An Assessment of the First Decade: An Issues Brief*. January, 2011. http://www.ucsusa.org/assets/documents/nuclear_power/20110127-ucs-brief-rop-first-decade.pdf. [Accessed 2/25/11]., p. 9

[209]NRC. *Consolidated Response to the 2009 Reactor Oversight Process External Survey*, May 7, 2010. http://adamswebsearch2.nrc.gov/idmws/DocContent.dll?library=PU_ADAMS^pbntad01&LogonID=b057ddde73b27056b40520cebe1c510c&id=101370042. [Accessed 3/4/11].

[210]See Section 6.3.

[211]Union of Concerned Scientists. *The NRC's Reactor Oversight Process: An Assessment of the First Decade: An Issues Brief*. January, 2011. http://www.ucsusa.org/assets/documents/nuclear_power/20110127-ucs-brief-rop-first-decade.pdf. [Accessed 2/25/11]., p. 9

[212]See Section 10.4.2.

alternative proposals from other sources. At least in this respect, the ROP is clearly a work in progress subject to continuous improvement.

We have not seen similar attention paid to the other source of input to the ROP, the baseline inspection program conducted by the resident inspectors at each plant. The Focus Point report discussed above had many positive comments about the program.[213] However, one person we spoke to who wished to remain anonymous told us that resident inspectors face the choice of becoming cozy with their plants or risk being ostracized, and recommended that they should be rotated more quickly than they are at present. We are not in a position to evaluate this comment. However, the NRC Inspector General concluded that the NRC headquarters staff could be influenced by the financial impact of a shutdown, contrary to the goal of having at-risk plants being inspected in a more frequent and timely manner. That seems to have been the case at the Davis-Besse plant.[214] If the headquarters staff can be susceptible to sympathy for the regulated, so too could the resident inspectors. This has led some observers to suggest the NRC Inspector General should be asked to examine it.

Beyond the specific technical issues in the ROP, as noted earlier, we are concerned that the performance indicators and baseline inspections focus almost entirely on lagging indicators.[215] They reflect events that have taken place in the past, rather than reflecting indicators that point to the future. And, since the Significance Determination Process is slow, the outcome of a plant assessment may either reflect a past problem which has been corrected by the time the plant gets the assessment letter, or it could have become a much more significant problem. Many in the industry will say that their probabilistic risk assessment modeling is all about anticipating events, which is true to a point. If however, the safety culture at a plant is the source of the biggest risk, then PRAs are not likely to be so helpful. We address this in more detail in Section 12, on Safety Culture.

NRC and the industry agree that safety culture is a critically important issue and a principal root cause of violations found in the Performance Indicators. If this is the case, it would seem that safety culture ought to be a *Strategic Area* in the ROP, with its own *Cornerstones* and *Performance Indicators*, as an integral part of the process of allocating additional resources to troubled plants. as shown in Fig. 10.4 (see next page). Safety culture would be integrated into the ROP, and any degradation of safety culture would draw stronger regulatory attention. As it is, it is treated as a lesser requirement or concern--a bad message. We have not thought through in detail what the performance indicators for safety culture should be, and they rightly should be developed primarily by the NRC and the affected stakeholders. However, we suggest that the thirteen safety culture components that are currently included in the ROP form a solid

[213] See Section 10.3.4.
[214] NRC. Office of Inspector General, NRC's Regulation of Davis-Besse Regarding Damage to the Reactor Vessel Head Case No. 02-035. December 30, 2002, p. 23. http://www.nrc.gov/reading-rm/doc-collections/insp-gen/2003/02-03s.pdf. [Accessed 2/25/11] See also Section 6.5 of this report.
[215] However, one PI seems to work especially well. The Annual ROP Assessment found the Mitigating System Performance Index identified 10 of the 16 Greater than Green findings in 2007.NRC. SECY-08-0046, 2008. htp://www.nrc.gov/reading-rm/doc-collections/commission/secys/2008/secys2008-0046/2008-0046.pdf.

basis.[216] The eight traits that are included in the NRC Safety Culture Policy[217] should also be considered, as should the NEI's safety culture process inputs,[218] or elements from the INPO safety culture assessment instrument.[219]

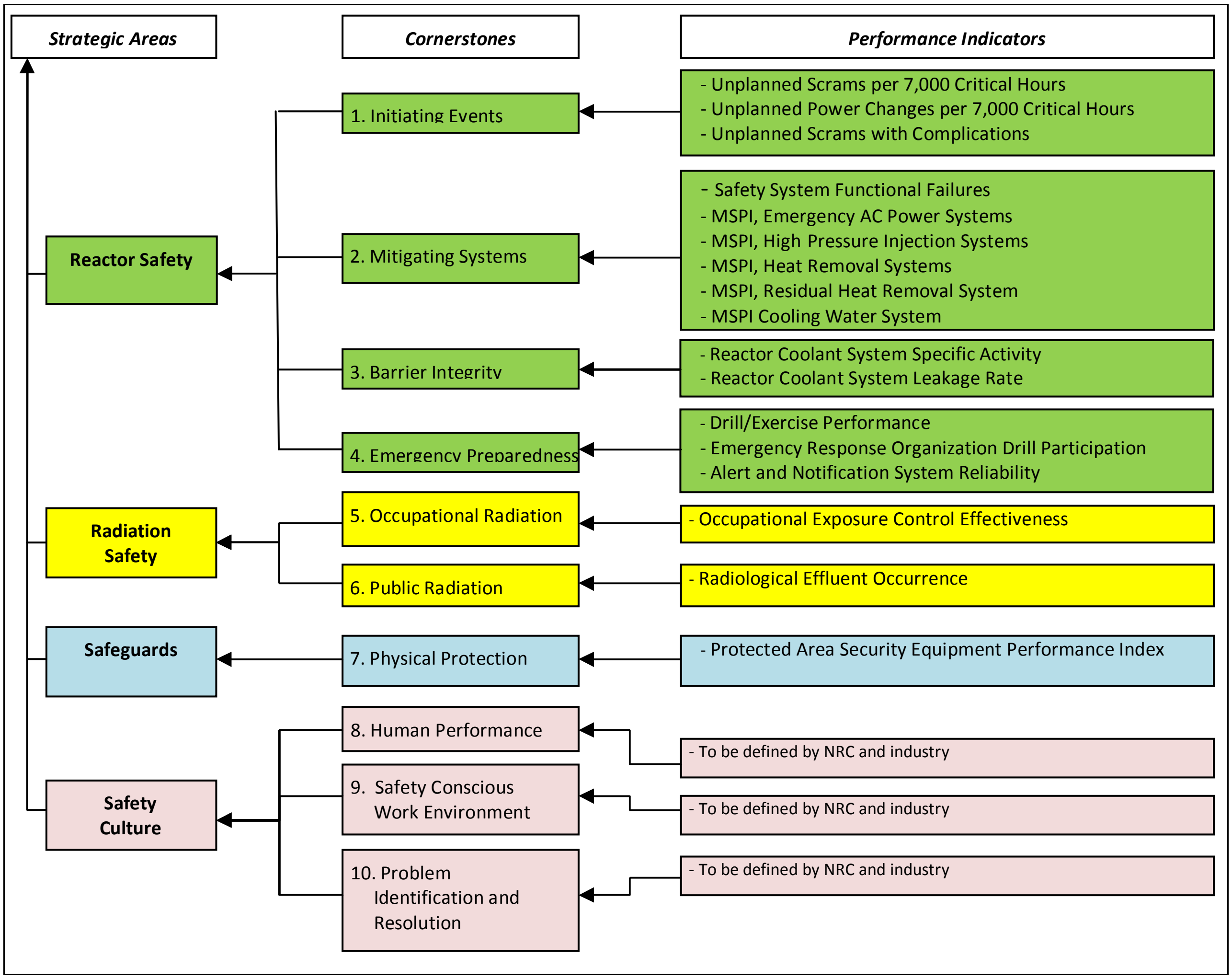

Fig 10.4: Proposed ROP Flowchart

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[216]These are: 1) Decision-Making; 2)Resources; 3) Work Control; 4) Work Practices; 5) Corrective Action Program; 6) Operating Experience; 7) Self- and Independent Assessments; 8) Environment for Raising Nuclear Safety Concerns; 9) Preventing, Detecting, and Mitigating Perceptions of Retaliation; 10) Accountability; 11) Continuous Learning Environment; 12) Organizational Change Management; and 13) Safety Policies. See NRC. *Safety Culture Initiative Activities to Enhance the Reactor Oversight Process and Outcomes of the Initiatives*. Secy -06-0122, May 24, 2006, Enclosure 2, p. 4. http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2006/secy2006-0122/2006-0122scy.pdf. [Accessed 2/14/11]. These are: 1) Decision-Making; 2)Resources; 3) Work Control; 4) Work Practices; 5) Corrective Action Program; 6) Operating Experience; 7) Self- and Independent Assessments; 8) Environment for Raising Nuclear Safety Concerns; 9) Preventing, Detecting, and Mitigating Perceptions of Retaliation; 10) Accountability; 11) Continuous Learning Environment; 12) Organizational Change Management; and 13) Safety Policies.

[217] See Section 12.5 of this report.

[218]See Section 12.4.2 of this report.

[219]See Section 12.4.3 of this report.

The NRC in its safety culture policy has also indicated concern about making mandatory specific safety culture requirements. We find that to be inconsistent with NRC's own conclusion that the cross-cutting issues can impact any cornerstone. Finally, we believe safety culture should examined as part of the Quality Assurance Program requirement.[220]

10.5 THE RELATIONSHIP BETWEEN NRC AND OSHA

Both NRC and OSHA have jurisdiction over occupational safety and health at NRC-licensed facilities. In 1988, NRC entered into a formal memorandum of understanding with OSHA about jurisdiction for occupational safety and health in civilian nuclear facilities.[221] The procedures were updated as late as 2004.[222] The rationale for this, according to the MOU, is that "Because it is not always practical to sharply identify boundaries between the nuclear and radiological safety NRC regulates and the industrial safety OSHA regulates, a coordinated interagency effort can insure against gaps in the protection of workers and at the same time, avoid duplication of effort."

According to the NRC Inspection Manual, this is how the duals system is supposed to work:

> "*Although NRC does not conduct inspections of industrial safety, in the course of inspections of radiological and nuclear safety, NRC personnel may identify safety concerns within the area of OSHA responsibility or may receive complaints from an employee about OSHA-covered working conditions. In such instances, NRC will bring the matter to licensee management. NRC inspectors are not to perform the role of OSHA inspectors; however, they are to elevate OSHA safety issues to the attention of NRC Regional management when appropriate. If significant safety concerns are identified or the licensee demonstrates a pattern of unresponsiveness to identified concerns, the NRC Regional Office will inform the appropriate OSHA Regional Office. In the case of complaints, NRC will withhold, from the licensee, the identity of the employee. In addition, when known to NRC, NRC will encourage licensees to report to OSHA accidents resulting in a fatality or multiple hospitalizations."*[223]*... "The chemical processing of nuclear materials at some NRC-licensed fuel and materials facilities presents chemical and nuclear operational safety hazards which can best be evaluated by joint NRC-OSHA team*

[220] 10 CFR Part 50, Appendix B

[221] Memorandum of Understanding Between The Nuclear Regulatory Commission and the Occupational Safety and Health Administration; Worker Protection at NRC-licensed Facilities. October 21,1988 http://www.nrc.gov/about-nrc/regulatory/enforcement/mouosha.pdf [Accessed 1/25/11]

[222] NRC. *Inspection Manual. Chapter 1007: Interfacing Activities between Regional Offices of NRC and OSHA*. http://www.nrc.gov/reading-rm/doc-collections/insp-manual/manual-chapter/mc1007.pdf. [Accessed 1/25/11]

[223] NRC. *Inspection Manual. Chapter 1007: Interfacing Activities between Regional Offices of NRC and OSHA*, p. B-3. http://www.nrc.gov/reading-rm/doc-collections/insp-manual/manual-chapter/mc1007.pdf. [Accessed 1/25/11]

assessments. Each agency will make its best efforts to support such assessments at about 20 facilities once every five years."[224]

However, it is not mandatory for NRC to refer an industrial safety concern to OSHA. According to the NRC Enforcement Manual,

> *"For accidents involving a fatality or multiple hospitalizations, the MOUs do not require NRC to report such matters to OSHA. But in keeping with established practices, if the licensee refuses to report these events to OSHA, the NCR Regional Office OSHA Liaison Officer will inform the OSHA Regional Office.... Communication with OSHA Regional Offices should be done orally, unless OSHA requests a written notification in a particular case."*[225]

There are four kinds of hazards that may be associated with NRC-licensed nuclear facilities:

a. Radiation risk produced by radioactive materials;
b. Chemical risk produced by radioactive materials;
c. Plant conditions which affect the safety of radioactive materials and thus present an increased radiation risk to workers. For example, these might produce a chemical explosion, and thereby cause a release of radioactive materials or an unsafe reactor condition; and,
d. Plant conditions which result in an occupational risk, but do not affect the safety of licensed radioactive materials. For example, there might be exposure to toxic nonradioactive materials and other industrial hazards in the workplace.

Generally, NRC covers the first three hazards listed in paragraph (a, b, and c), and OSHA covers the fourth hazard (d). State OSHA plans can have either full or partial jurisdiction over occupational injury and illness prevention in nuclear operations. Table 10.4 (next page) shows the different states that are involved.

We searched the OSHA *Integrated Management Information System (IMIS)* between 1992 and 2009 and found 70 OSHA inspections of nuclear plants which resulted in 42 violations. Of these, 10 resulted from one inspection for violations that appeared to be related to construction in a nuclear power plant. Worker complaints led to 34 inspections; referrals (most likely from a nuclear plant operator after being notified by a NRC inspector about a hazardous condition) resulted in 18 inspections; and OSHA itself initiated 11 inspections. In all, over 17 years the probability that one of the 65 nuclear power plant facilities would be inspected by OSHA was 0.06 per year and the probability of getting a violation as a result of such inspections was 0.037.

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[224] Ibid., p B-4.
[225]NRC. *Nuclear Regulatory Commission Enforcement Manual, Revision 7,* October 1, 2010, p. 7-29. http://www.nrc.gov/reading-rm/basic-ref/enf-man/manual.pdf [Accessed 2/5/11]

Table 10.4: States with OSHA Plans with Jurisdiction in the Nuclear Fuel Cycle

	Facilities	State OSHA Plan
Mining	20	Alaska, Arizona, Nevada, New Mexico, Oregon, Utah, Virginia, Washington, Wyoming
Milling	1	Utah, Wyoming
Conversion	1	Kentucky
Enrichment	1	Kentucky
Fuel Fabrication	4	Virginia, North Carolina, South Carolina, Tennessee, Washington
Reactor Operations	66	Arizona, California, Iowa, Kentucky, Maryland, Michigan, Minnesota, North Carolina, South Carolina, Tennessee, Vermont, Virginia, Washington.
Spent Fuel Storage	50	Arizona, California, Iowa, Kentucky, Maryland, Michigan, Minnesota, North Carolina, Oregon, South Carolina, Tennessee, Vermont, Virginia, Washington.
Recycling (Mainly defense)	4	Kentucky, Tennessee
Waste Disposal (Mainly transuranic)	1	New Mexico
Waste Disposal (High level; Inactive)	1	Nevada

Because communications between NRC staff and OSHA regional offices are supposed to be verbal, there is not much of record of what leads to a referral, and it is hard to perform an assessment of it. Our impression from talking to many people is that this system does not work well. NRC staff do not generally refer cases to OSHA and as far as we have been able to determine, the proposed joint NRC/OSHA evaluation of front-end facilities is not taking place. Having said that, given that OSHA is stretched so thin and given that the nuclear plants generally have very good safety records compared to other industries, would it be a good use of OSHA's time to spend much effort on these plants? If we based our assessment on the outcomes, that is, occupational injury and illness rates as reported for both nuclear plant operations and for maintenance outages,[226] we conclude that the current system is probably acceptable, at least for nuclear power plants, although we do not understand why the NRC inspectors should be able to treat a non-nuclear occupational safety risk in any lesser way than they do with a nuclear occupational risk.

In-situ leach mining also points to the problem of dual jurisdictions. In 2003, NRC finalized a *Guide* for reviewing licensing applications for these facilities.[227] Even though NRC is the principal regulator of such facilities, and even though safety and chemical risks are probably a much greater concern that radiation exposure, the *Guide* states, "*While occupational and safety concerns are important and need to be included in the development of standard operating procedures, NRC regulatory authority is limited to those instances where occupational safety concerns may affect radiological operations or accidents.*"[228]

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[226] See Section 8.4.
[227] NRC. *Standard Review Plan for In Situ Leach Uranium Extraction License Applications.* NUREG-1569, June 2003. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1569/sr1569.pdf. [Accessed 3/3/11].
[228] *Ibid.*, p. 5-10.

10.6 MAINTENANCE OF FACILITIES

Maintenance, renovation and repair operations are a point of particular risk, because first, they are not routine operations, and second, they usually involve bringing in outside contractors and workforces to perform the tasks. Bringing together several different contractors and workforces in the same facility can be very difficult and has often led to great hazards in the construction industry.[229]

To address the challenges, nuclear operators and NRC have gone to great lengths to improve procedures. There are a large number of documents that guide how NRC licensees are to perform maintenance work (see Box 10.1).

Box 10.1. Principal Documents Related to NRC Maintenance Rules[230]

NRC Maintenance Rule—10 CFR 50.65
Statements of Consideration for the several revisions of the rule
Reg. Guide 1.160, Rev. 2 (endorses NUMARC 93-01, Rev. 2)[231]
Reg. Guide 1.182 (endorses revised Section 11 of NUMARC 93-01)
NRC Baseline Inspection Procedure 71111.12 [all MR except (a)(4)]
NRC Baseline Inspection Procedure 71111.13 [covers (a)(4)]
NRC Supplemental Procedure 62709
Section 7.11 of the NRC Enforcement Manual
NRC Inspection Manual, Chapters 0609, 0612 and 9900
NUREG 1648, Lessons Learned from Maintenance Rule Baseline Inspections
Section 17.6 (MR) and parts 17.4 (0-RAP) of NUREG-0800, The Standard Review Plan
Section 17.6 (MR) and parts 17.4 (0-RAP) of RG. 1.206 COLA Guidance for 10 CFR Part 52 applicants
Inspection Procedure (IP) 62706.52 for Maintenance Rule program implementation inspections
Any other Maintenance Rule–related NUREGs, or NRC generic communications

The age of the plants both in the US in general and information inspection information in the NRC inspections database caused us to look further at the plant maintenance issue. We found that the maintenance regulation permits a great deal of flexibility which may be appropriate in light of the highly diverse nature of maintenance work. The licensee sets the maintenance standards, although there is in the regulations a reference to industry-wide standards developed by utility groups, as well as a subsequent revision to Section 11[232] that has been

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[229] Gittleman JL, Gardner PC, Haile E, Sampson JM, Cigularov KP, Ermann ED, Stafford P, Chen PY Case Study: City Center and Cosmopolitan Construction Projects, Las Vegas, Nevada: Lessons learned from the use of multiple sources and mixed methods in a safety needs assessment. *Journal of Safety Research* 41: 263–28, 2010.
[230] *MRUG Update*, Winter 2010. http://mydocs.epri.com/docs/CorporateDocuments/Newsletters/MRUG/1020599.html [Accessed 2/5/11].
[231] Nuclear Energy Institute. *Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants.* NUMARC 93-01, Revision 2, April 1996. http://www.nrc.gov/reactors/operating/ops-experience/maintenance-effectiveness/mainten-effect-files/mrule-numarc-9301-revised.pdf [accessed 2/5/11]
[232] *Ibid*.

endorsed by the NRC.[233] The NRC Enforcement Policy[234] makes clear that corrective action is considered prompt and comprehensive if the licensee makes a prompt decision on operability and either decides to maintain the facility or procedure in the as-found condition or promptly initiates a corrective action plan (p. 21). In other words, the decision-making is assigned to the licensee.

We met with the maintenance contractors and unions that supply crafts workers for outages specifically to determine whether they thought the current regulatory system is deficient. We did not receive any suggestions about needed changes. If we based our assessment on the outcomes, that is, reported occupational injury and illness rates as reported for maintenance outages,[235] we conclude that the current system is probably acceptable, at least for nuclear power plants. We did not have time to assess whether this is also true for other fuel cycle licensee categories.

10.7 WORKER TRAINING REQUIREMENTS

NRC requires its licensees to assure that workers are properly trained for their duties.[236] NRC's training regulation states, *'Training and Qualification of Nuclear Power Plant Personnel,' requires that each nuclear power plant licensee or applicant for an operating license implement training and qualification programs that are derived from a systems approach to training.*"[237] In our discussions with industry stakeholders, we found no indication that training is deficient. The safety record is good. Although the training rule is vague, it appears to work.

10.8 THE NRC REGULATORY RESEARCH PROGRAM

This is how the NRC describes its research program:
"The Office of Nuclear Regulatory Research (RES) supports the regulatory mission of the U.S. Nuclear Regulatory Commission (NRC) by providing technical advice, tools, and information to identify and resolve safety issues, make regulatory decisions, and issue regulations and guidance. This includes conducting confirmatory experiments and analyses; developing technical bases that support the NRC's safety decisions; and preparing the agency for the future

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[233]NRC. *Monitoring the Effectiveness of Maintenance at Nuclear Power Plants; Confirmation of Effective Date and Availability of Guidance*. *Federal Register*, 65:31493, 2000. http://groups.google.com/group/gov.us.topic.energy.nuclear/browse_thread/thread/b9125cd0ace76f8b
[234]*Federal Register*, 75:60485-60487, September 30, 2010. http://www.nrc.gov/about-nrc/regulatory/enforcement/frn-vol75-no189.pdf [Accessed 2/5/11]
[235]See Section 8.4 of this Report.
[236] See 10 CFR Part 50*, "Domestic Licensing of Production and Utilization Facilities," Section 50.120.*
[237] NRC. *Qualification and Training of Personnel for Nuclear Power Plants*. Regulatory Guide 1.8, Revision 3, May 2000.
http://adamswebsearch2.nrc.gov/idmws/DocContent.dll?library=PU_ADAMS^pbntad01&LogonID=3945b16d9cb63df0c6e7c8878918e8b9&id=003937433. [Accessed 2/21/11]

by evaluating the safety aspects of new technologies and designs for nuclear reactors, materials, waste, and security."[238]

The NRC research program includes a range of safety and health-related issues, from basic fire protection to health effects from radiation exposure. It recently established a Safety Culture research focus which is discussed in Section 12.

