Safe Management of Nuclear Waste and Used Nuclear Fuel

(March 2005)

Introduction

This WNA Position Statement summarises the worldwide nuclear industry's record, progress and plans in safely managing nuclear waste and used nuclear fuel. The global industry's safe waste management practices cover the entire nuclear fuel-cycle, from the mining of uranium to the long-term disposal of end products from nuclear power reactors.

The Statement's aim is to provide, in clear and accurate terms, the nuclear industry's "story" on a crucially important subject often clouded by misinformation.

Inevitably, each country and each company employs a management strategy appropriate to a specific national and technical context. This Position Statement reflects a confident industry consensus that a common dedication to sound practices throughout the nuclear industry worldwide is continuing to enhance an already robust global record of safe management of nuclear waste and used nuclear fuel.

This text focuses solely on modern civil programmes of nuclear-electricity generation. It does not deal with the substantial quantities of waste from military or early civil nuclear programmes. These wastes fall into the category of "legacy activities" and are generally accepted as a responsibility of national governments.

The clean-up of wastes resulting from "legacy activities" should not be confused with the limited volume of end products that are routinely produced and safely managed by today's nuclear energy industry.

On the significant subject of "Decommissioning of Nuclear Facilities", which is integral to modern civil nuclear power programmes, the WNA will offer a separate Position Statement covering the industry's safe management of nuclear waste in this context.

Essential Messages

Nuclear power is a remarkably clean technology precisely because of its energy intensity. By producing huge quantities of energy from small quantities of nuclear fuel, nuclear power creates correspondingly small amounts of nuclear waste and used nuclear fuel.

Once generated, these end products become, by their very nature, less radioactive over time, ultimately returning to levels of radioactivity found in Nature. Much of this radioactivity dissipates within a few decades of its creation. Some of the radioactivity is less active and thus decays more slowly, requiring that certain materials be isolated for tens of thousands of years.

Most of the radioactivity that results from the consumption of nuclear fuel in power reactors is kept concentrated in very small volumes. This highly radioactive material is categorised as "used nuclear fuel" (UNF) or "high level waste" (HLW). Because UNF, if it is reprocessed, is the source of HLW, we hereafter use the term "UNF-HLW". This material holds about 99% of the total radioactivity content - but only 1% of the total volume - of the end products from a nuclear reactor.

The corollary is that the large bulk of nuclear waste from a nuclear reactor - some 99% of the volume - contains only 1% of the radioactivity. Most of this volume is "low level waste" (LLW); it consists of clothing, rags, and other materials that have become very slightly radioactive but have not had contact with the nuclear reactor process. The remainder is "intermediate level waste" (ILW); it consists of (a) materials such as filters and resins that have been in closer contact with the nuclear reactor process; and (b) materials such as mortar that are added to stabilise these wastes. This ILW tends to decay rapidly to become LLW and can then be treated as such.

Nuclear fuel facilities also produce some effluents and emissions containing very low levels of radioactivity. These are discharged into the environment, but only after being treated, controlled and monitored in accordance with strict standards and regulations. Human health safety and environmental protection are paramount.

Facilities that play a role in manufacturing nuclear fuel also generate end products that contain very low levels of radioactivity. At the front end of the cycle, uranium mining and milling generate large volumes of by-products called "tailings". At a later stage, when uranium is enriched, the associated by-product is "depleted uranium" (because it now lacks natural levels of the fissile uranium isotope). Tailings, which are classified as LLW, and depleted uranium are treated in strict accordance with the human safety and environmental standards applicable to such materials.

Overall, the nuclear industry takes care of all of its nuclear wastes and used nuclear fuel. From point of origin to disposal, nuclear wastes and UNF are safely controlled and managed under the oversight of independent regulators and in accordance with strict standards and regulations.

Through the International Atomic Energy Agency (IAEA), national authorities have cooperated to create a global framework for the control and management of UNF and nuclear waste. Much of this work is embodied in the "Joint Convention on the Safety of Spent [Used] Fuel Management and on the Safety of Radioactive Waste Management". As a formal obligation equivalent to a multinational treaty, the Joint Convention prescribes agreed principles and requirements that are implemented by national nuclear regulatory authorities in signatory States. The IAEA serves as a secretariat for this international system of safe management.

Competent national authorities act in the context of the Joint Convention - for example, in carefully evaluating proposed activities that can generate nuclear waste and UNF. To gain approval, such activities must meet well-established standards and thereafter are continually subject to independent inspection and review.