10.9 OVERALL ASSESSMENT OF THE REGULATORY SYSTEM

In 1995 Entergy bought the Pilgrim Nuclear Station in Massachusetts. It had been a plant with a history of operating problems which was slated for decommissioning when it was bought. Entergy turned that plant around and made it into a high performance operation in terms of safety.[239] The NRC may not be able to require its licensees to be outstanding performers, but it does have the duty to set conditions of licensing, and those conditions include safety and health requirements. It may be worth revisiting those conditions to make sure they are consistent with the greater emphasis on safety culture in the ROP.

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[238] NRC, Office of Regulatory Research. Research Activities FY 2010-FY 2011, p.ii. NUREG 1925, Rev. 1, December 2010 http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1925/r1/sr1925r1.pdf. [Accessed 2/12/11]

[239] Zachary GP. Entergy has figured out a way to make aging atomic power plants pay--and is fueling the industry's unlikely resurgence. CNN Money, May 1, 2005. http://money.cnn.com/magazines/business2/business2_archive/2005/05/01/8259698/index.htm. [Accessed 2/20/11]

11

Self-Regulation in the Nuclear Industry

To our knowledge, the nuclear industry is unique among American industrial sectors in that it not only has a strong industry-wide policy of self-regulation, but it has established its own organization which in many ways has as much leverage over the industry as does the NRC. This organization is the Institute of Nuclear Power Operations (INPO), which was established immediately after Three Mile Island. We were unable to meet with INPO in the time available to us. Therefore, we have relied on the book by Rees as our primary source for the first 15 years of INPO's existence.[240] Additionally, we have relied on a presentation on INPO that was made by its President and CEO, retired Admiral James O. Ellis, Jr. before the Deepwater Commission. We have included his presentation in **Annex 6.**

11.1 THE ROLE OF INPO

The Report of the President's Commission on the Accident at Three Mile Island recommended that the industry needed to change the way it operated:[241]

> *"To the extent that the industrial institutions we have examined are representative of the nuclear industry, the nuclear industry must dramatically change its attitudes toward safety and regulations. The Commission has recommended that the new regulatory agency prescribe strict standards. At the same time, the Commission recognizes that merely meeting the requirements of a government regulation does not guarantee safety. Therefore, the industry must also set and police its own standards of excellence to ensure the effective management and safe operation of nuclear power plants.*
>
> *"The industry should establish a program that specifies appropriate safety standards including those for management, quality assurance, and operating procedures and practices, and that conducts independent evaluations. The recently created Institute of Nuclear Power Operations, or some similar*

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[240]Rees JV. *Hostages of Each Other: The Transformation of the Nuclear Industry Since 1980.* University of Chicago Press, 1995.

[241]*Report of the President's Commission on the Accident at Three Mile Island*, 1979, p. 8. [Emphasis Added]. http://www.threemileisland.org/downloads/188.pdf. [Accessed January 16, 2011].

organization, may be an appropriate vehicle for establishing and implementing this program.

"There must be a systematic gathering, review, and analysis of operating experience at all nuclear power plants coupled with an industry-wide international communications network to facilitate the speedy flow of this information to affected parties. If such experiences indicate the need for modifications in design or operation, such changes should be implemented according to realistic deadlines."

The nuclear power operators established INPO in December 1979 *"...to promote the highest levels of safety and reliability – to promote excellence*."[242] It has four programs:

- **Plant evaluations** that focus on safety and reliability
- **Training and accreditation** for nuclear power professionals. It administers the National Academy of Nuclear Training for this purpose.
- **Events analysis and information exchange** of lessons learned and best practices
- **Assistance** to nuclear power operators related to the management and operation of nuclear plants.[243]

Thirty years later, the CEO of INPO testified before the National Commission on the British Petroleum Deepwater Horizon Oil Spill and Offshore Drilling and stressed these programs make INPO effective as part of the nuclear power industry's effort to self regulate.[244] Following its review of INPO's impact on the nuclear industry, the Deepwater Commission concluded that this was one example of an industry reforming itself to focus on process safety and in so doing, transforming an inherently risky industry into a much safer one.[245]

The Commission pointed out several key aspects which in its view made INPO a success, and concluded that the essential features of a self-policing safety organization are: complete credibility in terms of expertise and organizational agenda; an industry-wide commitment to rigorous auditing and continuous improvement; and benchmarking against global best practices.[246] They concluded that INPO had been a central element --if not *the* central element-- in the transformation of the nuclear industry, and that it should be a model for other high risk industries, such as deepwater drilling.

[242] http://www.inpo.info/AboutUs.html. [Accessed January 16, 2010] Rees points out that the industry had another motivation as well. It wanted to escape more stringent regulation by the NRC. Rees JV. *Hostages of Each Other: the Transformation of the Nuclear Industry since 1980.* University of Chicago Press, 1995, p. 43.
[243] http://www.inpo.info/AboutUs.html. [Accessed January 16, 2010]
[244] See Annex 6.
[245] National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling. *Deep Water: The Gulf Oil Disaster and the Future of Offshore Drilling*, January 2011, p. 229. https://s3.amazonaws.com/pdf_final/DEEPWATER_ReporttothePresident_FINAL.pdf [accessed January 16, 2011.]
[246] *Ibid.*, p. 241. This is what the INPO did in the mid-1980s when it found that the U.S. industry was lagging behind the performance of plants in Germany, France, Japan and Switzerland. See Rees JV. *Hostages of Each Other: the Transformation of the Nuclear Industry since 1980.* University of Chicago Press, 1995, p. 92-93.

11.2 THE IMPORTANCE OF CONFIDENTIALITY

INPO has argued in the past that it is important to keep its assessments private so its experts and the nuclear power plant staff can freely communicate.[247] It litigated the issue with Ralph Nader for nine years until winning in the Supreme Court in 1993. Reese was able to write his book not through INPO cooperation but by getting INPO materials from the Tennessee Valley Authority, which as a Federal agency is subject to the Freedom of Information Act.

Release of information on the performance of the industry to the public has long been urged.[248] First, the *Sillin Report*, which was commissioned in 1985 by the utility industry and authored by leaders of the industry, concluded the following:

> "*INPO should report the number of plants performing at or above the industry's standard of acceptable performance and the number evaluated as below that standard of performance. Those plants evaluated as achieving excellent performance in their operations should be identified by name, and those evaluated as requiring special attention and assistance also should be identified by name.*" [249]

Similarly, the National Research Council recommended in 1992: "*It is the Committee's opinion...that the nuclear industry should continue to take the initiative to bring the standards of every American nuclear plant up to those of the best plants in the United States and the world. Chronic poor performers should be identified publicly and should face the threat of insurance cancellations*."[250]

At this stage, INPO safety culture reports are available to the NRC at each plant, and INPO plant assessments are reviewed by NRC to make sure the agency has not missed anything in its own reviews. If NRC can have access to the reports, why not the public? This issue was heavily debated by the industry after release of the *Sillin Report* in 1985, and it was the *only* recommendation not accepted by the industry.[251]

It might be wise for the industry to return to this debate in light of its heightened embracement of safety culture over the past 20 years. At the very least, making public the best and worst performance will benefit both. Making such information public would enhance INPO's powers; in fact we believe that the full extent of INPO's powers and industry standards of excellence will never be fully realized without publication of its conclusions. Moreover, an open industry will

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[247]Ibid.

[248]Rees JV. *Hostages of Each Other: the Transformation of the Nuclear Industry Since 1980.* University of Chicago Press, 1995, p 118.

[249]*Ibid.*, p. 119 [Emphasis Added].

[250]*Ibid.*, p. 120. [Emphasis Added].

[251]Government Accountability Office. NRC Oversight of Power Plant Safety has Improved, but Refinements are Needed. Washington, DC, 2006, p. 9. http://pbadupws.nrc.gov/docs/ML0915/ML091590728.pdf

be a more credible one. As stated by Ivan Selin when he served as NRC Chairman in an address to the American Nuclear Society in 1992, *"...[P]ublic credibility cannot be achieved without public participation.*"[252]

We are not suggesting that it should be INPO that releases its findings. We agree with the utility owners that it should be their responsibility to publicly release the findings that INPO has made during a plant evaluation. Recently, that happened at Energy Northwest's Columbia Generating Station, which had rated low compared to other nuclear power plants.[253]

11.3 REES' FINDINGS ABOUT INPO

Rees began examining the industry when he moved near a nuclear power plant. His analysis generally agrees with the Deepwater Horizon Commission but he highlights additional elements. First, INPO and the industry are integrated. INPO's Board is from the industry, but it rarely overrules INPO's staff. Second, INPO inspects not only plants, but also the management level support. Third, INPO recalibrates standards to raise performance expectations (as it did in response to the *Sillin Report* and by launching the "professionalism project"). Fourth, INPO grades the plants and in an annual meeting of top executives from all the nuclear power plants announces winners and losers, in what might be called "management by embarrassment."[254] Finally, INPO cultivates ties with the CEOs of its members so it can go over the head of a recalcitrant plant management to get a problem corrected or if necessary plant managers replaced.[255] There is no doubt that INPO has substantial influence over the industry's operation.

We provide Additional Descriptions of INPO in the Next Section on Safety Culture

[252]Rees JV. *Hostages of Each Other: the Transformation of the Nuclear Industry Since 1980.* University of Chicago Press, 1995, p. 214.
[253]Cary A. Energy Northwest nuclear plant scores low in reliability. Tri City Herald, November 2, 2010. http://www.tri-cityherald.com/2010/11/02/1233869/energy-northwest-nuclear-plant.html#. [Accessed 3/11/10].
[254]Rees JV. *Hostages of Each Other: the Transformation of the Nuclear Industry Since 1980.* University of Chicago Press, 1995, pp. 49, 54, 92, 110-118 and 152-69.
[255]*Ibid*., 99, 110-118. Rees describes in vivid detail on pp. 110-118 how INPO went about getting the managers of the Peach Bottom plant replaced.

12

Building a Safety Culture

From the beginning, the developers of nuclear energy took safety and health seriously. In the spring of 1943, the Health Division of the Manhattan Engineering District was created to oversee the safety and health of all workers.[256] However, throughout the cold war years, expediency was made in the defense nuclear facilities that placed workers at serious risk. We have not assessed whether that attitude of expediency made its way into the civilian nuclear facilities.

According to Rees, in the two first decades of the civilian nuclear power operations a "fossil fuel mentality" prevailed, with little appreciation for the high risks of nuclear power and the degree of management oversight it requires. Nuclear power plants were characterized by management exercising top-down domineering control of workers, and in return, getting little loyalty from workers.[257] It was in part this type of culture that INPO sought to change, particularly in its "professionalism project," when it was started in the mid to late 1980s.

Both the *President's Commission on the Accident at Three Mile Island* and the NRC's independent review following TMI emphasized the need for a stronger safety culture. Yet history confirms that it is not easy to maintain such a focus. In the aftermath of Davis-Besse, reviews by the NRC, the GAO, and the operator all concluded that the conditions that led to this near disaster could have been prevented, had both the NRC and the plant followed established procedures.[258]

12.1 SAFETY CULTURE EXPLAINED

Procedures to assure safe management and operation of complex systems seem to many to have developed less through systematic analysis and more through trial and error--often following big errors with terrible consequences, and strange names forever ingrained in our culture: Three Mile

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[256] *Strong Memorial Hospital and the University of Rochester School of Medicine and Dentistry's Contribution to the Manhattan Project*. http://www.history.rochester.edu/urhist/kurt.htm. [Accessed 2/8/11]
[257] Rees JV. *Hostages of Each Other: the Transformation of the Nuclear Industry Since Three Mile Island.* University of Chicago Press, 1995, pp. 15-19, 158-160.
[258] See Section 6.5.

Island, Piper Alpha, Bhopal, Chernobyl, Exxon Valdez, the Columbia and Challenger space shuttle disasters, and now Deepwater Horizon.

Forty years ago, when occupational safety and health regulations started to develop in the U.S., they were specification- and demand-focused. Employers were expected to operate within a certain limit, often using specified procedures. There were two problems with that approach. The first was that it takes very long to promulgate regulations. By the time they are adopted, best practices may have moved far ahead of where they were when the regulatory development process was started. Therefore, those regulations tend to play catch-up with reality. The second problem was that they did not always allow for innovation. A good example of this is the rule governing radon exposures in underground mining.[259] These regulations do not encourage excellence and innovation to go beyond the letter of the law. This can lead the regulated to equate compliance with safety.

The radiation disciplines were among the first to recognize this issue, in part because they were among the first to recognize that the relationship between the amount of radiation to which a population was exposed and the risk of cancer seemed to be linear, and therefore there were no absolutely safe limits of exposure to radiation, either on the low end or the high end.[260] So, instead of adhering to a required maximum level of "safe exposure," they adopted the rule of *ALARA: As Low As Reasonably Achievable*.[261] In safety and health, that was the start of a process-focused approach to standards and regulations.

The International Commission on Radiological Protection (ICRP) has described this concept in terms of three principles:[262]

- **Justification.** No practice involving exposure to radiation should be adopted unless it produces a net benefit to those exposed or to society generally.
- **Optimization**. Radiation doses and risks should be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account.
- **Limitation**. The exposure of individuals should be subject to dose or risk limits above which the radiation risk would be deemed unacceptable.

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[259] 30 CFR 57.5038. http://www.msh a.gov/30cfr/57.5038.htm. [Accessed 2/11/11]. It is 40 years old and four times higher than the recommended exposure limited developed by NIOSH based on the best available evidence, and even NIOSH's recommendation is now over 20 years old. National Institute for Occupational Safety and Health. A Recommended Standard for Occupational Exposure to Radon Progeny in Underground Mines. DHHS (NIOSH) Publication No. 88-101, October 1987. http://www.cdc.gov/niosh/88-101.html. [Accessed 2/12/11]

[260] International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann. ICRP 21 (1-3), 1991.

[261] According to NRC's definition, ALARA means *"making every reasonable effort to maintain exposures to radiation as far below the dose limits in this part as is practical consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest."* 10 CFR 20.1003. http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/part020-1003.html. [Accessed 2/27/11].

[262] *Ibid.*

After Chernobyl, and with further refinement in 1991, the International Atomic Energy Agency created the first safety culture framework for the nuclear industry.[263] It made a very important distinction between safety management and safety culture. Safety management focuses on the tools needed to operate the organization safely. Safety culture embraces the whole organization: its people and environment.

12.2 ETHICS: WORKERS AS A VULNERABLE POPULATION

The scientific consensus that it is prudent to assume that the consequences of exposure to radiation have a linear dose-response relationship even at very low exposure levels has been adopted as a policy in the US and elsewhere. This has a profound impact on workplace safety and health. The ethical corollary of ALARA is the recognition that workers are in a vulnerable position in a workplace where managers potentially have all the control over the culture. If managers of nuclear power plants refuse to take ALARA seriously, the workers that are employed become vulnerable to radiation exposure. For ALARA to work, workers should have a say in how it is implemented.

This has been clearly played out, both regarding exposure to radiation and more generally, in the US DOE. For the past 30 years DOE has been grappling with an ethical and policy framework about how to manage workplaces in which there could be risks that have no known lower limits. This framework is founded on the view that DOE workers represent a "vulnerable population" and that respect for their autonomy gives them an absolute right to make personal, informed decisions about being exposed to potential risks.[264] DOE workers experienced a variety of hazardous exposures in their occupational contribution to the security of the United States. They did so without full information about the health risks that were entailed and, even when they did know, made a personal sacrifice to ensure the safety of their fellow citizens. Congress recognized this when, with broad bipartisan agreement, it adopted the *Energy Employees Occupational Illness Compensation Act* in 2000.[265]

12.3 DEEPWATER HORIZON FINDINGS

The National Commission on the British Petroleum Deepwater Horizon Oil Spill and Offshore Drilling concluded that the root cause of the Deepwater Horizon disaster was failures of

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[263]International Atomic Energy Agency. Safety Culture. Report of the International Nuclear Safety Advisory Group. Safety Series No.75-INSAG-4. Vienna, 1991. http://www-pub.iaea.org/MTCD/publications/PDF/Pub882_web.pdf. [Accessed 2/15/11].

[264] U. S. Department of Energy, Office of Science, *Creating an Ethical Framework for Studies that Involve the Worker Community: Suggested Guidelines*, Germantown, MD, 2000. http://humansubjects.energy.gov/doe-resources/ethframe-web.htm [accessed 7/14/09]

[265] Title 36 of Public Law 106–398

management and communication and the failure to integrate the corporate cultures, internal procedures and the decision-making of the various contractors involved.[266]

> "*...[C]hanges in safety and environmental practices, safety training, drilling technology, containment and clean-up technology, preparedness, corporate culture, and management behavior will be required if deepwater energy operations are to be pursued in the Gulf -- or elsewhere*."[267]

The Commission concluded that the critical change in corporate culture was a new focus on safety. As the Commission wrote, *"...government oversight alone, cannot reduce...risks to the full extent possible. Government oversight...must be accompanied by the oil and gas industry's internal reinvention: sweeping reforms that accomplish no less than a fundamental transformation of its safety culture.*"[268] What was required was an unwavering commitment to safety and a relentless focus on preventing accidents. The Commission noted that British Petroleum had had reductions in injuries and illnesses of 75% since 1999, but nevertheless had had several major accidents. Thus, the company's focus had been on *individual* safety rather than *process* safety. [269]

The Commission also noted that the emphasis on process safety is particularly important where the industry is inherently risky.[270] They observed that in the U. S., fatalities in offshore drilling are four times greater than in Europe, underscoring the fact that it is not the inherent risk but the underlying safety culture that is responsible.[271] They then went on to discuss the example of changes in civil aviation, nuclear power, the chemical industry, and the Nuclear Navy where inherently risky industries and operations were made much safer by adopting process safety.[272]

12.4 AFTER DAVIS-BESSE: A SERIOUS FOCUS ON SAFETY CULTURE

In 2004, following the near disaster at Davis-Besse, Senator George Voinovich convened hearings on the safety culture in nuclear power plants.[273] These hearings led to the following exchange:

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[266] 42 CFR 84 §7384. http://www.dol.gov/esa/owcp/energy/regs/compliance/law/EEOICPAALL.htm [Accessed July 14, 2009]
National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling. *Deep Water: The Gulf Oil Disaster and the Future of Offshore Drilling*, January 2011, p. 122.
https://s3.amazonaws.com/pdf_final/DEEPWATER_ReporttothePresident_FINAL.pdf [accessed January 16, 2011.]
[267] *Ibid*., p. 142.
[268] *Ibid*., p. 217
[269] *Ibid*., p. 218-22. The unreliability of occupational injury and illness data (see Section 2) underscores the need to go beyond reports of individual impacts.
[270] *Ibid*., pp. 224-225
[271] *Ibid*., p. 228
[272] *Ibid*. 22. 229-235
[273] U.S. Senate. Committee on Environment and Public Works, Subcommittee on Clean Air, Climate Change, and Nuclear Safety. *Oversight of the Nuclear Regulatory Commission,* May 20, 2004.
http://www.access.gpo.gov/congress/senate/pdf/108hrg/94607.pdf. [Accessed 3/4/11].

Senator Voinovich: "*Why do you disagree with everyone that you should put in place a regulation to monitor safety culture? Why do we not have a regulation in terms of safety culture?*" [274]
[NRC Chairman] Mr. Diaz: "*Sir, obviously the Commission is very concerned with the safety culture at each and every one of our facilities. However, we believe that the safety culture as a whole becomes sometimes ambiguous. We are not in the business of managing these utilities or these reactors."*[275]
Senator Voinovich: *"You had a standard to use because you said you were not going to let [Davis-Besse] open because they did not have the safety culture. Why do not we make that applicable to all the facilities?"*[276]
Mr. Diaz. "*Because it will get into an area that the Commission believes that we should not be, which is managing the facility."*[277]
Senator Voinovich: "*But you are doing it at Davis-Besse. You are going to go in there for the next 5 years.*"[278]
Mr. Diaz: *"[W]e are going to assess what the safety culture is and then we are going to assess how the management of the facility deals with the safety issues. That is our responsibility. We will deal with how they manage safety. We have indicators. We have many ways of actually addressing that issue. The safety culture issue becomes imbedded inside of the relationships between the employees and the management. We do not believe that is the role of the Commission."*[279]*...*
Mr. Diaz. "*If I may add, on the issue of Davis-Besse, on safety culture, the licensee did not meet its own standards of safety culture. We do hold them accountable for those standards. We want every licensee to have very high standards.*
Senator Voinovich: "*You should set the standards for them*."[280]
Mr. Diaz: "*Well, that is an issue that is a very difficult issue. Again, we might be getting into the prerogative of the management of this facility. The Commission has been discussing this for many years*."[281]...
Mr. Diaz: "*The Institute [of] Nuclear Power Operations, ... [has] a separate initiative underway in which they are intensively looking at this very same issue, again to try to enhance the overall level of the safety culture at the plants. We are collaborating with them to the extent that they are keeping us informed of their activities. We are very interested in the work that they are doing. We want to assess where they are in relation to where we are."*[282]

[274] *Ibid.*, p. 25.
[275] *Ibid*.
[276] *Ibid*.
[277] *Ibid.*
[278] *Ibid.,* p. 25.
[279] *Ibid*., p. 26.
[280] *Ibid.*
[281] *Ibid.*
[282] *Ibid*., p. 33.

> **[NEI Vice President] Fertel**: *"The NRC should set standards. They should set regulatory standards on safety that if you are meeting, it is clear that you are focused on the right things. Beyond that, the industry, and what was alluded to by the Chairman was the industry is responsible for management. What we do not want to ever do is take that accountability away. You want to maintain the accountability of safety as job one from the top CEO on down through the people on the floor doing the work... How would you know good safety culture when you saw it? How would you know it when it was not there? Some of the easy things that people say is: If you walk around the plant, basically cleanliness is an indication. Well, if you look at what was going on at Davis-Besse, changing filters every week rather than monthly, is an indication of a problem.... Coming over here in a car, I was talking with Dr. Jones and he said, 'Well, what does the resident [NRC inspector] look for?' I said, 'Well, maybe that is one of the things that NRC has to reassess. Rather than checking every little thing, they should be looking for bigger and broader indications of problems.'*"[283]...
> **[Union of Concerned Scientists] Mr. Lochbaum**: "*[T]he NRC has a safety culture problem of its own. Surveys conducted by the Inspector General and the GAO have shown that, for example, that the NRC workers who have raised safety issues, one-third of them feel that they have been retaliated against for having done so. Those kinds of problems that Davis-Besse had to fix, we feel the NRC needs to fix internally so it has a good safety culture, as well as all the plants in the country.*"[284]

Following these hearings the industry and the NRC intensified their focus on safety culture throughout the nuclear industry. It was not easy. Figuring out the roles and responsibilities of operator, regulator and industry has been a process ever since. It is by no means complete.

12.4.1 INPO's Safety Culture Principles

In 2004, INPO assembled a Safety Culture Advisory Group consisting of senior executives from INPO's member companies. They used the experience that INPO had gained over the years to define what they meant by the term "safety culture" and to develop principles that could be used to put the definition into effect. INPO published the definition and principles in a pocket-sized guide for distribution to everyone in the industry.[285] In October 2009, the Guide was updated by another INPO Advisory Group, again made up of executives.

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[283] *Ibid.*, pp. 45-46
[284] *Ibid.*, p. 46
[285] Institute of Nuclear Power Operations. *Principles for a Strong Nuclear Energy Safety Culture. November,* 2004. It is important to note that the principles build on years of activity at INPO. As the guide notes in the introduction, "*This document is complementary to, and should be used in conjunction with, previously published principles documents. It builds on and supports Principles for Enhancing Professionalism of Nuclear Personnel, March 1989. It contains concepts consistent with those described in Management and Leadership Development, November 1994; Excellence in Human Performance, September 1997; Principles for Effective Self-Assessment and Corrective Action Programs, December 1999; and Principles for Effective Operational Decision-Making, December 2000.*"

INPO's Definition of Safety Culture

Safety culture: An organization's values and behaviors—modeled by its leaders and internalized by its members—that serve to make nuclear safety the overriding priority. ***Culture is for the group what character and personality are for the individual***

The eight Principles INPO has focused on are:[286]

1. Everyone is personally responsible for nuclear safety.
2. Leaders demonstrate commitment to safety.
3. Trust permeates the organization.
4. Decision-making reflects safety first.
5. Nuclear technology is recognized as special and unique.
6. A questioning attitude is cultivated.
7. Organizational learning is embraced.
8. Nuclear safety undergoes constant examination.

The INPO guide says that it is important to understand that these principles are not all inclusive. Rather they are r*epresentative* of the behaviors and actions that are likely to increase safety performance. INPO encourages the industry adopt such principles and make them part of the daily assessments that are made of safety in each power plant.

Already in 1995, INPO had developed a 74 page Safety Culture Assessment instrument[287] which most likely has been improved over the years. INPO evaluates safety culture in each nuclear power plant every two years.[288]

12.4.2 The NEI Safety Culture Process

Beginning in 2008, the Nuclear Energy Institute launched an effort to advance the safety culture process. As part of it, the nuclear industry has been pilot testing a process for managing safety culture. That process is described in a draft NEI document, NEI 09-07, "*Fostering a Strong Nuclear Safety Culture.*" NEI wanted to take the INPO Principles one step further, and create a process for adopting them most effectively in nuclear power plants. The pilot testing is expected to be completed this year.[289]

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[286] *Ibid*.
[287] Rees JV. *Hostages of Each Other: the Transformation of the Nuclear Industry Since Three Mile Island.* University of Chicago Press, 1995, pp. 164.
[288] Nuclear Energy Institute. *Fostering a Strong Nuclear Energy Safety Culture.* Washington, DC, June 2009, p. 4. http://pbadupws.nrc.gov/docs/ML0915/ML091590728.pdf [Accessed 2/11/11].

[289] Nuclear Energy Institute. *Fostering a Strong Nuclear Energy Safety Culture.* Washington, DC, June 2009, p. 4. http://pbadupws.nrc.gov/docs/ML0915/ML091590728.pdf [Accessed 2/11/11].

The NEI document notes that the *"...challenge in monitoring and managing safety culture is seeing the faint signals of emerging problems amidst the normal noise of a large, productive organization. In high-performing organizations, the faint signals may include subtle patterns linking seemingly unrelated equipment failures or human errors; anecdotal information; or perceptions and attitudes reflected in employee survey data, for example. NEI 09-07 describes a systematic way to examine this disparate data by having management step back periodically from their other daily activities and review the normal noise with a 'safety culture filter.'"*

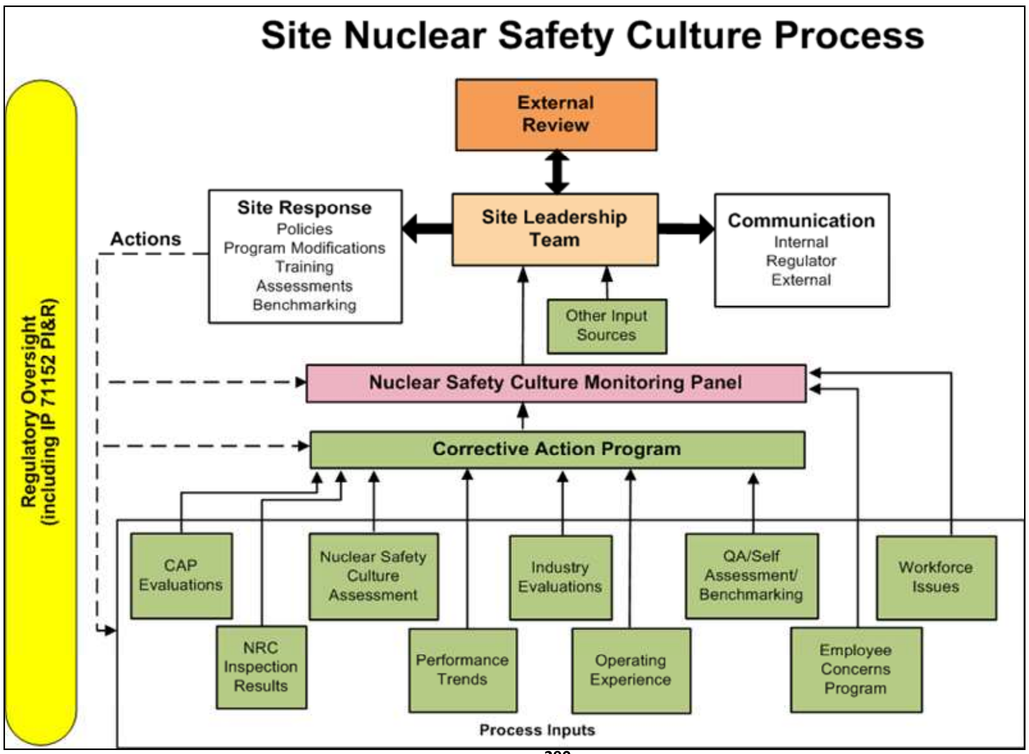

Fig. 12.1: The NEI Nuclear Safety Culture Process[290]

Fig. 12.1 is a schematic of the NEI safety culture process. This figure shows that there are many inputs into the decision-making process about safety, and that they need to be coordinated. The pink box in this chart (Nuclear Safety Culture Monitoring Panel) and the two green boxes (Workforce Issues and Employee Concerns Program) were added to make sure that all the safety program inputs *and* worker concerns are integrated into the safety culture process.[291] This is a significant change or addition to the INPO model.[292]

NEI describes the inputs into the process in this way: "*Each input has an owner whose responsibilities include assessing the data against the INPO principles and attributes and*

[290] This is an updated chart from the one in NEI 09-07. It was provided by Tom Houghton at NEI.
[291] We would note, however, based on NEI's description quoted on the previous page, that management is in control of the assessment, with workers providing input.
[292] Houghton T., Nuclear Energy Institute. Interview, Washington, D.C., February 17, 2011.

reporting their results to the site leadership team on a periodic basis."[293] These are the basic inputs, as taken from the NEI document:[294]

- **NRC inspection results**. These include the baseline inspections of plant and processes (especially the problem identification and resolution inspection which also looks at safety conscious work environment and any past nuclear safety culture assessments), supplemental inspections, event follow-up, etc. These are extremely valuable inputs for the site, and may incorporate insights into nuclear safety culture.
- **Nuclear Safety Culture Assessment**. Using a common industry guideline, sites conduct a self assessment of nuclear safety culture on a biennial basis. This is already an INPO requirement. What has been added is a common industry approach, including Third Party Assessments.
- **Industry Evaluations**. INPO evaluations are conducted on an approximately biennial basis, in the alternate year from the nuclear safety culture assessment. Included in the INPO evaluation is an assessment of nuclear safety culture. Thus the site would receive a nuclear safety culture assessment almost every year. These industry evaluations are available to NRC on site.
- **Operating Experience.** Data on previous deficiencies (such as operations, design, and equipment) are used to improve procedures and processes and to avoid future problems. Information from OE can also be used to look for nuclear safety culture issues.
- **QA/Self Assessment/Benchmarking/Behavioral Observations**. Each site performs a variety of self reviews. These include audits required in the quality assurance programs, department self assessments, and benchmarking of other sites in the industry (or other industries). It also includes observation programs by managers and supervisors in the field.
- **Employee Concerns Program/ Safety Conscious Work Environment**. This program looks at the site's safety conscious work environment and provides opportunities to raise issues outside the normal chain of command.
- **Site Performance Trends.** Each site has a broad suite of indicators which it uses to assess performance. These indicators go beyond the ROP performance indicators (which generally measure plant-wide outcomes) and assess intermediate outcomes, which, if not corrected, could lead to safety system failures, scrams or events. Trends can be developed in these indicators and the cause of the trend – be it process or design deficiencies, training, resources, or nuclear safety culture issues – can be examined and corrective action taken. Examples include operator workarounds, control room deficiencies, preventive maintenance deferred, open positions, etc. These trends would be available to NRC on site.
- **Additional Inputs**. Note that a site may have additional process inputs that it finds effective in helping to assess nuclear safety culture.

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[293] Nuclear Energy Institute. *Fostering a Strong Nuclear Energy Safety Culture.* Washington, DC, June 2009, p. 4. http://pbadupws.nrc.gov/docs/ML0915/ML091590728.pdf [Accessed 2/11/11].
[294] *Ibid*., p. 4-5.

12.5 THE NRC NUCLEAR SAFETY CULTURE POLICY

NRC Policy Statements are not enforceable, but they guide the organization. Before the current safety culture policy was adopted, the Commission dealt with the subject at least twice in formal statements.

In the 1989 *Policy Statement on the Conduct of Nuclear Power Plant Operations*, the Commission wrote: "*The phrase 'Safety Culture' refers to a very general matter, the personal dedication and accountability of all individuals engaged in any activity which has a bearing on the safety of nuclear plants....the recognition that their importance lies not just in the practices themselves but in the environment of safety consciousness which they create*."[295] It then goes on to lay out what is the general framework used in today's thinking about safety culture processes: top management engagement, corrective action policies and strict requirements for adherence, internal performance reviews, *"... staff training and education emphasizes the reasons behind the safety practices established, together with the consequences for safety of shortfalls in personal performance.*"[296]

Then, in 1996 it issued a forceful *Policy Statement for Nuclear Employees Raising Safety Concerns Without Fear of Retaliation*[297] *"...to set forth its expectation that licensees and other employers subject to NRC authority will establish and maintain safety-conscious environments in which employees feel free to raise safety concerns, both to their management and to the NRC, without fear of retaliation. The responsibility for maintaining such an environment rests with each NRC licensee, as well as with contractors, subcontractors and employees in the nuclear industry. This policy statement is applicable to NRC regulated activities of all NRC licensees and their contractors and subcontractors.... The Commission emphasizes that employees who raise concerns serve an important role in addressing potential safety issues. Thus, the NRC cannot and will not tolerate retaliation against employees who attempt to carry out their responsibility to identify potential safety issues."*[298]

In 2006, the NRC Commissioners initiated a focus on "Safety Culture" *"to more fully consider safety culture in the NRC's assessments of inspection findings and overall nuclear power plant performance. More recently, the Commission directed the NRC staff to (1) consider the need for an agency wide safety culture policy statement that would apply to all entities regulated by the NRC and (2) recommend whether and how to better integrate security culture considerations*

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[295] NRC. *Policy Statement on the Conduct of Nuclear Power Plant Operations.* Federal Register, 54: 3424-3426, January 24, 1989. [Emphasis Added]. http://www.nrc.gov/reading-rm/doc-collections/commission/policy/54fr3424.pdf. [Accessed 3/1/11].

[296] *Ibid.*, p. 3425.

[297] Federal Register 61: 24336-24340, May 14, 1996. http://www.nrc.gov/about-nrc/regulatory/enforcement/fpolicy.html [Accessed 3/1/11]

[298] Ibid., p. 24336. The right to engage in a "protected activity without fear of retaliation is embedded in Section 211 of the Energy Reorganization Act of 1974 and NRC regulations at 10 CFR Section 30.7.

into the NRC's safety and security oversight activities."[299] Why this new focus? Because, "*The culture of an organization affects the performance of the people in it. Weaknesses in an organization's safety culture may set the stage for equipment failures and human errors that can have an adverse impact on safe performance.*"

In 2008, the NRC began a three-year process, with extensive public input, to develop a stronger statement on safety culture policy. Table 12.1 shows the evolution in the development of the statement on Safety Culture from 2009 until it was completed in December 2010.

Table 12.1: NRC Staff Drafts of Safety Culture Policy Definition, 2009 and 2010.

2009 Draft	December 2010 Final Draft
That assembly of characteristics, attitudes and behaviors in organizations and individuals, which establishes that as an overriding priority, nuclear safety and security issues receive the attention warranted by their significance	Nuclear Safety Culture is the core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals to ensure protection of people and the environment

There are significant changes in this evolution. The final draft includes a "*collective commitment...* to... *emphasize safety over competing goals*." And, the final draft does not include the word "*security*" in it, based on this reasoning: *"An overarching safety culture addresses both safety and security and does not need to single out "security" in the definition."*[300] This leaves us to wonder: if culture is all-encompassing, then why is the title Nuclear Safety Culture Policy, rather than just Safety Culture Policy. The 1989 policy statement did the latter. From an occupational safety and health point of view, the broader definition would be more desirable.

The Policy describes the "traits" it is trying instill in this way:[301]

(1) **Leadership Safety Values and Actions** - Leaders demonstrate a commitment to safety in their decisions and behaviors;
(2) **Problem Identification and Resolution** - Issues potentially impacting safety are promptly identified, fully evaluated, and promptly addressed and corrected commensurate with their significance;
(3) **Personal Accountability** - All individuals take personal responsibility for safety;
(4) **Work Processes** - The process of planning and controlling work activities is implemented so that safety is maintained;
(5) **Continuous Learning** - Opportunities to learn about ways to ensure safety are sought out and implemented;

[299] NRC. *Final Safety Culture Policy Statement*, January 5, 2011. NRC–2010–0282. [Emphasis in original]. http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2011/2011-0005scy.pdf. [Accessed 2/13/11]
[300] *Ibid*., p. 16.
[301] *Ibid*.

(6) **Environment for Raising Concerns** - A safety conscious work environment is maintained where personnel feel free to raise safety concerns without fear of retaliation, intimidation, harassment, or discrimination;
(7) **Effective Safety Communication** - Communications maintain a focus on safety;
(8) **Respectful Work Environment** - Trust and respect permeate the organization; and
(9) **Questioning Attitude** - Individuals avoid complacency and continuously challenge existing conditions and activities in order to identify discrepancies that might result in error or inappropriate action.

As we have discussed earlier, we think it is important to find a way to incorporate the safety culture policy into the ROP. This would put the policy into operation. We think these traits, combined with the existing 13 safety culture components that are already in the ROP, the NEI inputs listed above, or elements from the INPO Safety Culture Survey Instrument can form a set of performance indicators directed at a new, fourth Strategic Area in the ROP called Safety Culture.[302]

12.6 THE ROLE OF THE REGULATOR IN SAFETY CULTURE

The Deepwater Commission made a very important finding that is worth repeating here, because it helps place the NRC's reluctance to develop a safety culture *standard* or incorporate it into the ROP in perspective:

> *"All these foreign regulators—the United Kingdom, Norway, and Canada—had previously relied on the kind of prescriptive approach used in the United States, but in the aftermath of these fatal accidents in harsh, remote offshore environments, authorities elsewhere concluded that adding a risk-based approach was essential. They faulted reliance on the 'prescriptive regulation with inspection model' for being fundamentally reactive and therefore incapable of driving continuous improvement in policies and practices . According to Magne Ognedal, the Director General of the Norwegian Petroleum Safety Authority, the prescription-only model engendered hostility between the parties and put the risk—legal and moral—onto the regulator to accommodate changing technology, geology, and location, rather than onto the operator, where the responsibility rightly belonged. Under the new safety-management model, minimum standards for structural and operational integrity (well control, prevention of fires and explosions, and worker safety) remained in place. But the burden now rested on industry to assess the risks associated with offshore activities and demonstrate that each facility had the policies, plans, and systems in place to manage those risks. In the United Kingdom, such risk management plans were called a 'Safety Case.'"*

[302] See Section 10.3.4 of this report.

12.7 WORKER INVOLVEMENT: AN ESSENTIAL CHARACTERISTIC OF SAFETY CULTURE

INPO, with its heritage in the Nuclear Navy, has emphasized a management-led safety culture . In this industry, safety culture is still handed down from above. This approach, of course, is not confined to the nuclear industry. Nor is it confined to the U.S. The most recent International Agency on Atomic Energy report on safety culture shows this clearly: management is to show leadership, act forcefully, and motivate, while "personnel" are to be cooperative team players.[303]

The NRC Safety Culture Policy moves towards rectifying this, by emphasizing a "*collective*" responsibility. This collective responsibility is also found in Norway's administration of petroleum safety in the North Sea.[304] There are many similarities between its oil industry and the U.S. nuclear industry: high risk engineering-based operations; licensed operations with relatively few licensees; licensee responsibilty for developing safety culture and procedures; high union density; on-site resident inspectors and a very cohesive population with generally shared values whether they are managers or workers. There is also one very significant difference which works in favor of the nuclear industry and the NRC: the operations in the petroleum industry are much more heterogeneous and mobile.

Just as the NRC has struggled with how far its regulatory duties go in terms of assuring safety culture, Norway struggled with how to adopt a performance based system that would meet the needs of the operators and of the regulators.[305]

Under Norwegian law, employers are required to share responsibility for safety and health with workers and their representatives, and in practice there is very strong tripartite collaboration between the Petroleum Safety Authority, as regulator, operating companies and unions. Instead of being management-driven, safety culture is developed cooperatively (or collectively).

An important part of the regulatory function is to assure that a cooperative safety program is shared by workers and managers, exists in every workplace and functions effectively, so that workers understand the risks and the mitigating systems that are in place. The use of safety cases to plan work must be approved by both management and workers. For such cooperation to take place, workers must have parity with management in terms of expertise and resources.

We think the Norwegian model bears consideration, because (1) it resolves the issue of the role of the NRC and whether it needs to adopt detailed specifications for safety culture, either in

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[303] International Atomic Energy Agency. *Nuclear Security Culture*. IAEA Nuclear Security Series No. 7 IAEA, Vienna, 2009. http://www-pub.iaea.org/MTCD/publications/PDF/Pub1347_web.pdf. [Accessed 2/15/11].

[304] Hart S. Industry, Labour and Government in Norwegian Offshore Oil and Gas Safety: What Lessons can we Learn? *The Workplace Review*, November 7, 2007.
http://www.busi.mun.ca/mbarron/b6320/readings/Pages_from_WPR_nov07Issue.pdf

[305] Petroleum Safety Authority. *From Prescription to Performance in Petroleum Supervision*.
http://www.ptil.no/news/from-prescription-to-performance-in-petroleum-supervision-article6696-79.html. [Accessed 3/5/11].

regulations or in the ROP; (2) it leaves the duty of assuring safety culture to the operator; and (3) it overcomes the vulnerability of workers when all control is in the hands of management. As a first step, NEI could evaluate as part of its pilot project on safety culture processes whether power plants that have more employee involvement in safety programs also have better safety culture survey results and better safety outcomes.

12.8 OSHA'S EXPERIENCE WITH THE PROCESS SAFETY MANAGEMENT STANDARD[306]

OSHA's Process Safety Management of Highly Hazardous Chemicals Standard[307] was promulgated in 1992 in response to a series of chemical plant disasters here and abroad. The OSHA proposed standard established a comprehensive management program; a holistic approach that integrated technologies, procedures, and management practices. The proposal contains provisions addressing process safety information, process hazard analysis, operating procedures, training, supervision of contractors, pre-startup safety reviews, mechanical integrity, hot work permits, management of change, incident investigations, emergency planning and response, and compliance safety audits. It is, to put it simply, an early generation safety culture process. OSHA now has 20 years of experience administering the PSM, so we asked the OSHA PSM team to give us an assessment of what works well and was does not from a regulatory perspective. We think there are lessons here that can be used to incorporate safety culture into the ROP. [308] It seems NRC's safety culture team might benefit from sharing experiences with OSHA's PSM team.

12.9 FOOD FOR THOUGHT

Despite all their efforts to embrace safety culture, we cannot help but suspect that it is like fitting a round peg into a square hole. It will go, but the fit is not perfect. The industry and the NRC are comfortable with specifications derived from statistical estimates of risk based on either empirical data or careful modeling. In nuclear safety, this is called probabilistic safety assessment (PSA).[309] For material things, the variables are largely stable. The strength of steel is predictable. That is not so true for human beings -- or maybe it is that we consist of too many variables. As two observers

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[306] Long L. US Occupational Safety and Health Administration. Personal Communication, February 23, 2011. This information is based on ongoing staff reviews and does not necessarily reflect official OSHA policy.
[307] 29 CFR 1910.119
[308]These are the main issue: **Employee participation**. The current rule is insufficiently proscriptive about what should be required in terms of involvement by employees in the safety management process. **Process Safety Information**: Documentation to support which safety process actions were taken and at what time can be unreliable. It can be hard to see if an action preceded a risk or was adopted afterwards. **Process Hazard Analysis:** There should be greater specificity about management's obligation to accept or reject the findings of a plant's process safety monitoring team. **Compliance Audits:** It is difficult to determine if a mandated audit was done properly. More specificity is required about audit program procedure requirements, such as (1) How is sample size selected? (2) Audit plan should be documented in a report - what will be audited and how. (3) How will adjustments from the plan be handled? (4)Require the audit plan and report to be documented and retained.
[309] Also referred to as probabilistic risk assessment.

of the nuclear industry put it in 2005, "*The current approach internationally is to address organizational factors, usually under the umbrella of safety culture or safety management, outside the realm of operational and regulatory decision-making based directly on PSA. The implicit assumption is that safety culture is clearly a pervasive and important aspect of operations, but one whose effect on risk may be difficult to quantify.*"[310]

NRC's use of words adds to our questioning attitude. Words are important signals. We think it is significant that NRC has called it the ***Reactor*** Oversight Process, not the ***Safety*** Oversight Process. A violation of protected activity[311] is equated, in words, with a Safety Conscious Work Environment. And while Human Performance problems and the failure to identify and solve a problem point to broader management deficiencies, NRC conflates them to individual problems. The focus in the words is often on individual rather than process safety.