A prime example of such standards is the dose limits that are set to control the radiation exposure of workers and the public. Nuclear industry operations in each country must comply with these dose limits during the management of nuclear waste and UNF. In actual practice, the combined radiation exposure - to workers and the public - that arises from the industry's management of these materials is well below the dose limits set by competent authorities. In fact, public exposure to the nuclear industry's sources of radiation represents a tiny fraction of the normal exposure received from omnipresent natural background radiation. It is widely accepted that meeting this standard and thereby protecting human health will ipso facto avoid adverse environmental consequences.

Within this robust regulatory framework, the nuclear industry continues to build on its success in accounting for nuclear waste and UNF, in concentrating nuclear waste, in confining nuclear waste and UNF, and in minimising its already-small levels of radioactive discharge into the environment. Particularly notable improvements have been made at nuclear power reactors in reducing the volume of end products through a combination of fuel consumption efficiency, waste segregation and decontamination, and waste compaction.

For LLW, disposal facilities are already operational in most countries with major nuclear programmes. Safe disposal of tailings from mining and milling and safe storage of depleted uranium are also an operational reality.

For UNF-HLW, the nuclear industry operates according to equally well-established standards and procedures.

As a basic step in handling used nuclear fuel, plant operators use interim storage facilities - usually on-site - that are designed to ensure a high degree of human safety and environmental protection while levels of radioactivity begin to decay. This interim storage occurs first in special cooling ponds. During this phase, the radioactivity of the recently used fuel dissipates significantly in a relatively short period of time (e.g., 5-10 years).

Some countries have dealt with UNF as a waste, and have chosen to condition UNF - that is, to prepare and package it directly - for safe storage in dry, specially engineered containers awaiting long-term disposal.

Other countries have chosen instead to "reprocess" UNF, thereby recovering the remaining energy value in the UNF. Reprocessing leaves as waste a combination of HLW and slow-decaying ILW, the combined volume of which is reduced from the original UNF volume by more than 75%. This reduced waste volume is also stored in a dry mode, in specially designed canisters ready for long-term disposal.

Both direct disposal of UNF and the disposal of HLW and ILW after reprocessing are safe long-term methodologies that confine the materials in a highly stable and durable form.

What remains is the question of the facilities to be used for disposing of conditioned UNF-HLW and ILW. For these materials, "deep geological repositories" have now achieved strong scientific validation and international support as a sound means of safe long-term disposal.

Deep geological repositories involve placing the most highly radioactive materials in sealed containers within engineered vaults in carefully selected geological formations located deep underground. This method of disposal offers an assured means to isolate UNF-HLW and ILW over time periods sufficiently long to preclude any adverse impact on life on the Earth's surface. Repository plans generally allow for retrieval of nuclear waste, at least for an extended period of time. But the designs also provide for safe isolation even without human management.

In several countries, deep geological repositories are being developed using extensive procedures of technical evaluation and public consultation. The careful application of this validated disposal technique offers a practical method by which we in this generation can derive the benefits of nuclear technology while fulfilling our moral and environmental responsibilities to the next generation.

Progress in creating sites for deep geological repositories varies from place to place, and in some countries progress has notably lagged due to public controversy. The identification of sites and the development of repositories inherently involve a political process that depends on winning broader public support. For its part, the nuclear industry has made considerable progress in managing nuclear waste and used nuclear fuel and in developing plans for safe long-term disposal.

In light of the demonstrated technical feasibility of deep geological repositories, the challenge of long-term disposal should not inhibit national decisions to construct new nuclear power reactors.

In contrast to common perception, the cost of managing and disposing of nuclear waste and UNF represents a very small percentage of the overall cost of producing nuclear energy.

In most countries, nuclear power companies are now required, in selling electricity to consumers, to make relevant financial provisions to cover the full costs of safely managing nuclear waste and UNF. These costs, which include disposal, represent a few percent of the total cost of nuclear power generation as reflected in the price of electricity.

Thus, the costs of responsible management of nuclear waste and UNF are being fully met by present-day consumers of nuclear-generated electricity, not passed on to taxpayers or to future generations. Assuming adequate political will, these accumulating payments can now be used to fund safe, available, and environmentally sound disposal options.

Due to strong international safety standards, sound management of reactor operations and nuclear materials, and continuing technological progress in handling nuclear wastes and used fuel, the global nuclear industry today has essentially no adverse impact on human health or the global environment, and this will remain true even as the nuclear industry expands worldwide.