More broadly, as long as safety culture is treated as ancillary to the ROP, it signals that it is of secondary consequence. Although NRC's intent in developing and modifying the ROP was to be able to identify a degrading safety culture early on, it is its own failure in instilling its ROP with a safety culture approach which identifies risks and uproots the underlying causes that belies the intended purpose. That approach is not consistent with the NRC Safety Culture Policy. Somehow, that inconsistency has to be solved.

Finally, the biggest questions about safety culture are these: if the companies that are NRC licensees are to *"emphasize safety over competing goals"* why does NRC continue to have to issue citations for violation of Safety Conscious Work Environment? How do you maintain the required level of interest and commitment over time? At what point and under what circumstance do competing goals become the overriding priority? And, in competitive markets, how do you prevent another high risk strategy like the one adopted by Northeast Utilities in the 1990s from becoming the leading objective?[312]

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[310] Ghosh ST, Apostolakis, GE. Organizational contributions to nuclear power plant safety. *Nuclear Engineering and Technology*, 37: 207-220, 2005. [Emphasis Added]
[311] Protected activity refers to a worker's right to raise concerns about safety risks in a NRC licensed facility.
[312]See Section 5.3 of this report for a description of Northeast Utilities.

13

The Future:

Changes in the U.S. Nuclear Fuel Cycle and Their Implications

The U.S. Energy Information Administration projects that nuclear power will increase its output of electricity by about 10% in this decade. This increase will come from new plants being built and existing plants becoming even more efficient. It means more pressure on the entire fuel cycle.[313]

13.1 MINING

We have addressed mining in other sections.[314] The market forces appear to be favorable towards uranium recovery in the U.S., but our safety and health infrastructure is poorly prepared for this. Upgrades are needed.

13.2 AGING FACILITIES

When the current reactors were built, they were planned to have a 40-year life cycle. The newest reactor to be licensed in America's nuclear plants began operation in 1996. Most were built well before then.

Of the commercial nuclear power plants currently in operation, only two have been in operation for fewer than 20 years, Comanche Peak Unit 2 (1993) and Watts Bar Unit 1 (1996). Forty-three have been in operation 21-29 years, 50 have been in operation 30-39 years, and 9

[313] US Energy Information Administration. *Annual Energy Outlook 2011 (AEO2011), Early Release. http://www.eia.gov/forecasts/aeo/pdf/0383er(2011).pdf.* [Accessed 2/13/11]
[314] See sections 7.2.1 and 10.2 of this Report.

have been in operation more than 40 years (Fig 13.1). Since a decade or more may elapse between the issuance of a construction permit for commercial nuclear power plants and the issuance of an operating license, design of the newest plants in the fleet began more than thirty years ago. To be sure, these plants have been maintained carefully, upgraded extensively, and today produce more energy per unit than when they were built. Still, their "bones" are getting old.

Fig 13.1: Age of our Nuclear Reactors

This is hardly an original observation and both the industry and NRC have prepared for it. The NRC has produced "...a systematic compilation of plant aging information" to assist NRC staff and facility owners in the review of licensing applications.[315] Nevertheless, in spite of the preparations, there are many concerns, including metal fatigue; integrity of piping; maintenance of valves and pumps; risk of electrical cable and systems failures; and auxiliary power generators, among others.

13.3 AGING WORK FORCE AND LOOMING SKILLS SHORTAGE

Seventy-eight million American children were born between 1945 and 1964, with 1957 being the peak birth year. On average, they entered the workforce 23 years after they were born. These baby boomers advanced to adulthood in parallel with the nuclear power industry boom. Many baby boomers entered the workforce in a nuclear plant and because the jobs were good, they ended up staying there. Of the 104 currently licensed nuclear reactors in the US, the first license granted was in 1964, the year the first baby boomer cohort entered the job market. By the time the last of the baby boomers entered the job market, all but 4 or 5 reactors had been licensed. Consequently, there has been very little turn-over of the workforce. See Fig. 13.2.

[315] NRC. Generic Aging Lessons Learned (GALL) Report. NUREG-1801, Rev. 2 Final Report, December 2010. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1801/r2/index.html. [Accessed 1/20/11].

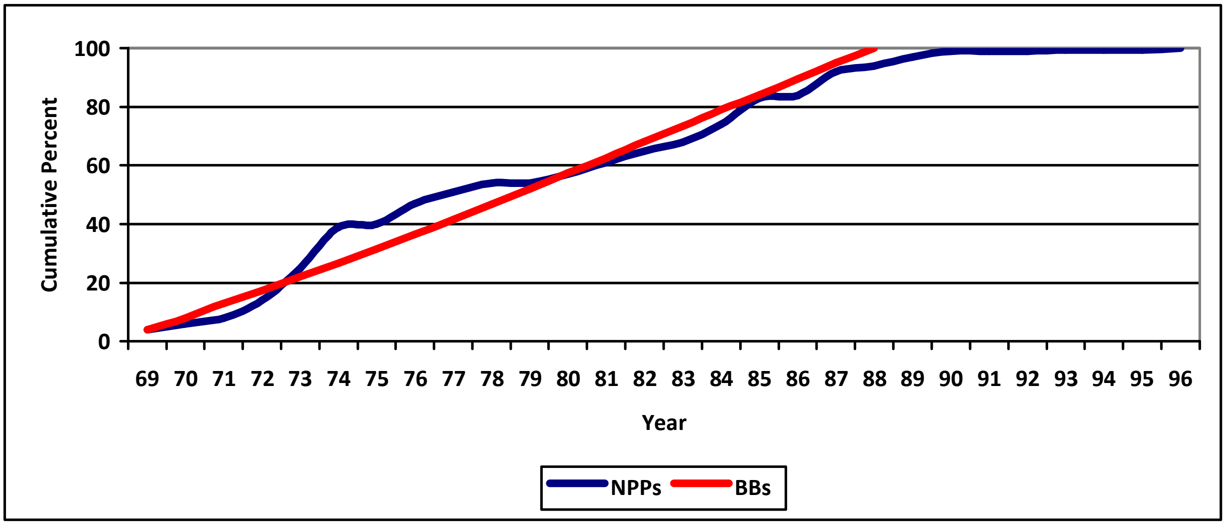

Fig. 13.2: Cumulative total (%) of Nuclear Power Plants (NPPs) Licensed and Baby Boomers (BBs) Reaching Working Age (average=23 years)

Fig. 13.3 shows the aging of the nuclear workforce. By 2009 the median age had reached 49. The curve is starting to lean hard to the right.

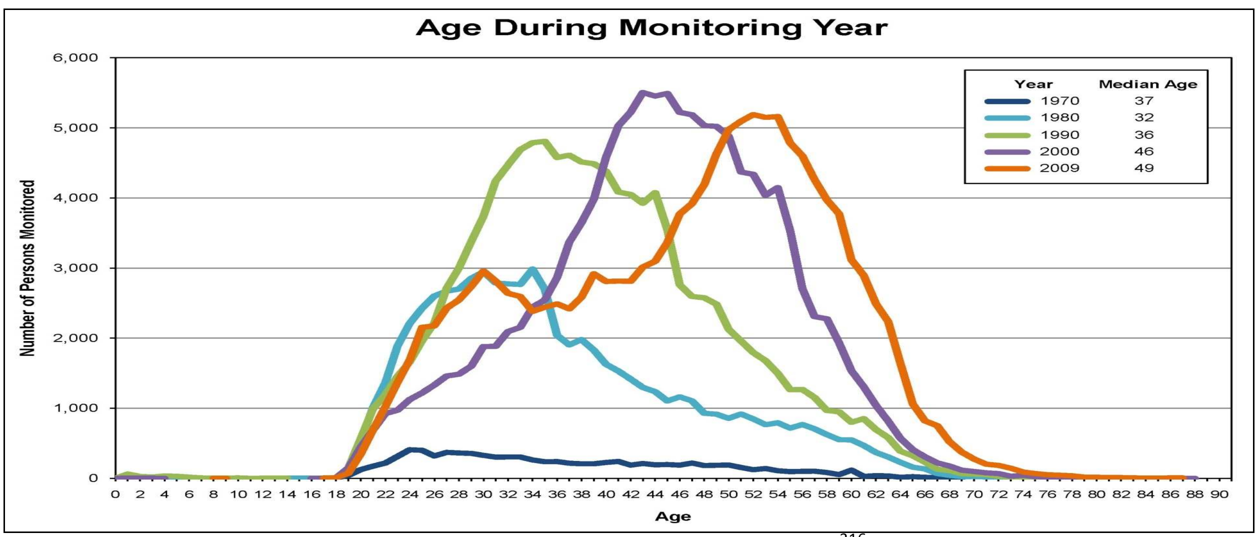

Fig. 13.3: Age of Workers Monitored as recorded in the NRC REIRS Program[316]

We also examined the age for one of the principal crafts engaged in maintenance and outage work. Fig. 13.4 shows the age distribution of the members of this craft. The data underlying this figure are the eligible population of workers in this craft's national group health plan. As can be seen, a large portion of the workers fall the older ages, with the baby boomers falling between the two vertical red lines in the chart.

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[316] Provided by Derek Hagemeyer, Oak Ridge Associated Universities, February 23, 2010.

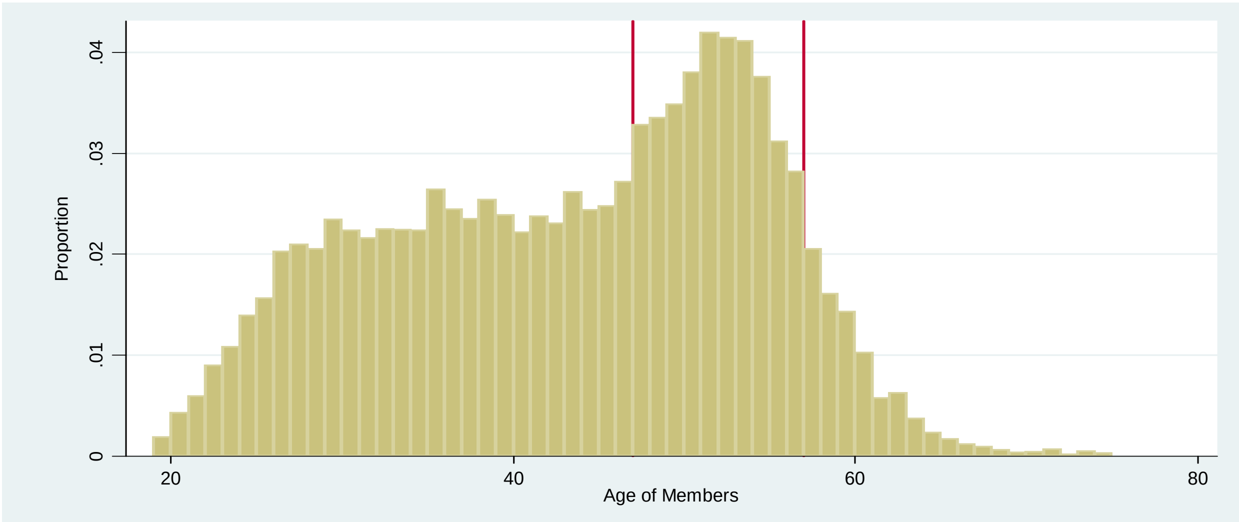

Fig 13.4: Age Distribution of a Leading Maintenance and Outage Craft, 2007-08[317]

The baby boomers are now starting to retire. The first ones who reached the age of 62 and wanted to take early Social Security could do so in 2008, so the retirement trend is going to increase fast. There are three reasons why this should cause concern:

- It is hard to recruit young people into crafts occupations. This is no secret, and the so-called looming skills shortage has been discussed widely. Yet the nuclear industry requires a large workforce of highly skilled crafts workers.
- The aging facilities will require more maintenance, and therefore will need a larger supply of skilled operators and crafts workers.
- NRC has applications for construction and operating licenses for approximately 30 new reactors, and if these are to be built at the same time it will put an enormous pressure on the pool of available, highly skilled crafts workers.

There are also several reasons why this may not be as great a problem as it appears, and the majority of the individuals we spoke to favor this reasoning:

- If nuclear power plants end up not being built, then developing a large specialized workforce does not make sense. There has to be long-term sustainable employment for the workforce.
- The industry, contractors and unions have established many efforts to fill the gap that could result from baby-boomer attrition.
- Many nuclear power plant operators say they track their workforce beginning at age 55 in anticipation of an average retirement age of 60, to make sure they replace every skill that the person who retires well in advance of the actual retirement.
- Several also expressed the view that "if you build them they will come." Construction of a nuclear power plants offers several years of good jobs with good pay, and many workers will relocate for that opportunity. Another way of expressing this is that if the

[317] Provided by Dr. Douglas Myers, Duke University Medical Center, March 8, 2011.

labor market conditions are favorable then recruitment takes care of itself. In regional markets with high pay, there is an abundance of applicants for slots at all levels expertise. It regional markets with low pay, it is much harder to find qualified people.

- There is no shortage of available training system capacity, which can be mobilized to fill the need for large numbers of crafts workers.

13.4 STORAGE OF SPENT FUEL

The Electrical Power Research Institute (EPRI) recently reviewed to risks of moving spent fuel from storage pools to dry storage.[318] As mentioned earlier, most spent commercial nuclear fuel is stored in water pools at the nuclear power facilities. There are two main pressures to move spent fuel to dry storage: security risks and a shortage of storage pool space, and for these and other reasons, it is desirable to reduce the cooling down time that the fuel spends in water to fewer than five years. EPRI estimates that at the current pace of development, by end of 2009 13,500 MTUs[319] of spent fuel had been placed in 1,200 dry cask systems, and that by 2020 this will have grown to 32,000 MTUs. Even so, the transfer of spent fuel will not reduce the amount stored in pools since the amount of spent fuel is also projected to increase, so it is likely that there will be pressure to increase the rate of transfer.

There are potential risks of radiation contamination during such transfer. For the fuel that is in storage now and has been so for decades, EPRI estimates an average dose of 0.4 rem absorbed dose per storage unit. If spent fuel is left to cool down in water for fewer than five years, that radiation risk could increase. In addition, there are radiation risks when the dry packs are moved into transportation casks for off-site shipping. The EPRI concludes: "[I]t should be recognized that there will be a radiological impact to workers associated with this activity and the radiological impacts are directly proportional to the number of dry storage systems loaded."[320]

13.5 CONSTRUCTION OF NEW POWER PLANTS

NRC is expecting to review applications for licenses to build approximately 30 new reactors in this decade, although most industry experts seem to think that the actual number reactor plants to be built in this decade will be somewhere between four and eight. We examined the

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[318] Electric Power Research Institute. Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage After Five Years of Cooling. Final Report, November 2010. Kessler J. *Used Nuclear Fuel: Inventory Projections*. Presentation to Blue Ribbon Commission on America's Nuclear Future, Subcommittee on Transportation and Storage, August 19, 2010.
http://brc.gov/Transportation_Storage_SC/docs/TS_SC_08-19_mtg/2_EPRI_Used_Fuel_Inventory-August_2010_final_John%20Kessler.pdf.

[319] MTU means *Metric Tons of Uranium.*

[320] Electric Power Research Institute. Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage After Five Years of Cooling, Final Report, pp 2-10-2-11. November 2010.

NRC's review of the environmental impact statement for one such application, which includes an assessment of occupational risks to workers constructing the facility.[321] The Comanche Peak application is for two new Advanced Pressurized Water Reactors. It is projected that construction will take seven years and at peak employ 5,200 workers. The NRC estimates that occupational safety and health impact on construction trades workers will be:

- Fatal injuries, 0-2
- Recordable injuries, 558-887
- Occupational injuries and illnesses with days away from work or restricted duty, 197-361

The report notes, *"[The applicant] states that workers would have adequate training and personal protective equipment to reduce the possibility of harmful exposures. A safety and medical program will be provided for construction workers, and all construction contractors and site staff would be required to comply with site safety, fire, radiation, and security policies, procedures, and safe work practices; State and Federal regulations; and site-specific permit conditions. Emergency first aid would be available at the construction site. These actions would help minimize or prevent injury, illness, and death."*[322]

This assessment is clearly not acceptable or grounded in any knowledge of the state of construction safety today. NRC knows this. In 2009, the NRC Inspector General reviewed NRC's oversight of construction, and found that the agency had concluded as long ago as 1984 that lack of such expertise was a problem, and that even so, NRC's current Construction Inspection Program (CIP) was still lacking. This could: *"...[J]eopardize the CIP's goal to prevent recurrences of construction-related problems and may compromise the public's confidence in NRC's ability to effectively oversee new construction projects.*"[323] We agree. The NRC has brought a new focus to this need, by adding an Office of New Reactors and by creating a center for oversight of new construction in its Region II office, but in spite of these changes, we think may benefit from further review to see if it should be strengthened.

13.6 NEW TECHNOLOGIES, NEW RISKS

A number of new reactor designs are in development and will be deployed in the new generation nuclear power plants. We have not reviewed the risk associated with them, but note that the NRC in reviewing the license application for the Comanche Peak nuclear facility stated, "*The occupational [radiation] doses for APWR [Advanced Pressurized Water Reactor]*

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[321]NRC. *Environmental Impact Statement for Combined Licenses (COLs) for Comanche Peak Nuclear Power Plant.* Units 3 and 4, NUREG-1943, Vol. 1, August 2010, p. 4-68 - 4-69. http://adamswebsearch2.nrc.gov/idmws/DocContent.dll?library=PU_ADAMS^pbntad01&LogonID=c8dc97cf2326fa59825092ef3a4dd396&id=102180145. [Accessed 2/20/11].

[322] Ibid., p. 4-69

[323] NRC Office of Inspector General. *Audit of NRC's Oversight of Construction at New Nuclear Facilities*, OIG-09-A-17, September 29, 2009, p. ii.

designs are estimated to be less than the annual average occupational doses for current light-water reactors."[324]

13.6.1 Beryllium

Expanded use of beryllium in fuels is being researched, based on the theory that it will improve efficiency through better conductivity.[325] Beryllium is a hazardous substance which causes debilitating lung damage, and medical evidence of beryllium exposure has been found in workers in DOE facilities where testing has taken place.

The National Academies performed a review of beryllium and found:[326]

> *"Beryllium is a low-density metal that is used in a number of industries, including the automotive, aerospace, defense, medical, and electronics industries, for various applications because it is exceptionally strong, is light in weight compared with other metals, has high heat-absorbing capability, and has dimensional stability in a wide range of temperatures.*
>
> *"It is well established that beryllium can cause sensitization and [chronic beryllium disease] CBD. Sensitization is an immune response, not a disease, and does not have any symptoms.... CBD is a systemic granulomatous disorder that affects mainly the lungs.... Epidemiologic studies performed on cohorts of workers exposed to various forms of beryllium in different industries have indicated that sensitization and CBD can occur after exposure to beryllium even at concentrations below the current occupational exposure limit of 2 μg/m^3.*
> *"Progression to CBD appears to be influenced not only by the magnitude of beryllium exposure but also by the physiochemical properties of the form of beryllium (such as composition and particle size), the genotype and phenotype of the exposed person, and probably the route of exposure. Other possible risk factors that have not been systematically addressed include smoking status, race, sex, concurrent exposures, and other environmental stressors. There is little published information on the rate of progression from asymptomatic immunologic sensitization to CBD.*"

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[324] NRC. *Environmental Impact Statement for Combined Licenses (COLs) for Comanche Peak Nuclear Power Plant.* Units 3 and 4, NUREG-1943, Vol. 1, August 2010, p. 5-81. http://adamswebsearch2.nrc.gov/idmws/DocContent.dll?library=PU_ADAMS^pbntad01&LogonID=c8dc97cf2326fa598 25092ef3a4dd396&id=102180145. [Accessed 2/20/11].

[325] "IBC Advanced Alloys and Global Nuclear Fuel America Enter MOU to Study Beryllium-Enhanced Reactor Fuel." *Nuclear Street News*, February 18, 2011. http://nuclearstreet.com/nuclear_power_industry_news/b/nuclear_power_news/archive/2011/02/18/ibc-advanced-alloys-and-global-nuclear-fuel-america-enter-mou-to-study-beryllium_2d00_enhanced-reactor-fuel021801.aspx [Accessed 2/20/11].

[326] National Academies. *Health Effects of Beryllium Exposure: A Literature Review.* National Academy Press, 2007. http://www.nap.edu/openbook.php?record_id=12007&page=2 . [Accessed 2/21/11].

As near as we can tell there have been no medical studies to determine whether beryllium poses a risk. Beryllium can be found in "no-sparking" tools that are used widely in nuclear power plants, and beryllium dust accumulates in tool boxes where these are stored. That dust is believed to be sufficient to cause health effects in susceptible individuals.

Recently, NIOSH issued an alert which states: "*WARNING! Workers exposed to particles, fumes, mists, or solutions from beryllium-containing materials may develop beryllium sensitization or chronic beryllium disease, a potentially disabling or even fatal respiratory disease.*"[327] Beryllium is highly hazardous, especially for a subset of individuals susceptible to its effects and for whom there appears to be no lower level threshold of safety. This is much the same as for radiation, where there also is no know threshold of safe exposure. Consequently, the concept of ALARA that has been adopted for radiation should also apply to beryllium.