Summary

The safe management of nuclear waste and used nuclear fuel is a widespread, well-demonstrated reality. This strong safety record reflects a high degree of nuclear industry expertise and of industry responsibility toward the well-being of current and future generations. Accumulating experience and knowledge will only reinforce this already robust safety record.

The current generation of humankind must not abdicate its duty to employ available, affordable and scientifically reliable means to meet its responsibility for disposing safely of nuclear waste and used nuclear fuel. Continued development of deep geological repositories and their operation beginning in this decade is essential if this responsibility is to be met.

The nuclear industry has demonstrated that it accepts the management responsibility for nuclear waste and used nuclear fuel as a fundamental duty and is prepared to fulfil its obligation with professional dedication and technological skill.

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Annex A

A Broader Perspective on Nuclear Waste and Used Nuclear Fuel

The following analysis places the safe management of nuclear waste and used nuclear fuel into the overall case for nuclear energy:

NUCLEAR POWER IS NOW WIDELY RECOGNISED AS ESSENTIAL IN SOUND ENERGY PLANNING

As the rapid expansion of global energy demand brings fossil fuel reserves under increasing supply and price pressure, and as nations intensify their efforts to mitigate the environmental damage from fossil fuel combustion, national planners are focussing increasingly on nuclear power as a means of achieving multiple goals: energy independence, price predictability, and clean air.

Nuclear power is today the one proven technology able to produce energy cleanly and safely on the massive, sharply expanding scale that is needed to meet - and to reconcile - world energy and environmental needs. Other clean-energy technologies have an important role to play, but renewables still face major questions as to their affordable and potential for large-scale use, particularly as key renewables such as wind and solar provide energy only intermittently.

From a national perspective, nuclear power also affords an excellent means of diversifying energy sources, providing base-load electricity cleanly and reliably while reducing vulnerability to sharp price fluctuations and crippling disruptions in energy supply.

At present, nations representing two-thirds of world population use nuclear power to make 16% of the world's electricity. Both the number of nations using nuclear power and also the intensity of use within many of those nations can be expected to increase. In key countries such as China and India, which together comprised some 40% of world population, construction and use of nuclear power will increase quite sharply.

Significantly, nations that once considered abandoning nuclear power are reconsidering, and several large countries nations without nuclear power - including Poland, Vietnam, Turkey, and Indonesia - are now developing plans to introduce it. Increasingly, nuclear power is recognised as a central element in any well-balanced energy strategy on both a national and global level.

NUCLEAR POWER IS CLEAN

Whereas the combustion of fossil fuels - coal, oil and natural gas - releases atmospheric emissions of carbon dioxide and other pollutants that are widely understood to be major causes of global warming and acid rain, nuclear fuel consumed in power reactors does not produce any such emissions. Consequently, nuclear power plays an increasing role in many nations' plans to mitigate air pollution and global warming while meeting future energy needs.

Nuclear power is a remarkably clean technology precisely because of its energy intensity. By producing huge quantities of energy from small quantities of fuel, nuclear power creates correspondingly small amounts of waste and used nuclear fuel. These end products are effectively contained and safely managed.

The effluents and emissions discharged from a nuclear reactor (which result, for example, from cleaning and maintenance activities) are carefully monitored, under strict regulations, to ensure that these releases have no adverse impact on human health or the environment.

In comparison, fossil fuels generate enormous quantities of waste, many of which are freely released into the environment. Some of this waste - notably, coal ash - is often simply buried in landfill sites, even though it is toxic and slightly radioactive. Other fossil waste, such as sulphur dioxide, is normally removed from flue gas at significant expense. But even larger quantities of fossil waste are not managed at all but simply dispersed into the atmosphere.

The allocation of costs is similarly disproportionate as between nuclear waste and fossil waste. In the nuclear industry, the cost of safely managing nuclear wastes and used nuclear fuel is factored into the bills paid by consumers of nuclear-generated electricity. In contrast, when fossil fuels emit huge volumes of pollutants into the atmosphere, the costs are borne by society as a whole in the form of worldwide pollution-induced illnesses and a degraded global environment.

In order to gain an accurate perspective on the amount of radiation emitted by the nuclear industry, it is useful to compare the radiation exposure arising from nuclear industry activities with the levels of radiation to be found in Nature. Radioactivity occurs naturally in soils and rocks, in the atmosphere, and even in the human body.

Even for people in close proximity to nuclear industry sources, exposure from these industry sources equals no more than a few percent of the normal exposure they receive from omnipresent natural background radiation. For the vast majority of people elsewhere - i.e., people who do not live near nuclear industry sources of radiation - their personal exposure from nuclear industry sources is well under one percent of natural background radiation.

People are also exposed to radioactivity by many industrial activities outside the nuclear industry. Examples of these other sources of radiation are the production of oil and gas, the combustion of coal, the production and use of phosphate fertiliser, the production of titanium pigment for paint, and the treatment of wastewater.

Such common non-nuclear activities are a source of very low exposures to radiation comparable with the exposure resulting from routine operations in the nuclear industry.

NUCLEAR POWER IS SAFE

The absence of any significant environmental impact from the nuclear industry demonstrates, in practice and on the record, the continued success of robust and well-proven nuclear power technologies, the reality of competent safety and environmental oversight by national and international authorities, and the responsible behaviour of well-established nuclear operators.

Because the nuclear industry's strong performance in safety yields nuclear "incidents" only rarely, the media often give greater attention to even a minor nuclear incident causing little or no harm than to the frequent and seriously harmful accidents involving fossil fuel production or use.

For example, coalmining accidents kill thousands of people each year. Indeed, the death rate from worldwide coalmining exceeds, in just two days, the fewer than 50 persons who died from direct radiation exposure or fallout-induced thyroid cancer as a consequence of the world's major nuclear accident at Chernobyl, Ukraine in 1986. (Reference: UNSCEAR, the UN Scientific Committee on the Effects of Atomic Radiation.) Oil and gas-related accidents kill many more, while large oil spills have had a devastating environmental effect on sea coastlines and marine ecology.

Arguably even more significant than these specific fossil fuel-related accidents is the enormous worldwide discharge of pollutants into the atmosphere from fossil fuel combustion - a stream of emissions that continues to degrade human health and the global environment.

Annex B

Common Misperceptions about Nuclear Waste

Below are five commonly heard expressions of public concern that have arisen from an inadequate public debate about nuclear power - a debate in which facts have often been eclipsed by ideology and myth. The nuclear industry must bear some responsibility for these misperceptions and is striving to correct them:

Myth #1: The nuclear industry does not know what to do about nuclear waste.

> Reality: The nuclear industry carefully accounts for all of its nuclear waste, and solutions for safely managing waste are comprehensively practiced and continually improved.

Myth #2: Nuclear waste lasts forever and cannot be managed safely.

> Reality: Nuclear waste naturally becomes less radioactive over time, ultimately becoming essentially non-radioactive. Most of the radioactivity in nuclear waste disappears within a few decades of its creation. Some of the radioactivity is less active and thus decays more slowly, requiring that some materials be isolated for tens of thousands of years. The nuclear industry has an excellent worldwide track record in safely managing nuclear waste. Accidents with health or environmental consequences have been extremely rare and invariably quite limited in effect.

Myth #3: Nuclear waste will end up in a "nuclear waste dump".

> Reality: Well-engineered and highly safe nuclear waste facilities do exist, and others are being developed or planned for long-term disposal of materials that pose the greatest radioactive hazard (i.e., UNF-HLW and ILW).

Myth #4: The huge cost for managing waste makes nuclear energy uneconomic.

> Reality: The full cost for safely managing nuclear waste represents a few percent of the total cost of nuclear power generation and is generally included in the cost of electricity.

Myth #5: The nuclear industry is secretive about nuclear waste.

> Reality: The nuclear industry routinely provides all relevant data to nuclear safety authorities about its waste. Upon review and verification, this information becomes part of publicly accessible national reports on the inventory of radioactive waste.

Annex C

Nuclear Waste and Used Nuclear Fuel Repositories

ROLES AND TYPES OF REPOSITORIES

Two general types of sites are used for disposal: (1) those for LLW; and (2) those for conditioned UNF-HLW and ILW.

Due to its limited hazard potential, solid LLW is disposed of in standard containers that are placed in purpose-built engineered facilities on the surface or at shallow depth. Liquid LLW is generally converted to smaller volumes of solid LLW, leaving a residual liquid of low radioactivity that can be safely discharged according to strict regulations.

Having a higher hazard potential, UNF-HLW and ILW are placed in robust, corrosion-resistant containers for eventual disposal in well-selected and highly engineered deep geological repositories:

- When UNF is dealt with as waste, its existing ceramic form helps to ensure its long-term confinement within the sealed containers.
- When UNF is reprocessed, long-term confinement is ensured by first stabilising the HLW and ILW - typically in a durable matrix of glass or concrete - before sealing it in containers for disposal.