13.6.2 Engineered Nano-materials

One of the biggest changes in materials use in nuclear power generation is likely to be the application of engineered nano-materials,[328] a field that is expanding rapidly, and where the DOE has made major investments in new research programs, particularly at Brookhaven National Laboratory and at the Lawrence Berkeley Laboratory. Engineered nano-materials can improve the strength and durability of concrete, improve electrical generating efficiency by reducing friction and improving conductivity and transmission efficiency, among other things. Nano particles are engineered from a variety of materials including carbon, silica, titanium, aluminum, silver, platinum and gold. Little is known about their health effects, except for those from carbon-based materials.

Recently, NIOSH issued a draft Current Intelligence Bulletin which states: *"The concern about worker exposure to CNT [carbon nano-tubes] or CNF [carbon nano-fibers] arises from results of animal studies. Several studies in rodents have shown: (1) an equal or greater potency of CNT compared to other inhaled particles known to be hazardous to exposed workers (ultrafine carbon black, crystalline silica, and asbestos) in causing adverse lung effects including pulmonary inflammation and fibrosis.*"[329]

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[327] NIOSH. *NIOSH Alert: Preventing Sensitization and Disease from Beryllium Exposure.* DHHS (NIOSH) Publication Number 2011–107, February 2011. http://www.cdc.gov/niosh/docs/2011-107/pdfs/2011-107.pdf. [Accessed 2/21/11].

[328] Engineered nanomaterials (also known as "nanoparticles") are materials that have been purposefully manufactured, synthesized, or manipulated to have a size with at least one dimension in the range of approximately 1 to 100 nanometers and that exhibit unique properties determined by their size. They are to be distinguished from nano-sized particles that are released when materials are manipulated, such as in diesel exhaust or welding fumes.

[329] NIOSH. *Occupational Exposure to Carbon Nanotubes and Nanofibers*. DHHS (NIOSH) Publication No. 2010–XXX, (Draft) December 2010. http://www.cdc.gov/niosh/docket/review/docket161A/pdfs/carbonNanotubeCIB_PublicReviewOfDraft.pdf [Accessed 2/21/11].

It is the fact that these nano-materials mimic the toxic effects of asbestos in particular that gives great concern to OSH professionals. There is an extensive body of the health effects of asbestos, which includes debilitating lung disease and several types of cancer. The DOE Former Worker Medical Screening Program has detected high rates of asbestos disease among workers who have been employed in the nuclear weapons industry, with an overall prevalence of 12.6% for all workers examined. There is still plenty of asbestos to deal with in many nuclear power plants both during routine maintenance and during eventual demolition after their useful life has ended. Adding nano-materials to this burden requires much greater attention to occupational safety and health precautions.

14

Alternatives to the Once-Through Fuel Cycle:

The West Valley Demonstration Project

We were asked to look at alternatives to the once-through fuel cycle. There are not many alternatives to look at. It is either once-through or via a detour through reprocessing. A few countries already rely extensively on reprocessing. Our experience in the U.S. is limited. In the civilian nuclear industry we only have the experience at West Valley, New York, to evaluate.

14.1 BACKGROUND ON THE WEST VALLEY DEMONSTRATION PROJECT

In 1960, New York State bought over 3,000 acres of land in West Valley, New York, with aim of creating an atomic industry park. From 1966 to 1973 a private company called Nuclear Fuels Services developed and operated about 200 acres of the site as a nuclear fuel reprocessing center, and accepted radioactive waste for disposal until 1975. During the operation of the plant, 640 metric tons of spent reactor fuel was processed, resulting in the production of 660,000 gallons of highly radioactive liquid waste. The liquid waste was stored in an underground waste tank. NFS also utilized a 15-acre area for the disposal of radioactive waste from commercial waste generators, and another seven-acre landfill was used to dispose of radioactive waste generated from reprocessing. In 1972, faced with much stricter environmental, permitting and licensing requirements , NSF concluded the venture was not commercially viable and abandoned it.[330]

In 1980, Congress authorized the West Valley Demonstration Project (WVDP), in part to clean up the mess that had been left behind. It authorized DOE to carry out a high-level liquid nuclear waste management demonstration project to prepare high-level radioactive waste for disposal. The objective was to solidified the high-level radioactive waste using a technology known as vitrification (or by another technology if determined to be more effective); containers suitable for permanent disposal of the high-level waste were to be developed; the solidified waste was to be transported to an appropriate federal repository for permanent disposal; the

[330] West Valley Demonstration Project Nuclear Timeline. http://www.wv.doe.gov/Site_History.html. [Accessed 2/9/11]

low-level radioactive waste and transuranic waste were to be disposed of; and the tanks, facilities, materials, and hardware were to be decontaminated and decommissioned.[331]

In 1996, Radioactive vitrification began and continued into 2001, emptying the high-level waste tank and producing 275 stainless steel canisters of hardened radioactive glass. Subsequently, it added a facility for remote decontamination of highly radioactive waste and since then work has been performed to decontaminate and decommission the site.[332]

In 1999, the DOE awarded the WVDP Voluntary Protection Program recognition with a Star (best safety performance) designation based on the safety performance reports made by WVDP and its adoption of an Integrated Safety Management System that is described in Box 14.1.

Box 14.1: The West Valley Demonstration Project Integrated Safety Management System

OBJECTIVE of ISMS is to systematically integrate safety into management and work practices at all levels so that missions are accomplished while protecting the public, the worker, and the environment. This is accomplished through effective integration of safety management into all facets of work planning and execution.

GUIDING PRINCIPLES,

- **Line Management Responsibility for Safety** - Line management is directly responsible for the protection of the public, the workers, and the environment.
- **Clear Roles and Responsibilities** - Clear and unambiguous lines of authority and responsibility for ensuring safety are established and maintained at all organizational levels within the Department and its contractors.
- **Competence Commensurate with Responsibilities -** Personnel possess the experience, knowledge, skills, and abilities that are necessary to discharge their responsibilities.
- **Balanced Priorities** - Resources are effectively allocated to address safety, programmatic, and operational considerations.
- **Identification of Safety Standards and Requirements** - Before work is performed, the associated hazards are evaluated and an agreed-upon set of safety standards and requirements is established.
- **Hazard Controls Tailored to Work Being Performed -** Administrative and engineering controls to prevent and mitigate hazards are tailored to the work being performed and associated hazards.
- **Operations Authorization -** The conditions and requirements to be satisfied for operations to be initiated and conducted are clearly established and agreed-upon.

CORE FUNCTIONS:

- **Define the Scope of Work -** Missions are translated into work, expectations are set, tasks are identified and prioritized, and resources are allocated.
- **Analyze the Hazards -** Hazards associated with the work are identified, analyzed and categorized.
- **Develop and Implement Hazard Controls -** Applicable standards and requirements are identified and agreed-upon, controls to prevent/mitigate hazards are identified, the safety envelope is established, and controls are implemented.
- **Perform Work within Controls -** Readiness is confirmed and work is performed safely.
- **Provide Feedback and Continuous Improvement -** Feedback information on the adequacy of controls is gathered, opportunities for improving the definition and planning of work are identified and implemented, line and independent oversight is conducted, and, if necessary, regulatory enforcement actions occur.

SAFETY MECHANISMS:

- Departmental expectations expressed through directives (policy, rules, orders, notices, standards, and guidance) and contract clauses.
- Directives on identifying and analyzing hazards and performing safety analyses.

[331] West Valley Demonstration Project Act. Public Law 96-368.
[332] West Valley Demonstration Project Nuclear Timeline. http://www.wv.doe.gov/Site_History.html. [Accessed 2/9/11]

- Directives that establish processes to be used in setting safety standards.
- Contractor policies, procedures and documents established to implement safety management and fulfill commitments made to the Department.

RESPONSIBILITIES are clearly defined in documents appropriate to the activity. DOE responsibilities are defined in Department directives. Contractor responsibilities are detailed in contracts, regulations and contractor-specific procedures.

IMPLEMENTATION involves specific instances of work definition and planning, hazards identifications and analysis, definition and implementation of hazard controls, performance of work, developing and implementing operating procedures, and monitoring and assessing performance for improvement.

Because DOE and NRC have determined that the WVDP processed waste is "waste incidental to reprocessing" (WIR) it is not subject to NRC regulation. WIR is managed under DOE's self-regulatory authority.[333]

14.2 OCCUPATIONAL HEALTH RISKS AT WVDP

NIOSH has performed a detailed site history profile of the WVDP.[334] From 1966-1973, when reprocessing was a commercial operation, it employed about 200 permanent employees, and quoting an insurance survey of the plant, "*To facilitate operations and meet AEC established radiation exposure criteria the plant utilizes about 1000 temporary laborers each year. Radiation exposure and contamination hazards are extensive and ever present in this type of operation."*[335] In other words, when there were processes with high radiation risk, the plant would employ temporary workers for short periods of time to avoid exceeding maximum radiation doses. NIOSH also found that,

> *"[T]he West Valley reprocessing plant was an extreme radiological environment throughout the operations era.... the principal focus of the radiation protection program at West Valley during its operations era was to minimize the number of individuals receiving exposures in excess of legal maximums... Personnel exposures could not be optimized in accordance with normal radiation protection practice given the work environment.... significant contamination or exposure rates (or both) could have been present in areas not normally associated with personnel exposures, such as stairways, lobbies, etc."*[336]

In short, if the reprocessing of high level nuclear waste were to be economically feasible at that time, at least in the view of NFS, it would have to be performed in a highly reckless manner. Even

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[333] NRC. Regulatory Authority and Responsibilities for Waste Incidental to Reprocessing. http://www.nrc.gov/waste/incidental-waste/reg-authority.html. [Accessed 2/9/11].

[334] National Institute for Occupational Safety and Health. Site Profile for the West Valley Demonstration Project. ORAUT-TKBS-0057, August 17, 2007. http://www.cdc.gov/niosh/ocas/pdfs/tbd/wvdp-r0-p1.pdf. [Accessed 2/10/11]

[335] Ibid., p. 23

[336] Ibid.

then, the company concluded it was not profitable. Not a good example from either an OSH or economic perspective!

Following start-up of operations under Congressional authorization and funding in the early 1980s, the WVDP plant was operated to the extent possible to keep workers within permitted radiation levels. In the 1980s, when the most hazardous waste was being addressed, radiation released was 3-4 times higher than after 1990 (see Fig 14.1).[337] After having processed seriously high level waste in the 1980s, operations were improved and downscaled in 1989, with dramatic effect.

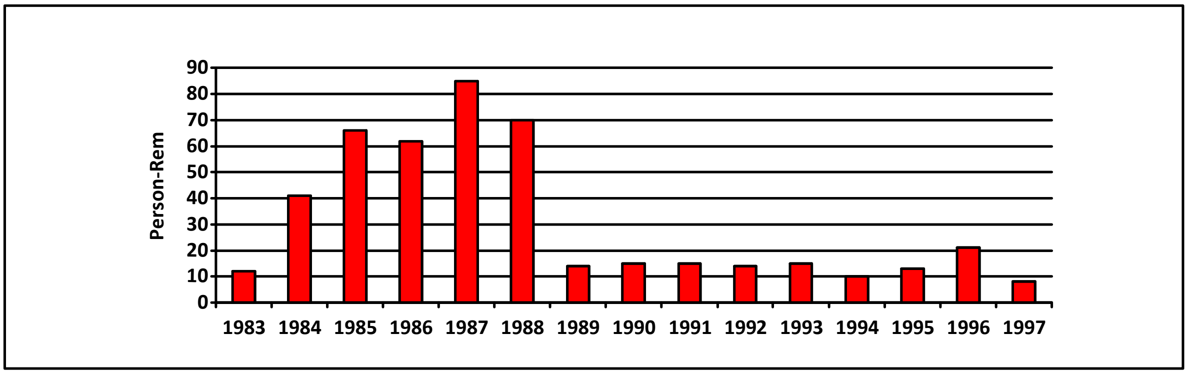

Fig. 14.1. Occupational Radiation Dose Received by Workers, WVDP

Approximately 105 workers from WVDP have filed claims for compensation under the Energy Employees Occupational Illness Compensation Program. Of these claims, 29 have been approved, 27 for radiation-associated cancers.[338] This suggests that the levels of radiation exposure that occurred in the early years of reprocessing must have been well above the regulatory limits that were in place at the time.

14.3 FINDINGS FROM WVDP

The West Valley demonstration proved that it was not feasible to re-process high level nuclear waste economically and safely, and with the technology in the 1960s and 1970s, probably not safely at any cost. It also points to the OSH hazards that need to managed during the closure period of the nuclear fuel cycle.

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[337] Hoffman RL. radiation safety at the west valley demonstration project. US Department of Energy, Contract No. DE-AC24-81, NE44139DOUNU44139-75, May 6, 1997.
http://www.osti.gov/bridge/purl.cover.jsp;jsessionid=12BB416C98560DE8E140E2456061F48C?purl=/668378-6VGfDL/webviewable/ [Accessed 2/9/11]

[338] US Department of Labor. Office of Workers' Compensation Programs (OWCP), EEOICP Program Statistics.
http://www.dol.gov/owcp/energy/regs/compliance/statistics/WebPages/W_VALLEY_DEM.htm [Accessed 2/9/11]

15

Findings and Conclusions

The Blue Ribbon Commission on America's Nuclear Future (BRC) asked us to study whether occupational safety and health conditions in today's U.S. nuclear industry are reasonably safe, and if those conditions have improved since the Three Mile Island accident in 1979. The BRC also asked us to look to the future, to try to anticipate worker safety and health risks that should be addressed by the industry, its government regulators and private watchdogs. With new nuclear reactors recently approved for construction, and given the need to extend the operational life of existing reactors by many years and even decades, these are critical questions for workers, licensees and the American public.

Over the six weeks allotted, we performed a limited review of the literature and spoke with stakeholder representatives from utilities, contractors, unions, government regulators, environmental groups and the Nuclear Energy Institute (NEI). Of note, in the time available to us, we were unable to gain access to anyone at the Institute for Nuclear Power Operations (INPO), and the Nuclear Regulatory Commission (NRC) had not completed preparation of written responses to a long list of question we submitted to it. Despite these limitations, we believe that the our findings and conclusions are sound.

15.1 FINDINGS

In consultation with the Commission staff, we defined this charge as four distinct issues:

1. Are the occupational safety and health practices and risks in today's nuclear fuel cycle sufficient to assure workers reasonably [as defined in Occupational Safety and Health Act] safe and healthy working conditions at each stage of the nuclear fuel cycle?
2. How do the occupational safety and health practices and risks in today's nuclear power industry compare to those in other types of electrical power production (hydro, coal, natural gas)?

3. What are the occupational safety and health practices and risks [qualitative and quantitative] at each stage of the nuclear fuel cycle in today's industry compared to 30-40 years ago?
4. What changes can we anticipate in the nuclear fuel cycle over the course of the foreseeable future that will affect occupational safety and health practices and risks in nuclear power generation?

15.1.1 Safety of Today's Working Conditions

Overall, we found that the record of occupational health and safety (OSH) performance for civilian electricity generation using nuclear fuel is very good, and that this industry's OSH performance has improved in measurable terms since Three Mile Island (TMI). We base this finding on the following data:

- Performance Indicators in nuclear power plants. We focused on the two most important ones, scrams and actuations. We found that both had declined by over 90 percent since TMI.
- Occupational Radiation Dose. We found that the average recorded dose per worker with measurable dose has declined by over 90 percent between 1983 and 2008.
- Occupational Injuries and Illnesses. We found that the nuclear power plants operate at a very high level of safety, comparable to service industries like insurance or finance.

However, this finding must be viewed in the context of the potentially catastrophic risk inherent in nuclear power generation. Notwithstanding the U.S. industry's strong safety culture, and its very good record in OSH, reportable accidents have continued to occur at American facilities even after improved oversight mechanisms were instituted following TMI.

We also note that safety performance is not uniform throughout the nuclear fuel cycle. Not all nuclear power plants perform equally well. We believe that there is room for improvement throughout the front end of the cycle, especially in mining, and also during construction and maintenance operations in all parts of the cycle.

We gave a great deal of thought to whether the distinction that the industry and the NRC make between "nuclear/radiation safety" and "industrial safety" is good for "worker safety." This has led to dual jurisdictions between the NRC and OSHA in general and NRC and MSHA in some mining operations. We concluded that although the existing system is cumbersome, there is nothing to suggest that this undercuts safety and health. Having said that, we think it would be wise for NRC, OSHA and MSHA to re-assess their regulatory duties and interagency coordination.

15.1.2 Nuclear Industry Safety Compared to Other Energy Sectors

Compared to other major U.S. energy sectors —indeed to all U.S. industries— the nuclear industry's level of OSH performance has been very good. We base this finding on occupational injury and illness data reported to the Department of Labor. We found occupational safety and health risks in nuclear power plants are 80% below those reported by fossil fuels operations, and also significantly lower than for hydro and alternative sources of electricity. Had the nuclear plants operated at the same level of safety performance as the fossil fuels and hydro plants do, it would have experienced 13-29 occupational fatalities during the period 2003-2008. Instead, it had no fatalities.

15.1.3 Safety Practices throughout the Cycle Compared to 30-40 Years Age

We found that before TMI, the industry lacked appreciation for the complexity of its technology. It had adopted a "fossil fuels mentality" which was poorly suited for the much higher risk and more complex operating environment of nuclear power. We also found the regulatory system at that time lacking. Subsequent to TMI, both the industry and the NRC went through a major transformation. The industry established a self-regulatory system by creating the Institute of Nuclear Power Operations (INPO), and the NRC went through a thorough reassessment. In the mid to late 1980s INPO instituted the "professionalism project" to rid the industry of the remnants of "fossil fuels mentality." Following the Davis-Besse event in 2002, the industry and the NRC committed themselves further to adopting a safety culture, which is a work in progress. The great improvements in all safety and health indicators document that the industry has made great strides in its safety performance. To continue to improve will require a great deal of commitment.

We were impressed with the transformation that the industry went through in response to electricity market deregulation in the 1990s, when a major consolidation of ownership took place. We think the industry will be better off in terms of safety and health as a result of having large, more specialized ownership, with more resources and expertise. Having said that, there is risk in competing in deregulated markets when so much of operating costs are fixed as a result of the substantial investments that are required to build and maintain nuclear power plants. In this respect, the lesson of Northern Utilities and its Millstone disaster is a more significant point of reference than Davis-Besse.

We think that making the safety work of NRC and INPO more publicly transparent could drive further improvements in safety culture and industry credibility. Safety culture should be incorporated as a strategic area of the NRC's Reactor Oversight Process. It is certain that significant resources must continue to be dedicated by operators, contractors, unions and other stakeholders to training for safe work in the nuclear environment. For its part, we would encourage the industry to take safety culture and self-regulation to an even higher level. This might be accomplished by considering processes by which both plant managers and workers are made jointly responsible for signing off on safety cases and the monitoring of operations.

We found that both the industry and the NRC have two different levels of emphasis on safety: a very high one in reactor operations, and a somewhat lesser one in the front end. Although the radiation risks may not be as significant in the front end, workers are still faced with significant risks.

Regarding the back end of the fuel cycle, including disposal and also reprocessing, the track record is mixed. WIPP, the country's and indeed the world's only permanent deep geological disposal facility has had a very good OSH record since opening in 1999, but it experienced an occupational fatality during its construction, and early on had failures in its hoist. It is also worth remembering that during the mining operation at Yucca Mountain, workers were exposed to hazardous levels of silica dust. The track record of commercial reprocessing of spent fuel is not at all good based on the experience with Nuclear Fuel Services in West Valley, New York. The West Valley Demonstration Project, which took over the NFS facility in 1980 and began processing radiologic waste struggled with radiation risk during the first decade, but since 1990 it has operated in a much advanced stage.

15.4 Future Changes that are Likely to Affect Safety and Health

Looking ahead, we identified certain areas of significant concern that will require industry and regulators to take new actions to ensure that a well-trained workforce operates as safely as possible. In addition, we found that the industry could further improve OSH performance on the front end of the fuel cycle by selectively extending the oversight of the NRC and INPO or a self-regulatory group like it. We found, as the industry and the NRC have, that it faces a very serious workforce shortage that is not being addressed vigorously enough in light of the plans to build new reactors and the added burden of maintaining existing ones that now have been licensed for life cycles of up to 60 years. We found the NRC lacking in oversight expertise and possibly processes in construction, something the agency's Inspector General has also concluded.

New technologies can bring great safety and health benefits. It is expected that next generation reactors will pose fewer risks, but there are new technologies emerging that are of great concern in terms of occupational safety and health. In particular, we encourage the industry to pay careful attention to the use of engineered nano-materials and to beryllium.

We think that the future construction of new power plants (and demolition of the old ones when that work starts) holds out the opportunity for the industry to serve as a model of what good and safe construction can and should be. We have previously noted that if NRC is going to be a valued participant in this regard, it must significantly strengthen its capabilities in construction oversight.

15.5 Alternatives to the Once-Through Fuel Cycle

We found that the once-through fuel cycle does not in itself pose an OSH risk to industry workers. There are no data showing that the use of interim storage of spent fuel presents a significant OSH risk. There are great potential risks when transferring spent fuel from wet storage to dry casks, but we believe the procedures that have been developed for this work will provide adequate safeguards provided that the workers are adequately trained and supervised, and that quality assurance programs are in place.

In the 1960s and early 1970s, commercial recycling (or reprocessing) of nuclear waste was tried in West Valley, New York. It was a flawed process that produced significant occupational safety and health risks. It was not a good experience for workers.

We found that the current operation of WIPP appears to be within accepted margins of safety, and that significant improvements have been made over the past decade. However, constructing permanent storage facilities deep underground is not without risk to workers. One worker was killed during construction of the WIPP facility and at Yucca Mountain there were significant exposures to silica, which can cause lung damage. Such experiences need to be incorporated into the risk assessment when future facilities are planned, and prevented.

15.2 CONCLUSIONS

Today, the U.S. nuclear fuel cycle is an enterprise with 97 workplaces, where 119,000 Americans work in power plants, and another 9,000 work in uranium mining, milling, conversion, enrichment, fabrication and interim waste storage. For these workers and the American public, a nuclear industry defined by strong oversight, shared responsibility, and a transparent commitment to safe operation and safe workplaces is essential. Our conclusions are summarized below. We have ranked them according to importance.

1. On the Whole, Occupational Safety and Health Performance is Very Good

We find that occupational safety and health (OSH) performance is very good in the nuclear power plants and in the back end of the nuclear fuel cycle. Rates of reported occupational injuries and illnesses in nuclear plants have declined greatly since Three Mile Island. The probability of a serious injury or illness resulting from working in a nuclear power plant is very low— at only one-fourth to one-fifth of the rates reported by facilities using fossil fuels.