Disposal sites of both types - for LLW and for UNF-HLW and ILW - are called "repositories" and consist of engineered facilities built into carefully chosen geological settings of natural host materials such as clay, salt, or granite. The aim in each case is to isolate the end products so as to prevent both direct human contact and also any groundwater contamination that could transport radioactivity to the Earth's surface. A fundamental engineering parameter for repositories is the time-scale, which is especially important for conditioned UNF-HLW and ILW.

In disposing of conditioned UNF-HLW and ILW in deep geological repositories, the principal concern is to ensure that groundwater does not contact the disposed materials and then return to the surface as a radioactive hazard. The engineering of such disposal facilities is thus designed to create a series of successive barriers - through the stabilisation of the waste material, the use of sealed containers, and the choice of a stable and impermeable geological setting - so that the material's radioactivity will reach natural background levels before these barriers can be breached, even over time scales of tens of thousands years.

The governing standard is to prevent any adverse environmental impact on life on the Earth's surface. This standard is quantified by ensuring that any future human radiation exposures arising from deep geological repositories would be well below today's accepted dose limit for the public. Under this standard, the maximum allowable environmental impact would represent only a small fraction of natural background radiation and would thus have no adverse health consequences on humankind or the environment.

The essence of a deep geological repository is the containment and isolation of nuclear waste and UNF until their radioactivity levels become comparable to those that are natural in the earth's crust. Significantly, deep geological repositories have "natural analogues": places on Earth where naturally occurring radioactive materials have been isolated in their geological formation, without human intervention, for millions of years. Deep geological repositories build on this proven geological phenomenon by adding the benefit of highly engineered containers and barriers.

Once deep geological repositories have been created in many countries, it may prove efficient to seek economies of scale by rationalising the number of such repositories and thus concentrating investment. Such considerations may be especially relevant for countries where establishing the entire stream for waste management and disposal does not represent a sound economic and technological option.

For the foreseeable future, the emphasis must remain on the achievement, by the numerous countries with advanced economies and sophisticated nuclear programmes, of long-term disposal solutions so that they can fulfil their practical needs and moral responsibilities.

DEEP GEOLOGICAL REPOSITORIES: ACHIEVING TECHNICAL DEMONSTRATION AND BROADER PUBLIC SUPPORT

For low-level waste (LLW), interim storage and disposal sites are already operational in most countries with large nuclear programmes. For the more radioactive materials - UNF-HLW and ILW - operational interim storage sites are now commonplace in countries producing nuclear power. What remains is the question of long-term disposal of these materials.

A strong scientific consensus now supports deep geological repositories as a safe and feasible solution for the disposal of conditioned UNF-HLW and ILW. This consensus includes a wide range of experts in various fields - including geology, radiological protection, and environmental science - and is backed by numerous national scientific and engineering associations, key advisory committees of the IAEA, and many national nuclear safety authorities.

This scientific consensus was built through 30 years of worldwide research and studies demonstrating that the placement of conditioned UNF-HLW and ILW in sealed containers in highly engineered vaults in carefully selected geological formations will not adversely impact life on the Earth's surface, even over long time periods extending to tens of thousands years.

Deep geological repositories satisfy a long-term need by providing isolation, an increased level of safety, and fulfilment of this generation's moral responsibility to deal with nuclear waste and UNF. While not a replacement for long-term repositories, interim storage facilities do serve a valuable function by providing staging points for the accumulation and consolidation of UNF-HLW and ILW. During interim storage, natural decay can cool and reduce the radioactivity and thermal burden of these materials - greatly lessening the task of long-term disposal.

Geological repositories need not be sealed immediately. Instead, they offer a means by which UNF-HLW and ILW can be positioned for disposal, while access is maintained for decades. This interval of extended retrievability leaves open the opportunity for further developments in the science of disposal - through improved barriers and reduced waste volume - and also allows for further consideration of the option of reprocessing UNF to recover its energy value.

In some countries with nuclear power, decisions on the disposal of conditioned UNF-HLW and ILW in deep geological repositories have been repeatedly postponed due to an absence of political will. Common misperceptions about nuclear waste have combined with political timidity to produce an impasse. Overcoming this impasse and achieving broader public support is today the central challenge for the safe long-term management of UNF-HLW and ILW.

In several key countries, however, deep geological repository sites are at various stages of development in a process that includes identification and selection of candidate sites, site investigation studies in underground research laboratories, site selection with public participation, and licence applications for construction and operation at selected sites. As this process proceeds in diverse locations, accumulating knowledge and experience will help to optimise both facility design and the process of public involvement and approval.