Of great significance, we note that since TMI, the average radiation dose received by workers in nuclear power plants who recorded any dose has declined by over 90 percent. For many years, not a single worker in nuclear power plants has received a radiation dose over three rem, and in the most recent year with available industry-wide data (2008) only one facility reported any workers receiving radiation doses above two rem, and then it was only five workers. The NRC's maximum allowable annual dose of five rem is lagging industry practices and scientific consensus and should be reviewed.

The safety culture driving this performance, as described by industry participants, is often credited to the training received by the industry’s extensive reliance on managers drawn from America’s Nuclear Navy to straighten out operations following Three Mile Island in 1979. While the safety culture is procedure-based and intended to prevent nuclear accidents, it has clearly contributed to the good OSH performance of nuclear facilities.

The industry goes to great lengths to achieve its high level of operational safety and OSH performance. The owners of nuclear power plants acknowledge and embrace their responsibility for the safety of their operations to a much greater extent than we think is the case in other industries. Between seven and eight percent of personnel in nuclear facilities are employed in a safety assurance function. The owners have put in place an impressive system of self regulation by INPO. They are actively regulated by the NRC. Whereas NRC regulates to ensure that operators meet the conditions of their licenses, INPO's intended mission is to help facilities achieve higher standards of excellence in operations. Both NRC and INPO can impose sanctions if they find performance problems.

At least 50 U.S. nuclear plants have unionized workforces, and most of the outage work is performed by contractors using union workers. Union health and safety officers reported to us that labor relations with most nuclear operators are generally good, that joint health and safety committees operate at a number of locations, and that this contributes greatly to their safety.

Despite this overall commitment to safety, the level of safety performance is not uniform throughout the industry. There are still worksites in need of improvement. The general pattern of safe operation has been marred by periodic reportable-level incidents which should have been avoided. Three Mile Island and the near miss at Davis-Besse in 2002 are probably the best known, but there have also been other less well publicized incidents.

We believe that the industry and NRC should continue to strive to improve occupational safety and health throughout the nuclear fuel cycle and ensure that such performance is more uniform throughout the industry. The industry should do more to explain its safety record to the public. In particular, we think the nuclear power plant operators should make public the assessments that INPO conducts of their operations.

2. Significant Adverse Events Mar the Safety Record

NRC maintains records of precursor events and it is required to report annually on all abnormal occurrences to Congress. A significant precursor event is the highest risk rating assigned by NRC. An abnormal occurrence is an unscheduled event that the NRC rates as "significant" in terms of possible effect on public safety and health. According to the NRC, there have been at least a dozen and half significant precursor events and many more significant abnormal occurrences. We were able to obtain documentation on many of these, but not all. So far, as near as we can tell, no workers have experienced adverse health impacts from these events, at least for radiation exposure. However, as the Fukushima Daiichi event demonstrates, this will not necessarily always be the case. Based on the information available to us, we have found it useful to group these events in four different broad categories of risk:

- *Inexperience.* In 1979, the event at Three Mile Island in Pennsylvania revealed that the operator (and the entire industry) was applying a "fossil fuel" mentality that was lacking in understanding of the risks of nuclear power operations or the much greater level of effort required to manage them.

- *Overconfidence*. NRC and the operators rate risks based on probabilistic risk assessments (PRAs). PRAs are performed to allocate prevention resources to where they are most needed, but often they also become interpreted as being indicators of safety, which can result in plant operators and their staff becoming overconfident in the safety of a system or procedure. One good example of this was the hoist at the Waste Isolation Pilot Plant in New Mexico. The designer of the hoist estimated that the probability of a failure was one in 60 million, which plant operators took to mean failsafe. Consequently, neither required maintenance nor training of operating personnel was implemented. Not long after it was placed in operation, the hoist experience two serious failures and the underlying causes were design fault, failure to maintain equipment and failure to implement emergency procedures.
- *Complacency/negligence*. The Davis-Besse event in Ohio in 2002, which is described in detail in this report, revealed that both the operator and the NRC had been aware of a potential risk to a certain type of reactor yet failed to investigate with the result that very severe corrosion of the steel primary containment of the reactor vessel made the reactor highly vulnerable. Operating staff then sought cover up the event and provided falsified information to the NRC.
- *Risk taking*. In 1996, the NRC found that the safety culture at the Millstone nuclear power plant in Connecticut had deteriorated so severely that it shut down the plant for two years. Evaluations of the plant operation found that the operating company had decided to cut corners in order to decrease operating costs in anticipation of having to compete in open electricity wholesale markets.

The excellent safety record of the nuclear power industry must always be balanced against the likelihood of a potentially very significant event occurring in the future, even though it is not possible to quantify the probability or severity of such an event. Consequently, the nation, the industry and the regulators must be fully prepared for a worst-case event. Evidence from the Fukushima Daiichi plant suggests that the U.S. needs to assess whether such readiness is present.

3. Commitment to Safety Culture Must Be Constantly Renewed and Strengthened

Finding ways to maintain high safety performance over time will be NRC's and the industry's biggest challenge. After Three Mile Island, and more so after Davis-Besse, NRC has put a growing emphasis on understanding the safety culture of plants, and the organizational and human factors that control plant operations. There is evidence that this emphasis has had a positive impact on safety performance. Importantly, NRC has worked to identify early warning signs of safety culture degradation.

The emphasis on safety culture recognizes that the people who operate the nuclear fuel cycle are as important to safety as the technologies deployed—and that their behaviors can be hard to predict. The safety culture must aspire to make all personnel in the nuclear cycle, from top executives to crafts workers, equally aware of the need to be vigilant about risk. At this point, safety culture has been defined as a matter of policy by NRC, but only incorporated piecemeal into the NRC Reactor Oversight Process (ROP). The ROP essentially assumes that degradation in culture will be revealed in the reporting of performance indicators by the licensee and through inspections. We have proposed a fundamental change in the ROP in which safety culture is added as a strategic area, with its own cornerstones and performance indicators.

The NRC and the industry are trying to figure out how safety culture fits into the ROP. However, we have found little evidence that a high-performance safety culture can simply be imposed from outside an organization, even by an agency with as much power as the NRC. Safety culture must be built from within, and embraced by managers and workers equally. There is significant evidence to this effect within the nuclear power industry. Plants that NRC has struggled to bring into compliance can be turned into high safety performers when new owners committed to building internal safety culture take them over.

The nuclear power plant operators recognize that they have a general duty and a regulatory responsibility for identifying and resolving safety issues, and that worker involvement in safety processes is essential to this duty. The INPO principles of professionalism includes "a questioning attitude" which is an expectation of all workers. The Safety Conscious Workplace Environment is a cross-cutting issue in NRC's oversight of reactor operations. It allows workers to speak up about potential risks that they observe, without fear of retaliation by management.

As the industry works to strengthen its safety culture process, we believe there may be ways to achieve a higher level of self-regulation. In the wake of huge disasters on off-shore oil rigs in the North Sea, the region's oil industry and its regulators decided that best way to impose the highest level of accountability for rigorous safety processes was to hold both workers and managers responsible both for preparation for any new procedure, and for monitoring of operations. This greatly increased accountability for safety, and has worked well since by all accounts. U.S. nuclear power plants could take similar steps. U.S. plants have emphasized a safety-conscious work environment for many years, and many have adopted joint worker-management safety processes, with different degrees of emphasis. However, in our opinion, the North Sea model's heightened role for workers in the safety process would make sense for the U.S. nuclear industry and should be explored.

We think the NRC should revamp the ROP and replace the cross-cutting areas with safety culture as an added Strategic Area; this would recognize safety culture as a foundation of good safety performance and a fundamental part of the inspection process triggering enhanced regulatory oversight. The industry and NRC should explore creating a safety culture process that gives managers and workers greater parity and accountability in the administration of safety culture, along the lines of programs used by the North Sea offshore oil industry. We believe this approach holds the best hope for assuring safe working conditions.

4. Outage Work Can Be Improved

Periodically, usually every 18-24 months, nuclear plants are shut down for several weeks to undergo maintenance and refueling. In this process the vessel head of the reactor is open, creating inherently higher radiation exposure risks. Specialized contractors bring a thousand or more highly trained workers to perform this operation. Nuclear power plant operators take great care to plan for maintenance work and scheduled outages, and union health and safety representatives told us the industry is a safe place to work.

Occupational safety and health data provided to us by one maintenance contractor showed low occupational injury and illness rates for the nuclear industry compared to the same kind of work in fossil power plants. Even so, maintenance outage workers employed in nuclear plants have occupational injury and illness rates that are twice as high as those of in-plant operations personnel.

NRC does not maintain radiation data that are specific to maintenance work, but it does have data on what it calls "transient workers," who are employed in more than one nuclear plant per year. Most of these workers are engaged in outage work. Although their measured radiation dose is well within regulatory limits, transient workers receive radiation exposures that are 2.5 times greater than permanent in-plant workers. As a result, although transient workers comprise only 24 percent of the workforce that is monitored for radiation exposure in nuclear power plants, they receive 58 percent of the collective radiation dose.

While OSH has improved significantly in maintenance work, the industry's greatest opportunity for continued reduction in industry-wide collective radiation dose lies in reducing radiation exposure during outage work. To measure this, NRC should add two data components to the Radiation Exposure Information Recording System (REIRS) to better classify transient workers: a code for contractor and a code to indicate if the work performed was outage work.

5. Specific and Potential OSH Hazards Warrant Vigilance

We identified a number of areas where because of hazard or risk the industry needs to be especially vigilant.

- ***Aging Facilities.*** Most U.S. nuclear generating facilities are 30 years old or more and most are being given license renewals to operate with a life cycle of 60 years, rather than the 40 years for which they were originally approved. There is greater concern about material fatigue and the integrity of aging mechanical systems (including piping, valves and pumps, cables, switches, and auxiliary generators) as they get old, and there is also less empirical evidence to work from to anticipate and prevent failures. The industry and the NRC have recognized this concern and have taken numerous steps to address them. *Nevertheless, we believe that this is an issue that cannot be ignored in any assessment of the future safety of this industry.*
- ***Aging Workforce and Looming Skills Shortage.*** The 20th century build-out of nuclear power plants coincided with the baby boomer generation coming into the work force.

These workers are likely to retire in massive numbers in the next five years. There could be a shortage of experienced nuclear engineers, health physicists, plant operators and particularly skilled crafts workers essential to construction and maintenance. We have heard some in the industry say that the market will take care of this problem--a "build it and they will come" approach, but we also heard others say this is a concern. *In spite of many industry efforts, we do not see evidence that a new U.S. workforce is being developed fast enough, especially in some geographic areas. This may reflect deficiencies in some regional labor markets.*

- ***New Technologies, New Risks.*** While new-generation reactors are expected to reduce safety risks, new materials are being considered to enhance efficiency. Two of these materials pose potential OSH concerns: engineered nano-materials and beryllium. Some forms of engineered nano-fibers have been found to have risks similar to asbestos. Beryllium is highly toxic to susceptible individuals. In workplaces throughout the nuclear weapons complex where workers have been tested, a number of them have been found to have been sensitized to beryllium. Some have developed chronic beryllium disease. *Both of these hazards require utmost care in terms of safe handling practices. For susceptible individuals, there is no threshold of zero risk for beryllium exposure, and therefore it should be managed according to the ALARA ("as low as reasonably achievable") principle. As a precaution, the industry should institute a pilot medical screening study to determine if any workers test positive for beryllium sensitization*.
- ***Working in Underground Salt Formations***. We know of no studies about the occupational health effects of working in salt formations where there is significant exposure to salt dust. *This could be investigated through a pilot medical study of workers in the WIPP facility.*

6. The "Front End" of the Nuclear Fuel Cycle Needs Better OSH Focus

In terms of OSH, the U.S. nuclear fuel cycle appears to function on two levels: at a very high level for nuclear power plant operations and waste management, and at a somewhat lower level in the “front end” — uranium mining, milling and processing.

Mining receives the least OSH focus within the U.S. nuclear fuel cycle. Fewer than 500 U.S. workers are employed in mining operations; however, a number of companies are exploring the possibility of opening new mines. There are now 20 uranium mines in the U.S. The four in-situ leach operations, which produce 90 percent of the total uranium mined, are licensed by NRC. Underground and open pit mines are the only parts of the nuclear fuel cycle that are not licensed by NRC.

Occupational safety and health in underground mining is regulated by the Mine Safety and Health Administration (MSHA). MSHA's regulations are obsolete and it does not have a single radiation expert on staff. Studies of miners by the National Institute for Occupational Safety and Health, show serious health effects among those employed before 1970. There are no independent data in the U.S. on whether underground or in-situ leach mining or milling as practiced today poses a risk to workers. *We believe the industry would benefit by using the same approach to safety in all phases of the nuclear cycle. NRC should seek authority to license all mines. NRC should maintain in-plant inspectors in all large facilities that convert, enrich and fabricate fuel, and at mining sites where it has jurisdiction. A self-regulatory system, with an organization modeled after INPO, should monitor operations in the front end of the cycle. MSHA urgently needs to review its uranium mining program. NIOSH should perform field studies on all types of uranium mining operations to determine if current workers are safe.*

7. Construction of New Nuclear Power Plants Could Serve as a Model

The nuclear operators take their responsibilities as owners of new construction seriously. They recognize their responsibility for assuring that this work is done as safely as possible. The handful of construction companies that are capable of constructing a nuclear power plant are equally dedicated to safety. The construction of new nuclear plants could provide a great showcase for demonstrating how construction can be done both safely and efficiently, and this experience could be used to inform construction in other sectors about best practices.

In its review of environmental impact statements in applications to construct and operate new nuclear plants, the NRC seems to accept a risk of one occupational fatality, 100-200 serious occupational injuries and hundreds of recordable occupational injuries per reactor built. If the new reactors that have been proposed are built to this level of risk, the risks to construction workers will be enormous, and in stark contrast to NRC's adherence to ALARA when it comes to nuclear safety, and with no apparent understanding of current construction practices. The NRC has increased its competency in recent years by establishing an Office of New Reactors in its headquarters, and a center to coordinate all construction oversight in its Region II Office, which this evidence suggests was much needed. *We think NRC should examine its policies with regard to construction risks. To do this, NRC needs to continue to add more construction safety and health expertise. NRC should work with the licensees, the contractors and the building and construction trades unions to make new plant construction a model for all U.S. industries.*

8. OSH Risks in the Back End Should be Manageable in Diligent Operations

Spent fuel from civilian reactors is increasingly being stored in dry casks within secure facilities. Transfer of spent fuel from wet storage to dry casks includes several difficult work tasks which must be carried out with extreme care. Although there is potential for low level radiation exposure in dry storage facilities, we have found no evidence that this poses an unmanageable OSH hazard to workers. As concrete technology improves, the durability of the casks will be extended as well. Our experience with constructing two permanent deep geologic storage facilities --WIPP and Yucca Mountain-- demonstrates that in the future safety and health precautions during construction need to be significantly improved over the practices used in the past. Evidence from the operation of WIPP shows a very good level of safety, although potential chronic health effects from working in heavy salt dust has not been explored. We did not examine OSH risks in present-day reprocessing, since there is no reprocessing by the US civilian nuclear industry. The only example of commercial reprocessing we have to draw on is the Nuclear Fuels Services operation in West Valley, New York 40 years ago. Its safety record was not good, and by comparison, waste storage is advantageous from the OSH perspective. *Strictly in terms of OSH concerns for nuclear facility workers, finding permanent storage for nuclear waste is not an urgent issue. This is important in that there appears to be no viable alternative to the once-through fuel cycle in the foreseeable future. We also believe that horizontal deep geological disposal facilities (such as Yucca Mountain) may be advantageous over vertical (deep bore) facilities (such as WIPP) because the latter would require use of hoists that may pose a greater degree of risk to workers. Storage facilities should be subject to the same levels of self-regulation and government regulation as nuclear power plants.*

Glossary of Terms and Acronyms

Agreement State: as defined in 10 CFR 20.1003, means any state with which the Atomic Energy Commission or the Nuclear Regulatory Commission has entered into an effective agreement under which the state regulates the use of byproduct, source, and small quantities of special nuclear material in that state.

*ALARA (As low as reasonably achievable) i*s defined in 10 CFR 20.1003. It means making every reasonable effort to maintain exposures to radiation as low as possible, taking into account the state of technology, economics, and "other societal and socioeconomic considerations".

Average measurable dose: the dose obtained by dividing the collective dose by the number of individuals who received a measurable dose.

BWR means Boiling water reactor, in which the water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam is directed to drive a turbine and electrical generator, thereby producing electricity.

*Collective dose i*s defined in 10 CFR 20.1003, is the sum of the individual doses received in a given period of time by a specified population from exposure to a specified source of radiation.

CFOI is the Census of Fatal Occupational Injuries, which a complete database of all occupational fatalities in the U.S. It is maintained by the Bureau of Labor Statstics in the U.S. Department of Labor

DART—Days Away from Work, Restricted Duty or Transferred. This refers to a class of cases of occupational injuries and illnesses that all private employers in the U.S. are required to report to OSHA each year.

ENTOMB is a method of decommissioning a nuclear facility, in which radioactive contaminants are encased in a structurally long-lived material, such as concrete.

Exposure means being exposed to a hazard. There are three “routes of exposure” or “modes of intake”: skin contact, inhalation and ingestion. Exposure as it relates to radiation is defined in 10 CFR 20.1003.

"Greater than Green" means an inspection of a reactor facility has resulted in a finding. Findings are rated as White, Yellow and Red, in order of significance, with red being most significant. A facility that the NRC rates Green has no findings.

ISFSI (Independent Spent Fuel Storage Installation) is defined in 10 CFR 72.3. IFSIs are highly secure facilities where spent fuel and other radioactive wastes are stored in huge concrete and steel containers known as “casks”. This waste is much less radioactive than the fuel that is used in the reactors (since the reactors have used up most of radiation). The casks can store this material safely for very long periods of time.NRC currently licenses two ISFSIs: Trojan and GE Morris. There are another 48 ISFSIs are located on the site of licensed nuclear power plants.

ISL means In-Situ Leaching, which is a technology used to extract uranium from underground ore deposits.

License is defined in 10 CFR 20.1003 and is issued by the NRC.

Licensee is defined in 10 CFR 20.1003, means the holder of the NRC license. In general, anyone involved in the production or use of radiation has to be licensed and regulated by the NRC for that part the operation that involves potential exposure to radiation.

Licensed material is defined in 10 CFR 20.1003, and includes all the different forms or types of radiation that NRC regulates.

LWR (Light water reactor) means any commercial nuclear reactor that uses ordinary water as a coolant and is operated for the purposes of generating electricity. All reactors in nuclear power plants in the US are light water. There are different general types of LWRs: boiling water reactors (BWRs) and pressurized water reactors (PWRs). About one third of all reactors are BWRs and two thirds PWRs.

Measurable dose means a dose greater than zero. A measurable radiation dose is a dose that is greater than 0 (zero) rem.

Megawatt is a unit of electric energy, equal to the energy from a power of 1,000,000 watts over a period of one year. The capacity of a reactor is usually described in MW.

Mode of Intake: see Exposure.

MSHA means Mine Safety and Health Administration, U.S. Department of Labor.

Nuclear safety as used in this report is defined in section 3.4.

Occupational dose means the amount of a hazard that a worker has been exposed during a defined period of time. Occupational radiation dose is defined in 10 CFR 20.1003.

Occupational safety as used in this report is defined in section 3.4.

OSH is short for occupational safety and health.

OSHA means Occupational Safety and Health Administration, US Department of Labor.

PWR means Pressurized water reactor, which is a nuclear power reactor where cold water is heated up in the reactor until it turns to steam and the steam is directed into the turbines that generate electricity.

Radiation safety as used in this report is defined in section 3.4.

REIRS means the Radiation Exposure Information and Reporting System. REIRS is maintained by NRC. Licensees of NRC are required to report all radiation dose information on all individuals that they monitor to REIRS.

REM is a measure of the amount of radiation that a person absorbs into the body from exposure to radiation. There are different ways to calculate this amount. In the metric system rem is known as *Sievert (Sv)*. One rem equals 0.01 Sv, and 1 Sv=100 rem.

SAFSTOR is method of decommissioning in which a nuclear facility is placed and maintained in a condition that allows the facility to be safely stored and subsequently decontaminated (deferred decontamination).

TEDE (Total effective dose equivalent) is defined in 10 CFR 20.1003 means the cumulative average radiation intake by a population that has been monitored for radiation.

TMI refers to Three Mile Island, and specifically its No. 2 reactor, which suffered a partial meltdown in March 1979.

Transient individual is anyone who is monitored at more than one licensed site during the calendar year. The NRC knows which individuals are transient when it gets the radiation dose records on everyone who has been monitored and enters this in REIRS.

TRC—Total Recordable Cases. This refers to a class of cases of occupational injuries and illnesses that all private employers in the U.S. are required to report to OSHA each year.

Annex 1:

Statement of Work

The contractor shall perform the following Tasks, and to the extent feasible under time and budget constraints stated later, the analyses shall cover all phases of the nuclear fuel cycle. To the extent available data allow, analyses shall be presented separately for the categories of workers engaged in each phase identified in the prior paragraph. To more closely track the BRC's areas of emphasis, the contractor should focus first on the later phases of the fuel cycle: construction of reactors, operation of reactors producing special nuclear material and/or electricity, the maintenance and decommissioning/demolition of production and high-level waste processing facilities, and the transportation, storage and disposal of used/spent fuel and associated high-level wastes. If time and budget permits, the earlier stages of the fuel cycle (mining, milling, fuel fabrication, etc.) shall be similarly analyzed. The overall goals are to understand the history and to provide the BRC a basis for comparison between the OS&H experience of today's once-through fuel cycle and future alternatives that may reduce the need for uranium mining, milling and fuel fabrication.

Task 1: Characterize OS&H risks to workers in the domestic fuel cycle

1.1 Analyze historical injury and illness data and medical findings for workers in facilities that have been and are now part of the nuclear fuel cycle in the US
The contractor shall present a summary of the most recent data on injuries and illnesses associated with work in the categories of domestic federal government and private sector nuclear fuel cycle operations identified earlier that have been and are currently operating or have ceased operations and been decommissioned (e.g., decommissioned commercial nuclear power plants, the West Valley reprocessing facility, closed uranium mines), and shall present a working-lifetime estimate of such risks. For classes of facilities where there has been no recent (since 1980) activity, such as the construction of domestic commercial nuclear power plants, the contractor shall endeavor to obtain data from the prior period of active construction and operations.

1.2 Priorities for This Task
First priority for work shall be given to reactor construction and operations and the later stages of the nuclear fuel cycle, as identified above, for both commercial and DOE facilities. After that analysis is reasonably complete, and if time and money allow, work shall be conducted on the earlier stages of the domestic nuclear fuel cycle.

Task 2: The known and potential implications of changes in the recent past of practices in both the construction and industrial sectors on the current and future OS&H experience of the workforce involved in the once-through nuclear fuel cycle, and, where possible, a comparison with the OS&H implications of alternative fuel cycles (i.e., with recycling and/or reprocessing)

> The contractor shall describe the relevant changes in American laws, regulations, standard and/or best practices, training and other related factors in both the construction and industrial sectors since 1980 until today that have already had and will continue to have a significant impact on nuclear fuel cycle OS&H experience if the US continues to rely on the once-through fuel cycle. To the extent feasible, the contractor shall also assess the OS&H implications of potential policy changes in the US approach to the back-end of the nuclear fuel cycle that could impact future workers in the domestic nuclear fuel cycle, and compare them to the status quo associated with the once-through fuel cycle.

Deliverables:

The contractor and the BRC subject matter point of contact (BRC POC) shall jointly decide how the information and analyses are presented (e.g., in single comprehensive draft and final reports or in a series of more focused draft and final reports that might be organized, for example, by stage in the fuel cycle, commercial vs. federal experience, or in some other appropriate manner.). The contractor shall deliver draft and final reports describing its approach and findings for each of the two Tasks described above in a form suitable for publishing on the BRC webpage. While the anticipation is for one report on each Task, with the agreement of the BRC POC, the data and analysis on both Tasks could be combined in a single report. No matter what the structure of the reports, the contractor shall document the source of specific data and other relevant information, and shall when appropriate include in one or more appendices the references, data summaries, and other information that supports the basic content of the report(s).

Annex 2

Annual Whole-Body Radiation Doses at Licensed Nuclear Power Facilities, 2008

Facility	State	Date of First Operation	Type	Total Number Monitored	Number w/ Measurable Dose	Total Collective TEDE (person-rem)	Average TEDE per Worker w/ Meas. Dose (Person-rem)
Arkansas 1,2	Arkansas	1974|1978	PWR	3,177	1,791	196.047	0.11
Beaver Valley, 1.2	Pennsylvania	1976|1987	PWR	2,660	991	83.394	0.084
Braidwood 1,2	Illinois	1988	PWR	3,079	1,235	103.180	0.084
Browns Ferry 1,2,3	Alabama	1973 | 74 |76	BWR	4,580	2,633	482.127	0.183
Brunswick 1,2	N. Carolina	1976 | 1974	BWR	3,940	2,546	354.212	0.139
Byron 1,2	Illinois	1985 | 1987	PWR	3,473	1,483	140.809	0.095
Callaway 1	Missouri	1984	PWR	1,945	729	45.738	0.062
Calvert Cliffs 1,2	Maryland	1974 | 1976	PWR	2,149	745	74.149	0.01
Catawba 1,2	S. Carolina	1985 | 1986	PWR	3,541	1,110	85.080	0.077
Clinton	Illinois	1987	BWR	2,991	1,381	205.086	0.149
Columbia	Washington	1984	BWR	1,653	715	54.957	0.077
Comanche Peak 1,2	Texas	1980 | 1993	PWR	2,502	1,037	168.836	0.163
Cooper Station	Nebraska	1974	BWR	2,335	1,715	359.926	0.21
Crystal River, 3	Florida	1976	PWR	1,235	282	16.110	0.057
Davis-Besse 1	Ohio	1977	PWR	2,186	985	106.603	0.108
DC Cook 1,2	Michigan	1974 | 1977	PWR	3,270	971	76.460	0.079
Diablo Canyon 1,2	California	1984|1985	PWR	4,031	2,121	235.034	0.119
Dresden 2,3	Illinois	1991| 1971	BWR	3,709	2,307	198.153	0.086
Duane Arnold	Iowa	1974	BWR	1,188	276	24.187	0.088
Farley 1,2	Alabama	1977 | 1981	PWR	1,842	669	40.833	0.061
Fermi 2	Ohio	1985	BWR	1,535	460	35.186	0.077
Fitzpatrick	New York	1974	BWR	2,037	1,430	184.772	0.129
Fort Calhoun	Nebraska	1973	PWR	1,647	839	96.155	0.115
Ginna	New York	1969	PWR	2,110	976	101.996	0.105
Grand Gulf	Mississippi	1984	BWR	2,735	1,843	167.859	0.091
Harris 1	N. Carolina	1986	PWR	1,164	192	10.356	0.054

Hatch 1,2	Georgia	1974 | 1978	BWR	2,382	1,397	189.433	0.136
Hope Creek 1	Delaware	1986	BWR	1,126	999	34.510	0.035
Indian Point 2, 3	New York	1973 | 1975	PWR	1,025	1,456	142.728	0.098
Kewaunee	Wisconsin	1973	PWR	1,599	598	92.951	0.156
LaSalle 1,2	Illinois	1982 | 1983	BWR	3,883	2,402	217.567	0.091
Limerick 1,2	Pennsylvania	1985 | 1989	BWR	3,151	1,393	176.825	0.127
McGuire 1,2	N. Carolina	1981 | 1983	PWR	3,553	1,613	165.767	0.103
Millstone 2,3	Connecticut	1975 | 1986	PWR	3,416	1,467	272.693	0.186
Monticello	Minnesota	1970	BWR	1,466	351	43.777	0.125
Nine Mile Point 1,2	New York	1974 | 1987	BWR	2,660	1,391	301.824	0.217
North Anna 1,2	Virginia	1978 | 1980	PWR	3,755	795	61.003	0.077
Oconee 1,2,3	South Carolina	1973 | 73 |74	PWR	4,513	1,924	186.335	0.097
Oyster Creek	New Jersey	1991	BWR	3,111	1,511	211.932	0.14
Palisades	Michigan	1971	PWR	1,121	272	23.478	0.086
Palo Verde 1,2,3	Arizona	1985 | 86|87	PWR	4,198	1,706	159.913	0.094
Peach Bottom 2,3	Pennsylvania	1973| 1974	BWR	3,409	1,816	212.741	0.117
Pilgrim 1	Massachusetts	1972	BWR	615	377	22.568	0.0599
Perry	Ohio	1986	BWR	1,531	528	52.058	0.099
Pilgrim 1	Massachusetts	1972	BWR	615	377	22.568	0.06
Point Beach 1,2	Wisconsin	1970 | 1973	PWR	2,336	958	144.021	0.15
Prairie Island 1,2	Minnesota	1974 | 1974	PWR	1,971	1,060	126.723	0.12
Quad Cities 1,2	Illinois	1972 | 1972	BWR	3,647	2,065	274.444	0.133
River Bend 1	Louisiana	1985	BWR	2,603	1,809	311.697	0.172
Robinson 2	South Carolina	1970	PWR	1,893	788	68.381	0.081
Salem 1,2	Delaware	1976 | 1981	PWR	3,787	3,362	328.761	0.098
San Onofre 2,3	California	1982 | 1982	PWR	3,561	1,014	125.320	0.124
Seabrook	New Hampshire	1990	PWR	2,186	1,297	74.992	0.058
Sequoyah 1,2	Tennessee	1980 | 1981	PWR	2,513	960	83.730	0.087
South Texas 1,2	Texas	1988 | 1989	PWR	2,688	1,181	187.295	0.159
St. Lucie 1,2	Florida	1976 | 1983	PWR	2,877	1,127	112.234	0.1
Summer 1	South Carolina	1982	PWR	1,880	623	49.091	0.079
Surry 1,2	Virginia	1972 | 1973	PWR	4,170	1,069	150.269	0.141
Susquehanna 1,2	Pennsylvania	1982 | 1984	BWR	3,706	1,895	192.892	0.102
Three Mile Island 1	Pennsylvania	1974	PWR	1,192	64	2.219	0.035
Turkey Point 3,4	Florida	1974 | 1973	PWR	2,850	1,067	97.357	0.091
Vermont Yankee	Vermont	1972	BWR	1,799	1,402	213.680	0.152
Vogtle 1,2	Georgia	1987	PWR	2,436	1185	137.620	0.116
Waterford 3	Louisiana	1985	PWR	2,170	1268	134.221	0.106
Watts Bar 1	Tennessee	1996	PWR	3,437	887	70.648	0.08
Wolf Creek 1	Kansas	1985	PWR	1,800	911	94.997	0.104
Total Number of Workers with Monitoring Reports				**169,324**	**79,450**		

NOTE: Browns-Ferry 1,2,3 shutdown in 1985; re-started in 1991, 1995, and 2007 respectively
Source: NRC. *Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities, 2008*, Appendix B. NUREG-0713, Vol. 30, January 2010. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0713/v30/sr0713v30.pdf [Accessed 1/13/11]

Annex 3

Nuclear Power Fuel Cycle
Potential Occupational Health Hazards

THE FRONT END

Mining:
Open pit or underground mines: Uranium, radon/radon progeny, external radiation, inhalation of uranium ore dust, other radioisotopes, heavy metals, dust, silica, and diesel exhaust particulates.

Leaching (heap or in-situ): Uranium, radon, other radioisotopes, sulfuric acid, and other leaching chemicals, cadmium, arsenic, nickel.

Environmental concerns: Contaminated groundwater, waste rock, sludge, and dust containing toxic materials, waste piles emitting radon gas and seepage water containing radioactive and toxic materials, transportation of ore to mill.

Active and inactive domestic uranium mining are located in: Alaska, Arizona, Colorado, Montana, Nebraska, Nevada, New Mexico, North Dakota, North Dakota, Oregon, South Dakota, Texas, Utah, Virginia, Washington, and Wyoming

Milling:
Hazards include: uranium, radioactive thorium, radium, radon, sulfuric acid, other leaching chemicals, selenium, lead, arsenic, iron, molybdenum, vanadium, and uranium ore concentrate or "yellow cake" (U3O8); inhalation of radon/radon progeny, uranium ore dust, uranium concentrate dust, and external radiation.

Environmental concerns: uranium mill tailings piles and ponds containing toxic and radioactive isotopes of certain elements (uranium, thorium-230, radium-226, radon-222), (uranium, thorium-230, radium-226, radon-222), heavy metals, arsenic, contaminated scrap metal from plant repairs and D&D; groundwater contamination, transportation of yellow cake from mills to conversion plants. Thorium-230 has a half-life of ~80,000 years.

As of the end of 2009, the U.S. Energy Information Administration identified one operating uranium mill in Utah, three mills in standby status in Colorado, Utah, and Wyoming, and one under development in Colorado.

Conversion:

Depending on eventual use, processes include conversion of uranium ore concentrate to:

- Uranium hexafluoride—hazards include: fluorine, hydrogen fluoride, uranium heaxfluoride (UF6), uranyl fluoride (UO2F2), inhalation of uranium concentrate dust, external radiation including neutron radiation, strong acids and alkalis, heat, fire and explosion hazards.
- Uranium oxide (UO2)—hazards include radiological and chemical hazards of UO2 including inhalation hazards, spontaneous ignition of finely divided particles (pyrophoricity).
- Natural uranium metal—hazards include radiological and chemical hazards of uranium, spontaneous ignition of finely divided particles (pyrophoricity).

Environmental concerns: transportation to enrichment plants, chemical releases, external radiation from UF6 cylinders, pyrophoricity of some forms, fire and explosion hazards.

NOTE: the only operational conversion plant in the U.S. in 2010 is Honeywell International, Inc. at Metropolis, IL, across the river from Paducah, KY. Enrichment by gas centrifuge and/or laser separation would result in transportation of uranium hexafluoride from the Honeywell plant to more distant enrichment locations including Idaho, Louisiana, and North Carolina.

Enrichment:

The only operational enrichment plant in the U.S. in 2010 is located in Paducah, KY (formerly the Paducah Gaseous Diffusion Plant [GDP] operated by the Department of Energy), currently operated by the United States Enrichment Corporation (USEC). A new plant operated by URENCO is in start-up in New Mexico.

Hazards associated with the Paducah GDP include: UF6, fluorine, hydrogen fluoride, DUF6, U238, U235, uranyl fluoride, heat, noise, nickel, radiation, uranium daughters, Freon, beryllium, uranium tetrafluoride, PCBs, chlorine trifluoride, nickel, welding fumes, magnesium fluoride, mercury, asbestos, and external gamma and neutron radiation from UF6 and DUF6 cylinders. Exposures from processing of recycled uranium included transuranics, e.g., plutonium-239, neptunium-237, technetium-99. Highly enriched uranium (HEU) from weapons programs can be down-blended for use in nuclear power reactors.

Environmental concerns: UF6 releases, transportation accidents involving multi-ton UF6 cylinders shipped from enrichment plant to domestic and international fuel fabrication plants, gamma and neutron radiation from UF6 and DUF6 cylinders.

Fuel Fabrication:

Light water reactors may use low enriched uranium (LEU) or mixed oxide (MOX). LEU is changed chemically to uranium oxide (UO2) powder, which is formed into ceramic pellets and loaded into Zircalloy fuel rods. Mixed oxide fuel contains a combination of uranium oxide (UO2) powder and plutonium oxide (PuO2). Highly enriched uranium (HEU) can be used in some reactors.

Hazards include UF6, beryllium, uranium oxide powder, external radiation, and radiation from inhalation of uranium dust for LEU plus plutonium oxide for MOX fuel, HEU. Criticality accidents releasing lethal doses of radiation are a concern if proper storage practices are not followed.

Environmental concerns: chemical and radiation releases from fabrication plants, transportation accidents involving fuel rod assemblies shipped to nuclear power plants, gamma and neutron radiation from UF6 cylinders..

Uranium fuel fabrication facilities are located in Virginia, North Carolina, South Carolina, Tennessee, and Washington.

THE BACK END

Use of Fuel:

Reactor loading with fuel, unloading spent fuel and movement to storage pools or dry casks, and plant preventive maintenance are the major activities. As of October 2010, there are 104 nuclear power reactors licensed to operate in the U.S. Hazards include radiation, beryllium, maintenance & cleaning chemicals, asbestos, tritium leaks, welding fumes, heat and steam. NRC reported in 2008 that of 169,000 individuals who were monitored in commercial nuclear plants, almost 79,500 had received a whole-body dose of radiation (47%) though, as noted in the main report, all exposures were below the occupational standard of 5 rem.

Locations of commercial nuclear power reactors can be obtained from the U.S. NRC at: http://www.nrc.gov/reactors/operating/list-power-reactor-units.html .

Interim Storage of Spent Fuel:

Spent fuel assemblies are stored temporarily in storage pools for initial decay and eventually moved to dry casks stored at or near nuclear power plants. Spent fuel contains highly radioactive fission products, isotopes of iodine, other gases, technetium, actinides, cesium, strontium, neptunium, americium; radionuclides with long half-lives, e.g., tin-126 (100,000 years), cesium-135 (2.3 million years).

Corroding spent fuel elements in storage pools pose a hazard to workers and the environment.

A complete list of licensed/operating independent spent fuel storage locations by state is available at: http://www.nrc.gov/waste/spent-fuel-storage/locations.html .

Recycling or Reprocessing:
The first and only private commercial plant in the U.S. to reprocess spent nuclear fuel was the West Valley Facility in New York which operated from 1966 to 1972.

The U.S. Department of Energy's Idaho National Laboratory Chemical Processing Plant Bldg. CPP-601, and associated Tank Farm processed spent reactor fuel to recover and recycle highly enriched uranium (HEU). Hazards identified with this work include: highly enriched uranium, beta and gamma radiation, boric acid, hydrogen fluoride, nitric acid, CrO3, CrO4, mercuric nitrate, ammonium hydroxide, aluminum nitrate, mercury, gadolinium, tributylphosphate (TBP), kerosene, methyl isobutyl ketone (hexone), uranyl nitrate, nitrates of fission products, transuranics, La140, I-131, high level liquid waste, Ru-106, cadmium sulfate, cadmium nitrate, Pu-238, Pu-239, Pu-240, Pu-242, neptunium-237, technetium-99, MEK, sulfuric acid, sodium hydroxide, asbestos, chromic acid, soda ash, chromium, fission products, activation products, cesium-137, Europium-154, strontium-90, U-235.

Uranium recycled from spent fuel contains U-232, U-233, U-236, and U-237. Thallium-208, a strong gamma emitter, is one of the decay products of U-232.

Deconversion of depleted uranium: DUF6, uranium and fluoride compounds, e.g., hydrogen fluoride, uranyl fluoride, uranium, depleted UF4 (uranium tetrafluoride)

Only one depleted uranium deconversion facility is operating in the U.S. in 2010 at an Army ordnance plant in Jonesborough, TN. DOE is constructing two deconversion plants next to the Paducah GDP (Paducah, KY) and the Portsmouth GDP (Piketon, OH) to dispose of 771,000 tons of depleted uranium oxide over the course of 15-20 years. A private firm has applied for a license to operate a deconversion facility in Hobbs, NM, which may be operational in several years.

Final Disposal of Radioactive Waste:
No U.S. disposal site exists for the 60,000+ tons of nuclear power plant spent fuel rods generated thus far in 2011. Foreign or domestic disposal sites present safe and secure transportation concerns. The quantity of spent fuel waste that would have been transported to the Yucca Mountain site (if operational) in a single year is estimated to have exceeded the total of all shipments of such waste made in the United States between 1964 and 1997.

- **High level waste (HLW):** Waste from spent fuel and liquids from reprocessing
- **Transuranic waste (TRU):** Wastes containing plutonium, americum and neptonium isotopes
- **Low level waste (LLW):** Waste from enrichment and other parts of the "front end" other than mining
- **Byproduct waste:** mill tailings and other waste from mining

Decommissioning & Demolition:
Large volumes of asbestos, radioactively contaminated metals, concrete, other building materials can result when nuclear power plants are decommissioned and demolished.

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Annex 4

Greater than Green Inspections Findings And Problems in Safety Culture

Facility	Inspection Finding > Green	Cross-cutting Safety Culture Findings for Some Part of Year				
		2001	2002	2003	2004	2005
Arkansas 1,2	1W			PIR	PIR	PIR
Beaver Valley, 1.2	2W					
Braidwood 1,2	1W					
Browns Ferry 1,2,3	-					
Brunswick 1,2	1W					
Byron 1,2	-					HP
Callaway 1	3W		PIR	PIR	HP	HP
Calvert Cliffs 1,2	1Y, 3W	PIR	PIR			
Catawba 1,2	-					
Clinton	1W					
Columbia	1Y, 1W	HP	HP	PIR, HP	PIR, HP	PIR, HP
Comanche Peak 1,2	2W					
Cooper Station	5W	PIR, HP	PIR, HP	PIR, HP	PIR, HP	PIR, HP
Crystal River 3	1W					
Davis-Besse 1	1R, 1Y, 4W	--Addressed outside ROP--				
DC Cook 1,2	3W		PIR	PIR		
Diablo Canyon 1,2	-			PIR, HP	PIR, HP	
Dresden 2,3	2W				HP	
Duane Arnold	-					HP
Farley 1,2	-					
Fermi 2	1W				HP	HP
Fitzpatrick	-	PIR				
Fort Calhoun	2W					
Ginna	1W					
Grand Gulf	-					
Harris 1	2W					
Hatch 1,2	1W					
Facility	**Inspection**	**2001**	**2002**	**2003**	**2004**	**2005**

	Finding > Green					
Hope Creek 1	2W		PIR	PIR	PIR,SCWE	PIR, SCWE
Indian Point 2, 3	1R, 1Y,2W	PIR, HP	PIR,HP	PIR, HP	PIR	PIR
Kewaunee	1Y, 4W					
LaSalle 1,2	1W	HP	HP		HP	HP
Limerick 1,2	2W					
McGuire 1,2	-					
Millstone 2,3	-	PIR, HP		PIR		
Monticello	-					
Nine Mile Point 1,2	1W			PIR		
North Anna 1,2	-					
Oconee 1,2,3	7W					
Oyster Creek	3W	PIR	HP	HP	PIR	PIR
Palisades	2W	PIR, HP	PIR	PIR		
Palo Verde 1,2,3	1Y				PIR, HP	PIR, HP
Peach Bottom 2,3	3W			PIR	PIR	
Perry	5W				PIR, HP	PIR, HP
Pilgrim 1	-					
Point Beach 1,2	3R, 1Y, 3W		PIR	PIR, HP	PIR, HP	PIR, HP
Prairie Island 1,2	1W					
Quad Cities 1,2	-		HP	HP		
River Bend 1	2W					
Robinson 2	-					
Salem 1,2	1W		PIR	PIR	PIR, SCWE	PIR, SCWE
San Onofre 2,3	-					
Seabrook	1W	PIR	PIR			
Sequoyah 1,2	1W					
South Texas 1,2	-					
St. Lucie 1,2	-					
Summer 1	-					
Surry 1,2	2W					
Susquehanna 1,2	1W					
Three Mile Island 1	2W	HP	HP	PIR	PIR	
Turkey Point 3,4	-			PIR		
Vermont Yankee	1W					
Vogtle 1,2	-		PIR	PIR		
Waterford 3	1W					
Watts Bar 1	1W					HP
Wolf Creek 1	-					

Source: Government Accountability Office. *Nuclear Regulatory Commission Oversight of Nuclear power Plants Has Improved but Refinements are Needed.* GAO-06-129. http://www.gao.gov/new/items/d061029.pdf

Plants without Inspection Findings or Cross-cutting Findings highlighted

Explanation of Inspection Finding: These are rated as white, yellow and red in order of significance.