Where the public debate about disposal is still unresolved, the key challenges lie in two related areas: "technical demonstration" and "broader public support". Recent political progress in such countries as Finland, Sweden, and the USA shows that these issues are solvable when a sound technical solution is brought forward for full public consideration.

The process of "technical demonstration" of feasibility is proceeding in several countries at research laboratories in underground sites that have already been selected - or are candidates - as deep geological repositories. These investigations represent a necessary step in a sound process of public consultation and national decision-making.

Public deliberation has progressed notably in several national cases. In Finland, a full deliberative process led to an almost unanimous parliamentary vote, accompanied by strong local support, for a deep geological repository. In Sweden, the process is at an earlier stage, but a well-conceived public education effort has helped produce strong local support at two potential sites for a deep geological repository. In the USA, despite resistance led by local politicians, creation of the Yucca Mountain site for a deep geological repository was approved with a strong majority vote in Congress. France, already well advanced in public support of nuclear power, is developing an underground laboratory to assess potential sites for a deep geological repository.

This experience shows that clear, transparent, step-by-step decision-making - featuring public communication and involvement - can build local and national confidence to support site-selection and implementation of deep geological repositories.

Annex D

Nuclear Waste: A Surprisingly Small Burden

Nuclear power produces huge quantities of energy from very small quantities of nuclear fuel. In an industrial country, a typical city of one million people consumes the amount of electricity generated by a single 1,000 MWe (megawatt-electric) nuclear power reactor. How much waste results?

The annual operation of this reactor would typically create about 100 cubic meters of LLW (including some ILW that quickly decays to LLW). This waste consists of (a) contaminated materials such as resins, filters, rags, metals, clothes and mud; and (b) material such as mortar that is added to stabilise these wastes.

Generating the city's electricity for one year would use about 20 tonnes of uranium-based fuel, leaving an equivalent amount of UNF. The volume of highly radioactive material to be disposed of depends on how the UNF is treated:

- If UNF is conditioned for direct disposal, the 20 tonnes of UNF converts to a volume of about 40 cubic metres.

- If UNF is reprocessed and conditioned for disposal, the resulting waste converts to volumes of 3 cubic metres of HLW and 4 cubic metres of ILW - a reduction of over 75%. The HLW consists mainly of fission products and the material added (usually glass or concrete) to stabilise the waste. The ILW consists of parts of the UNF fuel cladding, which have been compacted.

The LLW Burden: The 100 cubic metres of LLW can be disposed of in a surface or shallow repository for this kind of material. Over 10 years, the LLW burden for a city of one million people would be 1,000 cubic metres. This volume would fit on a football field with a depth of 15 centimetres - about ankle deep.

The UNF-HLW and ILW Burden: The material requiring disposal in a deep geological repository is the 40 cubic metres of UNF or, if there is reprocessing, the 7 cubic metres of HLW and ILW. Over 10 years, the accumulated volume for a city of one million people would be either 400 or 70 cubic metres. If placed in a four-metre-high gallery in a deep geological repository, these 10-year volumes would require either 100 square metres of floor space (the size of a small home) or 17.5 square metres of floor space (the size of a bedroom).

From these figures, it can be seen that the use of nuclear power to electrify a large city produces, even over the course of a decade, a remarkably small burden of nuclear wastes of all kinds.

To generate the same electricity using fossil fuel would require 160,000 times as much coal - over 3 million tonnes annually. The associated volume of waste from fossil fuel is correspondingly large. Some of this waste (notably, coal ash) is often simply buried in landfill sites, even though it is toxic and slightly radioactive. But much is not, and carbon dioxide and other pollutants are released freely into the air. In contrast, the nuclear industry's waste is carefully confined, and the very minor radioactive discharges are rigorously limited to ensure there is no adverse human health or environmental impact.

This same city of 1 million people also generates a mass of industrial waste each year that is typically 2,500 times greater than the nuclear waste created while electrifying the entire city. Of this industrial waste, the mass of the toxic waste alone is some 100 times greater than the city's nuclear waste. Much of this toxic waste lasts indefinitely, never "decaying" as does nuclear waste. Thus, for reasons of volume and permanency, industrial wastes constitute a far greater challenge for safe management than nuclear waste, requiring both more space and also isolation for an indefinite time scale.

In contrast, after a few decades, most nuclear waste contains only very low levels of radioactivity, and the small volume of waste with a long decay life is suitable for safe disposal in a geological repository.

While the burden of nuclear waste is in any case remarkably small, reprocessing UNF offers a means to reduce still further - by over 75% - the overall volume of material requiring disposal in a deep geological repository. Reprocessing yields HLW and ILW in a safe and durable form of confinement, and meanwhile recovers the UNF's remaining energy value for potential recycling and reuse as nuclear fuel.

A single nuclear treatment plant that reprocesses 1,000 metric tonnes of UNF annually can, over a four-year period, recover the energy equivalent of 80-100 million tonnes of petroleum - about the annual oil production of Kuwait.

UNF contains valuable fissile material in two forms: plutonium (created during the fission of the original uranium fuel) and still-unfissioned uranium. Recycling these fissile materials can improve the energy yield of the original uranium fuel and can also lead to creating even more fuel. A plutonium-based Fast Breeder Reactor (FBR), while producing energy, can transform non-fissile uranium into fissile material, thus greatly extending future world supplies of nuclear fuel.

Widespread use of Fast Breeder Reactors is not on the near horizon. But anticipated advances in FBR technology and in the use of nuclear power have begun to raise appreciation among planners that the nuclear waste of today could become an important energy source of tomorrow.

Meanwhile, in today's context, the question of direct disposal of UNF versus reprocessing is not a matter of safe waste management. Both methods are proven and highly sound.

Annex E

Background Information

NUCLEAR WASTE AND USED NUCLEAR FUEL

1) Origin of Nuclear Waste and UNF. Nuclear power comes from the huge amount of energy, stored in the atomic nucleus, which is released as heat under controlled conditions in a reactor. This energy release results from the splitting of atoms of uranium in a process known as "fission".

Uranium is one of the "radioactive" elements. Also referred to as radionuclides or radioisotopes, these are atoms that continue to transform themselves into other elements while decaying to a stable (non-radioactive) state. Naturally occurring uranium consists of three radioisotopes: uranium-238 (99.3%), uranium-235 (0.7%) and uranium-234 (trace amounts), with the difference lying in the number of neutrons in the atomic nucleus. Of them, only U-235 is fissile, meaning able to be split.

The end products of controlled nuclear fission contain a diverse group of radioactive elements that decay at greatly differing rates. These end products are classified either as nuclear waste or as used nuclear fuel (UNF).

2) Categories of Nuclear Waste. Nuclear waste is categorised according to its radioactivity levels in three broad classes: low level waste (LLW), intermediate level waste (ILW), and high level waste (HLW). Some ILW decays rapidly to become LLW; some ILW, such as parts of UNF fuel cladding removed during reprocessing, decays slowly. Heat generation is a relevant concern only with HLW-UNF. This heat is described as the "thermal burden" in managing and disposing of these materials.

3) Energy Value in Used Nuclear Fuel. UNF contains radioactive substances that still have a great deal of energy potential. Some 96% of the mass of UNF can potentially be recovered and recycled for further use as nuclear fuel.

4) Role of Interim Storage of Reactor End Products. UNF-HLW is generally stored for several years in a pond at the power plant or at a reprocessing plant. On-site storage or storage at an interim surface-storage facility allows for natural radioactive decay to reduce both the radioactivity and the associated thermal burden of this end product.

RADIATION

5) Ionising Radiation. Radiation is energy transported by means of rays and particles. Ionising radiation is radiation that has sufficient energy to remove electrons from atoms. It is often referred

to simply as radiation. One source of radiation is the nuclei of unstable atoms. For these radioactive atoms to become more stable, the nuclei eject or emit subatomic particles and high-energy photons (gamma rays). This process is called radioactive decay. Unstable isotopes exist naturally; examples are isotopes of radium, radon, uranium, thorium, and potassium.

6) Types of Radiation. The major types of ionising radiation emitted as a result of spontaneous decay are alpha and beta particles and gamma rays. X-rays, another major type of ionising radiation, arise from processes outside the atomic nucleus. Alpha and beta particles, and gamma and X-rays, cause direct ionisation, meaning that they transfer their energy upon interaction with matter by giving energy to electrons. These ions (charged particles) can be accurately measured. Four types of ionising radiation are of primary concern for human health and environmental safety:

- Alpha particles. Alpha particles are essentially helium nuclei, consisting of two protons and two neutrons. These positively charged particles are commonly emitted in the radioactive decay of the heaviest radioactive elements such as uranium and radium. Because these particles are relatively large and slow-moving, they can be stopped by a piece of paper or are easily absorbed by the outer dead layer of human skin. They are not therefore a hazard outside the body, although they can be harmful if ingested or inhaled.