Legend of Cross-Cutting Findings:

HP = human performance; PIR = Problem identification and resolution

SCWE = Safety conscious work environment

Annex 5

White, Yellow and Red Inspection Findings for Nuclear Power Plants, 2000-2010

Facility	Type	Yr Lic	Inspection Finding										
			2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Arkansas 1,2	PWR	1974|1978					1W						
Beaver Valley, 1.2	PWR	1976|1987			1W	1W			1W				
Braidwood 1,2	PWR	1988			1W				1W				1W
Browns Ferry 1,2,3	BWR	1973 | 74 |76											1W|1Y
Brunswick 1,2	BWR	1976 | 1974					1W			1W			1W
Byron 1,2	PWR	1985 | 1987									1W		
Callaway 1	PWR	1984		2W	1W	1W							
Calvert Cliffs 1,2	PWR	1974 | 1976		1Y	2W				1W			1W	1W
Catawba 1,2	PWR	1985 | 1986											
Clinton	BWR	1987		1W					1W				
Columbia Gen. Sta.	BWR	1984		1Y|1W									
Comanche Peak 1,2	PWR	1980 | 1993			1W		1W				1W		
Cook 1,2	PWR	1974			2W		1W						
Cooper Station	BWR	1976		1W	2W		1W			1W	2W		
Crystal River, 3	PWR	1977						1W					
Davis-Besse 1	PWR	1974 | 1977				1W|1Y	1W	1R|1W					1W
Diablo Canyon 1,2	PWR	1984|1985											
Dresden 2,3	BWR	1991| 1971				1W						1W	
Duane Arnold	BWR	1974										1W	
Farley 1,2	PWR	1977 | 1981								1Y|1W	1W	1W	
Fermi 2	BWR	1985		1W									
Fitzpatrick	BWR	1974		1W									
Fort Calhoun	PWR	1973			1W			1W		2W			1Y
Ginna	PWR	1969			1W							2W	
Grand Gulf	BWR	1984											
Harris 1	PWR	1986		1W	2W								
Hatch 1,2	BWR	1974 | 1978						1W				1W	1W
Hope Creek 1	BWR	1986					1W						
Indian Point 2, 3	PWR	1973 | 1975	1R|1Y 1W		1W			1W					
Kewaunee	PWR	1973		1W	1W			1Y|2W		1Y	1W		

Facility	Type	Year Lic.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
LaSalle 1,2	BWR	1982 | 1983						1W					
Limerick 1,2	BWR	1985 | 1989			1W								
McGuire 1,2	PWR	1981 | 1983									1W		
Millstone 2,3	PWR	1975 | 1986	1W										
Monticello	BWR	1970											
Nine Mile Point 1,2	BWR	1974 | 1987			1W					1W		1W	
North Anna 1,2	PWR	1978 | 1980											
Oconee 1,2,3	PWR	1973 | 73 |74	1W	1W	2W	2W	1W		1W	1W		1W	1Y|1W
Oyster Creek	BWR	1991					1W	2W					
Palisades	PWR	1971		1W								1W	1W
Palo Verde 1,2,3	PWR	1985 | 86 |87						1Y		1W			
Peach Bottom 2,3	BWR	1973| 1974	1W	1W	1W		1W						
Perry	BWR	1970				1W	3W	1W					
Pilgrim 1	BWR	1972											
Point Beach 1,2	PWR	1986			1R|1W	2R		1W					
Prairie Island 1,2	PWR	1972		1W								3W	
Quad Cities 1,2	BWR	1970 | 1973								1W			
River Bend 1	BWR	1974 | 1974			1W	1W							
Robinson 2	PWR	1972 | 1972											1W
Salem 1,2	PWR	1985	1W			1W							
San Onofre 2,3	PWR	1970									1W		
Seabrook	PWR	1976 | 1981		1W								1W	
Sequoyah 1,2	PWR	1982 | 1982						1W					
South Texas 1,2	PWR	1990											
St. Lucie 1,2	PWR	1980 | 1981											1Y
Summer 1	PWR	1988 | 1989	1W						1W				
Surry 1,2	PWR	1976 | 1983		1W			1W		1W				
Susquehanna 1,2	BWR	1982		2W									1W
Three Mile Island 1	PWR	1972 | 1973		1W				1W					
Turkey Point 3,4	PWR	1982 | 1984							2W				1W
Vermont Yankee	BWR	1974						1W	1W				
Vogtle 1,2	PWR	1974 | 1973							1W				
Waterford 3	PWR	1972					1W						1W
Watts Bar 1	PWR	1987						1W	1W				
Wolf Creek 1	PWR	1985											

Inspection Findings are rated as green (no finding) and white (outside normal parameters but not low significance), yellow (moderate significance) and red (high significance).
Plants with no inspection findings are highlighted.

Annex 6

Remarks before the
NATIONAL COMMISSION on the BP DEEPWATER HORIZON
OIL SPILL and OFFSHORE DRILLING
August 25, 2010
The Role of the Institute of Nuclear Power Operations
In Self-Regulation of the Commercial Nuclear Power Industry
James O. Ellis, Jr.,
INPO President and Chief Executive Officer

Good afternoon.

I am Jim Ellis, the President and Chief Executive Officer of the Institute of Nuclear Power Operations, more commonly known as INPO. With me today is Dr. Zack Pate, who joined INPO in 1980, shortly after it was founded, and served as the Institute's CEO for many of its formative years from 1984 to 1998. Also with me is Lee Gard, my staff assistant.

I am pleased to be here to provide remarks to this Commission. Materials describing INPO's organization, programs, and activities were sent in advance – and I will not review those items today.

I am here today to address self-regulation in a high technology industry. I will first talk briefly about the founding of INPO and then I will discuss the key factors that have enabled INPO and self-regulation to effectively help improve safety in the commercial nuclear power industry.

Before proceeding, I want to acknowledge the eleven crew members of the Deepwater Horizon who died during the accident and express our condolences to their families, friends and colleagues. It is vital that the lessons learned and the actions to be taken as a result of this Commission's work and other investigations help prevent a repeat of such accidents.

THREE MILE ISLAND AND INPO'S FOUNDING

The founding of INPO and the beginning of self-regulation in the U.S. nuclear power industry came after the industry suffered its most serious accident – a partial meltdown of the Three Mile Island Unit 2 reactor core in March 1979.

The event quickly became widely known as TMI, and the image of the plant's cooling towers is one that has remained with the industry even today. And while there were no deaths, injuries or environmental damage caused by TMI, it did generate concerns and reactions similar to those being addressed in the aftermath of the Deepwater Horizon accident – including questions about the overall safety and integrity of the industry, a fear of the unknown with uncertainty about the causes and ultimate consequences, and a severe loss of public trust and confidence.

At the time of the TMI accident, the United States had 70 commercial nuclear power reactors in operation, with an operating record of more than 400 reactor-years of service without a major event impacting the public. Following TMI, nearly 100 nuclear power plants either planned or under construction were cancelled and no new permits or licenses for construction have been issued in the U.S. in 32 years.

The Three Mile Island accident was caused by a combination of human error, equipment and design problems. More broadly, the event showed weaknesses in the industry's approach to operational standards, training, the sharing and use of industry operating experience, and emergency response.

Recognizing the need for prompt and comprehensive action, key leaders in the commercial nuclear power industry moved quickly to form INPO. In fact, we were already incorporated by the time the report of the President's Commission on the Accident at Three Mile Island was issued in October 1979, seven months after the event. Recognizing the need for credible and authoritative leadership, the industry selected retired Vice Admiral Eugene P. Wilkinson as the Institute's first President and CEO. He had been Commanding Officer of USS Nautilus, the first nuclear powered vessel, and was a stalwart of the early Navy nuclear program.

Though both INPO and the industry that it serves have evolved over the years, the primary recommendations from that effort, known as the Kemeny Commission, formed the basis for INPO's cornerstone programs, which remain in place today. The four cornerstone programs – Evaluations, Training, Analysis, and Assistance – are described in detail in the materials provided in advance.

INPO is a nongovernmental corporation that operates on a not-for-profit basis. We operate independently of the industry – and we avoid any conflicts of interest. We, specifically, legally and philosophically, cannot act as an advocate for the nuclear power industry – that is not our role. Our role is to help the nuclear power industry set and achieve the highest standards of safety and excellence in operational performance.

Since our inception, all organizations that have direct responsibility to operate or construct commercial nuclear power plants in the United States have maintained continuous membership in INPO. Currently, we have 26 members that operate 104 nuclear power reactors in 31 states. In addition, many international groups and supplier organizations are voluntary participants in INPO.

We have a staff of about 400 nuclear power professionals, which includes about 60 employees on loan to us from member utilities. Our annual budget is $99 million, most of which comes from member and participant dues.

KEY FACTORS IN INPO'S EFFECTIVENESS

I'll now move on to discuss what we believe are the five key factors that have enabled INPO and self-regulation to be effective in fostering the highest standards of nuclear power safety at our nation's commercial nuclear plants.

The five key factors are: Chief Executive Officer (CEO) engagement, a nuclear power safety focus, support from the nuclear power industry, accountability, and independence.

CEO Engagement – gaining the support and personal involvement of the member company chief executive officers – was a fundamental element in the founding of INPO.
From the beginning, INPO's Board of Directors has been comprised of member CEOs and other senior utility executives. Mayo Shattuck, Chairman and CEO of Constellation Energy Group, is our current Chairman, and all of our other board members are CEOs or Presidents of the nuclear operating company.

We have found that working directly with CEOs is vital to maintaining industry support and responsiveness to our safety mission and initiatives. For example, we provide CEOs personally, in the presence of their line management, with detailed briefings of every evaluation conducted at their nuclear power plants.

We also communicate with and send requests for action on operational matters directly to CEOs. Earlier this summer, for example, I sent every CEO a letter that described a dissatisfying trend in recent nuclear power plant operational events, and asked them to coordinate with their management team and provide me personally with specific actions and response.

Every CEO also participates personally in the INPO annual conference, which focuses on nuclear safety, and during which operational events and nuclear power plant ratings assigned by INPO are discussed candidly with them.

Nuclear Safety Focus. The second key factor I will discuss is maintaining a Nuclear Safety Focus. INPO's mission, which has not wavered since its founding, is to promote the highest levels of safety and reliability -- to promote excellence -- in the operation of commercial nuclear power plants. The distinction of promoting excellence, rather than regulatory compliance, is fundamental to INPO's role in raising nuclear power safety performance.

Over the years, there have been many suggestions and requests for INPO to become involved in a variety of new issues, or with different stakeholders. And although each such endeavor may have provided some benefit to the nuclear power industry, they also would have diluted the attention and resources placed on our mission of excellence in nuclear power safety.

In the end, nuclear power safety is why we exist, and it is always through the lens of improving nuclear power safety that we examine any potential new activities or changes in the scope of current efforts.

Effective self-regulation. The third key factor in effective self-regulation and improving nuclear power safety has been the Support from the Industry. The nuclear power industry understands and has accepted that a key part of self-regulation is subjecting its plants to on-site peer reviews, which we call plant evaluations. The evaluations are intrusive, comprehensive, and performance-based, and their importance cannot be overstated. Since 1980, we have conducted nearly 1,200 plant evaluations, an average of more than 16 at every nuclear power plant, inspecting them, on average, once every two years.

The nuclear power industry participated in developing standards of excellence, and then committed to meeting the standards. The strong industry participation has continued, and it has played a key role in the numerous advanced standards and guidelines developed over the years, but the leadership of INPO, supported by our Board of Directors, makes the final decision on expected levels of performance.

Although INPO programs today are part of the fabric of the nuclear power industry, gaining wide acceptance in the early years was not easy. Some nuclear power plants questioned the technical credibility of the plant evaluation teams and were skeptical about the value of INPO evaluations. We addressed these issues and overcame the challenges by continuing to hire competent and operationally experienced staff, many of whom had valuable experience as managers in commercial or Navy nuclear power plants. And we continued to deliver plant evaluation reports that identified important safety and reliability issues that – when corrected – improved safety and reliability, thereby improving performance.

Industry Support. In addition to its acceptance and welcoming of INPO activities and programs, the nuclear power industry supports and participates in self-regulation through INPO with involvement in advisory groups, industry task forces and working groups, and by loaning employees to INPO to serve in a variety of functions, including as peer evaluators.

The support provides benefits to the individual organizations, as well as to the entire nuclear power industry. By serving as peer evaluators for example, professionals from individual utilities not only provide added and current experience to the INPO evaluation team, they also gain insight into nuclear power industry best practices and take that knowledge back to their own companies.

Through their participation peer evaluators also acquire a first-hand understanding of INPO's role and the importance of industry self-regulation. Over the years, more than 13,000 industry peer evaluators have served on INPO teams.

Accountability. The fourth key factor is Accountability. Self-regulation cannot be effective without an effective means of enforcement. During INPO's first five years, we completed a few rounds of evaluations at every nuclear power plant, and it was clear that not all members were responsive to INPO's findings.

To improve our effectiveness, we had a group of senior industry executives – led by Lee Sillin, former chairman of Northeast Utilities – do a broad self-assessment of INPO activities. Their recommendations included toughening the language in INPO evaluation reports, establishing a formal process for assessing the evaluation results, and assigning a numerical performance rating based on the assessment.

Doing that enabled us to exert more authority and demand more accountability. It also helped build our credibility with the nuclear power industry and with the regulator.
In addition, we changed our policy for distributing INPO evaluation reports. We made the evaluation reports confidential, distributed only to the utility whose nuclear power plant was evaluated. This change – from our initial policy of distributing all evaluation reports industry-wide – provided for more open and candid interactions and discussions of problems or areas for improvement. The confidentiality of reports has proven to be an important aspect of performance improvement and nuclear safety.

Sanctions can come in various forms. Although INPO does not have the statutory standing to shut down an operating plant, we, on several occasions over our first 15 years, exerted pressure that influenced nuclear power plant operators to shut down or delay starting up until specific safety issues we raised were properly addressed.

We also take formal follow-up actions when a plant exhibits a lack of responsiveness or chronically poor performance. In one notable case, a company's board of directors made changes in its executive leadership in response to our escalating concerns about their corporate management's lack of responsiveness. There have been other situations where companies have been unsuccessful in improving chronic low performance at their nuclear power plants, and – through INPO escalation and pressure – changes were made from the top down. In all these cases, our actions were taken with the full support of the INPO Board and the broader industry. It is this peer pressure that is perhaps INPO's most effective tool for driving real change.

Another incentive for nuclear power plants to perform well comes from the industry's collective insurance company, also known as Nuclear Electric Insurance Limited, or NEIL. After the TMI accident, all nuclear power plants were required to carry insurance through NEIL. NEIL, in turn, requires INPO membership as a condition of insurability, and it uses INPO plant evaluation ratings as a factor in setting insurance premiums.

Independence. The fifth key factor is Independence. For INPO to be successful in its self-regulation role, we must be a part of the nuclear power industry and a useful resource. But at the same time, we must remain independent and work to high standards.

In particular, we need to be independent from any one company or nuclear power plant. We accomplish this in the institutionalized ways in which we select team members and distinguish clearly between our evaluative role and the many other collaborative interactions and activities with our members.

Our mission is largely independent from the regulator – the Nuclear Regulatory Commission – but it is also complementary in that both organizations focus on nuclear safety. Over the years, the NRC has formally endorsed selected INPO programs as a satisfactory means for nuclear power plant operators to meet certain regulatory requirements. And INPO has provided the NRC with regular updates and communications on topics of mutual interest related to improving performance in the industry.

Results

Through its 30-plus-year history, INPO has continued to raise the bar for nuclear power plant safety and performance and has been a catalyst for action on important issues.
Since the founding of INPO and the start of self-regulation in the nuclear power industry, there have been significant performance improvements in essentially every measure of safety and reliability.

For example, in the early 1980s, the typical nuclear power plant had a capacity factor of 63 percent. Capacity factor is the actual amount of electricity generated by a plant divided by the amount it could have generated if it was operating continually at full capacity. The typical plant also experienced seven automatic shutdowns per year. And it had a collective radiation exposure that – although it met regulatory and health requirements – we felt could be significantly reduced.

Today, and throughout this past decade, the typical nuclear power plant now has a capacity factor above 91 percent, with zero automatic shutdowns per year, and occupational radiation exposure about six times lower than in the 1980s. In addition, the number and severity of operational events at nuclear power plants has dramatically improved since then.

Self-regulation, however, is not a perfect process. Over the last thirty years we occasionally find that – even with high industry standards, regulatory oversight, self-regulation and INPO – a series of errors or omissions can align to produce an unexpected major operational event or declining trend in industry performance. This reality demands constant vigilance.

In response to these issues, INPO, with industry support, conducts periodic critical self-assessments of our own performance, and we have, as a result, implemented many changes to our practices. As an example, in recent years we have significantly expanded our approach to dealing with organizational safety culture.

As industry programs have matured over the decades, the nature of issues often has become more subtle, making it more challenging to observe and quantify. So in order to maintain effectiveness, our evaluation process and other cornerstone activities must continue to evolve and improve.

Today, we often engage plants in discussing difficult issues such as risk assessment and risk management, operational decision-making, long-term equipment strategies, leadership capability and development, safety culture, and corporate governance and oversight.

Summary

In summary, we believe that INPO and self-regulation in the nuclear power industry represent a substantial and successful effort undertaken by a high-technology industry to raise its safety standards and performance levels.

We believe self-regulation has proven to work effectively in the nuclear power industry. And we also believe the key factors to successful self regulation have been and continue to be CEO engagement, a nuclear power safety focus, industry support, accountability, and independence.

Thank you for allowing me to speak before the Commission. I would be happy to answer questions.

The Study Team

Dr. Knut Ringen was the study director. He is a principal with Stoneturn Consultants in Seattle, specializing in environment, safety and health, risk management, workers' compensation and group health insurance. He is also Principal Investigator of the Building Trades National Medical Screening Program, which is funded by the Department of Energy to determine if construction workers who been employed in defense nuclear facilities are at significant risk for occupational disease. He was executive director of the Laborers' Health and Safety Fund of North America 1987-92, and executive director, The Center to Protect Workers' Rights, 1992-97 (now CPWR: The Center for Construction Research and Training), and has since then served as its senior science advisor. He has also worked as a study director at the National Academies and a special expert in occupational cancer control at the National Cancer Institute. It has conducted 25,000 examinations of workers and is the largest medical study of older construction workers in the U.S. He has served on many national expert committees. He was Chairman, DOL/OSHA Advisory Committee on Construction Safety and Health from 1993 to 1997. He is currently a member of the National Academies' Committee on Personal Protective Equipment. He is chairman of the Scientific Committee on Occupational Health in the Construction Industry, International Commission on Occupational Health (ICOH); and Vice President and Member of the Board of the Construction Section of the International Social Security Association (ISSA). He is a member of the European Academy of Sciences and Arts and the Collegium Ramazzini. He received the Doctor of Public Health degree from Johns Hopkins University for his research on the development of health policy. He also holds a Master of Hospital Administration degree from the Medical College of Virginia and a Master of Public Health degree from Johns Hopkins University.

Jacky Randall was the lead on understanding the regulatory system. She is a principal with Stoneturn Consultants in Seattle. She has more than 30 years of experience in the field of health and environmental policy. She has served as policy coordinator in the Office of the Secretary of DHHS and in senior legislative liaison and policy positions in the National Institute of Environmental Health Sciences and the National Institute for Occupational Safety and Health. Before starting STC she worked as the environmental health specialist in a major Washington, DC law firm. She has significant experience in several major policy issues, including Three Mile Island, Agent Orange, Superfund, cleanup of many of the major national hazardous waste sites, including Love Canal, several mining sites, the Brunswick, GA Superfund site, and the South Philadelphia Refinery site. She has a bachelor’s degree (magna cum laude) from the University of Washington in Chinese and political science, and was elected to Phi Beta Kappa. She also has two years of specialized graduate studies in law from the Georgetown University Law Center.

William McGowan was our researcher, especially on the nuclear fuel cycle. He has more than 40 years of experience in occupational safety and health as an administrator, researcher, safety engineer reviewing construction plans for code compliance, and technical writer at the University of Cincinnati following active duty military service in the US Army Ordnance Corps as a commissioned officer in a nuclear weapons unit. He has worked on various projects, including a US Department of Energy (DOE) funded research program that identified radiologic and chemical exposure hazards to construction workers at many of the DOE nuclear weapons research and production sites, and provided medical screening exams via the Former Worker Program to detect work-related diseases.

Jim Byers was the lead on labor-management practices and also editor of the report. He is president of Millian Byers Associates. Millian Byers has consulted on policy issues including energy, health care, environmental performance, investment and employment, sustainable development and transportation. Mr. Byers has 30 years of experience in policy issue management and communications. His areas of expertise include coalition building, labor-management relations, dialogue facilitation and issue management. Previously, Mr. Byers was a senior associate with the Washington political consulting firm of Walker / Free Associates. Before beginning his career in policy work, Mr. Byers worked for the National Broadcasting Company in New York and Washington, D.C. in business management and on-air technical operations, and for Doubleday & Company publishers in New York.

THE BLUE RIBBON COMMISSION ON AMERICA'S NUCLEAR FUTURE

In January 2010, the Secretary of Energy, acting at the direction of the President, established the Blue Ribbon Commission on America's Nuclear Future to conduct a comprehensive review of policies for managing the back end of the nuclear fuel cycle, including all alternatives for the storage, processing, and disposal of civilian and defense used nuclear fuel, high-level waste, and materials derived from nuclear activities. Criteria for evaluation should include cost, safety, resource utilization and sustainability, and the promotion of nuclear nonproliferation and counter-terrorism goals.

Members:

Lee Hamilton, Co-Chair, Director of The Center on Congress at Indiana University; former Member, U.S. House of Representatives (D-IN)

Brent Scowcroft, Co-Chair, President, The Scowcroft Group; former National Security Advisor

Mark Ayers, President, Building and Construction Trades Department, AFL-CIO

Vicky Bailey, Former Commissioner, Federal Energy Regulatory Commission; Former IN PUC Commissioner; Former Department of Energy Assistant Secretary for Policy and International Affairs

Albert Carnesale, Chancellor Emeritus and Professor, UCLA

Pete V. Domenici, Senior Fellow, Bipartisan Policy Center; former U.S. Senator (R-NM)

Susan Eisenhower, President, Eisenhower Group, Inc.

Chuck Hagel, Former U.S. Senator (R-NE)

Jonathan Lash, President, World Resources Institute

Allison Macfarlane, Associate Professor of Environmental Science and Policy, George Mason University

Richard A. Meserve, President, Carnegie Institution for Science; former Chairman, U.S. Nuclear Regulatory Commission

Ernie Moniz, Professor of Physics and Cecil & Ida Green Distinguished Professor, Massachusetts Institute of Technology

Per Peterson, Professor and Chair, Department of Nuclear Engineering, University of California - Berkeley

John Rowe, Chairman and Chief Executive Officer, Exelon Corporation

Phil Sharp, President, Resources for the Future