- Beta particles. Beta particles are fast moving electrons emitted from the nucleus during radioactive decay. Some beta particles can be stopped by a layer of clothing or by a few millimetres of a substance such as aluminium. They are, however, capable of penetrating the skin and causing damage to cells. As with alpha particles, they are generally more hazardous if inhaled or ingested.

- Gamma rays. Like visible light and X-rays, gamma rays are weightless packets of energy called photons. Gamma rays often accompany the emission of alpha or beta particles from a nucleus. They have neither a charge nor a mass and are very penetrating. Gamma rays can easily pass completely through the human body or be absorbed by tissue, and therefore pose a radiation hazard for the entire body. Very thick concrete or a few centimetres of lead are required to stop the more energetic gamma rays.

- X-rays. X-rays have essentially the same properties as gamma rays but differ in origin because X-rays are emitted from processes outside the nucleus. X-rays are used both for medical examinations and for cancer therapy to destroy malignant cells. Because of their many uses, X-rays are the single largest source of manmade radiation exposure. A few millimetres of lead can stop X-rays.

Another type of particle - the free neutron - can also cause ionising radiation, but indirectly. Being non-charged particles, neutrons transfer their energy through collisions with other particles. When a proton is struck by a neutron, however, it can absorb energy and move, and this positively charged particle can give up its energy through ionisation. Nuclear power reactors produce neutrons, and the shielding of workers and the public from these particles is achieved by the design and operational procedures of nuclear plants.

7) Sources of Radiation. Humans are primarily exposed to natural radiation from the sun, cosmic rays, and naturally occurring radioactive elements found in the earth's crust, such as uranium, thorium, and potassium, and their radioactive derivatives, including radon. Radiation is used on an ever-increasing scale in medicine, agriculture, and industry. Many medical and industrial facilities generate some radioactive waste; some of these facilities release a controlled amount of radiation into the environment.

8) Effects of Radiation. In strong doses or when it can reach vulnerable body parts, ionising radiation can cause biological changes in human cells. Some of those changes can cause cancer.

9) Measurement of Radiation Doses. Radiation doses are commonly measured and reported in a unit called the "millisievert" (mSv), which expresses the potential detrimental health risks to humans from exposure to ionising radiation. Extremely small quantities of radioactivity and radiation can be easily detected by current measurement techniques routinely used by the nuclear industry. This asset is part of the careful control and management of nuclear waste and UNF.

10) Internationally Recommended Radiation Dose Limits. The following are current recommendations of the International Commission on Radiological Protection (ICRP). These recommendations form the basis of the regulatory regimes in most countries:

- For the public, an annual dose limit per individual of 1 mSv, with a provision for higher doses in special circumstances, provided that the average over 5 years does not exceed 1 mSv per year
- For workers, an annual dose limit per individual of 20 mSv, averaged over 5 years (100 mSv in 5 years), with the further provision that doses should not exceed 50 mSv in any single year.

The dose limits apply to doses that arise from various types of human activities, including the nuclear industry. Dose limits exclude the doses people receive from natural background radiation. Accidents, emergencies, and long-standing radiation exposure situations are also excluded from the scope of dose limits.

11) Common Levels of Radiation Dose. Worldwide, the annual radiation dose per individual averages 2-3 mSv. The amount can vary widely because the principal source of exposure - natural background radiation - ranges from 1 to 10 mSv a year depending on a person's geographical location. From nuclear industry activities, the annual dose among the general public is typically less than a few tenths of 1 mSv even for the most exposed person, and usually the public's exposure is much smaller.

12) Radiation Doses from Medical Treatment. Every year millions of people, while benefiting from medical diagnosis, are exposed to radiation levels far higher than any exposure they may receive as a result of nuclear industry activities. For example, the average individual's annual radiation dose from diagnostic medical X-ray examinations is about 0.4 mSv. (A single chest X-ray is about 0.14 mSv.)

13) Radiation from Radon. One significant source of human exposure to natural radiation is Radon, a radioactive gas that is generated everywhere from elements that naturally occur in soil. Radon seeps into almost every home, particularly into basements and crawl spaces where it can sometimes accumulate to high levels. Unlike exposure to radioactivity from nuclear power plants, which is safely low and closely monitored, exposure to radon gas can result in a more substantial risk to human health that often goes unnoticed.

14) Overall Radiation Exposure. The World Health Organisation lists the following sources and distribution of average radiation exposure to the world population: Radon (43%); Medical (20%); Earth Gamma Radiation (15%); Cosmic Rays (13%); Food & Water (8%); Others, including all manmade sources (1%).