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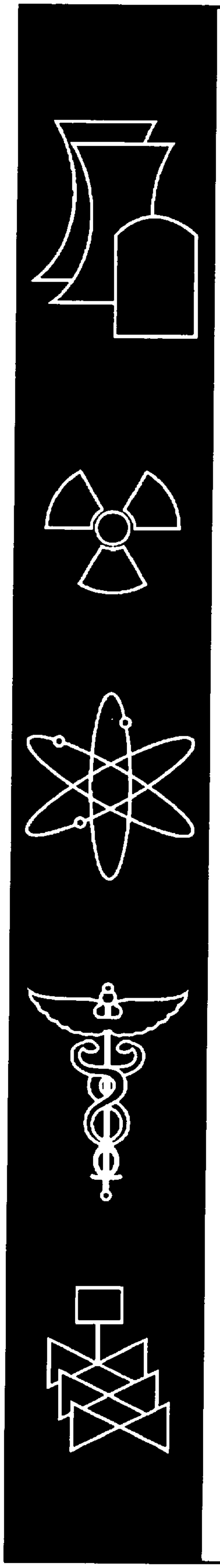

Limited Burnup Credit in Criticality Safety Analysis: A Comparison of ISG-8 and Current International Practice

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Limited Burnup Credit in Criticality Safety Analysis: A Comparison of ISG-8 and Current International Practice

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ABSTRACT

This report has been prepared to qualitatively assess the amount of burnup credit (reactivity margin) provided by ISG-8 compared to that provided by the burnup credit methodology developed and currently applied in France. For the purposes of this study, the methods proposed in the DOE Topical Report have been applied to the ISG-8 framework since this methodology (or one similar to it) is likely to form the basis of initial cask licensing applications employing limited burnup credit in the United States. This study limits the scope of the comparison to several of the fundamental burnup credit parameters: the nuclides credited in the analysis, the axial-burnup profile, and the cooling time. An investigation of other parameters, such as horizontal burnup effects and isotopic correction factors to account for biases and uncertainties in calculated actinide compositions, were beyond the scope of this review. This report compares the amount of burnup credit provided by the respective methodologies for typical axial-burnup profiles derived from averaging actual PWR axial-burnup distributions. In addition, a limited assessment of several atypical axial-burnup distributions is also included.

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1 INTRODUCTION

In August 1999, the Nuclear Regulatory Commission (NRC) issued Revision 1 of the Interim Staff Guidance 8 (ISG-8), "Limited Burnup Credit." The ISG-8 guidance accepts, in principle, the use of actinide-only burnup credit in criticality safety analyses of pressurized water reactor (PWR) spent fuel in transport and storage casks. ISG-8 limits the amount of burnup credit to that available from actinide compositions associated with PWR irradiation of UO_2 fuel with an assembly-average burnup of 40 GWd/MTU or less, and initial uranium enrichments of no more than 4.0-wt % ^{235}U without a loading offset penalty, and up to 5.0-wt % ^{235}U with a loading offset.

This study compares the subcritical margin associated with burnup credit provided using an implementation of ISG-8 with that obtained using an actinide-only burnup credit methodology currently applied in France. The amount of burnup credit is defined as the relative difference in the calculated k_{eff} using burnup credit compared with that obtained using unirradiated fuel compositions. At this time, France is the only other country with an approved burnup credit methodology for PWR fuel transport. Consequently, this study has limited the comparison of ISG-8 to the methods currently approved by the French Safety Authority.

ISG-8 restricts the application of burnup credit to assemblies that have not used burnable absorbers. The French methodology however has no such restriction. The assemblies used in the comparisons presented in this report do not employ burnupable absorbers and therefore the results and conclusions from these comparisons are only applicable to assembly types allowed within the constraints of ISG-8.

The ISG-8 guidance defines the limits of application and the key parameters which must be addressed by an applicant employing actinide-only burnup credit for safety evaluations in licensing submissions, without endorsing a specific methodology. For the purposes of this study, the Topical Report on actinide-only burnup credit, issued in 1998 by the U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management,[1] has been used to define the specific actinide set and the bounding axial profiles. While ISG-8 acknowledges the work in the DOE Topical Report, it does not approve the use of, nor endorse, the specific methodologies proposed in it. The burnup credit methodology proposed in the DOE Topical Report have been applied to ISG-8 because this methodology (or one similar to it) is likely to form the basis of initial cask licensing applications employing limited burnup credit in the United States. The amount of burnup credit provided by ISG-8 will depend on the cask design and the specific burnup credit methodologies employed in the licensing-basis analysis, which may be different than those presented in this study. Therefore, the results presented here are only intended to provide an approximate measure of the amount of burnup credit provided by the ISG-8 guidance with respect to current French practice for the fuel types currently permitted in ISG-8.

The burnup credit calculations performed using the ISG-8 and French methodologies have been compared for a 21-assembly OECD benchmark cask and a generic 32-assembly burnup credit cask which is prototypical of the next generation of PWR fuel transport casks likely to be used in the United States.

2 BURNUP CREDIT METHODS

2.1 ISG-8 APPROACH

The ISG-8 guidance allows for burnup credit for actinides only, but does not endorse the use of a particular subset of actinides. Instead, the guidance states that "the particular set of nuclides used to determine the *k*-effective value should be limited to that established in the validation process." For the purposes of this study, the subset of actinides proposed in the DOE Topical Report[1] have been adopted for comparison with the French methodology.[2] Although the NRC does not necessarily endorse this subset for a given application, the Topical Report reflects the current status of burnup credit validation efforts, and the use of these actinides is supported by measured isotopic data and criticality benchmarks. This set of actinides is very similar to that currently allowed in French practice. A comparison of burnup credit actinides is presented in Table 1. Actinide compositions for the ISG-8 calculations were obtained for a cooling time of 5 years.

ISG-8 also does not make specific reference to the axial-burnup profiles that should be used for criticality safety analyses, but states "The calculation of the k-effective value should be performed using cask models, appropriate analysis assumptions, and code inputs that allow adequate representation of the physics. Of particular concern should be the need to account for the axial and horizontal variation of burnup within a spent fuel assembly (e.g., the assumed axial-burnup profiles)...," leaving the onus on the license proponent to justify and support the use of a particular axial shape as being appropriate or bounding.

The axial-burnup profiles applied to the ISG-8 methodology for the purposes of this report are those presented in the DOE Topical Report. These profiles were determined to be bounding for PWR assemblies included in a database of calculated assembly profiles collected from a selection of utilities whose reactors represent the range of commercial PWR fuel lattices. The assembly profiles are used for the qualitative purposes of this study, although the bounding nature of these profiles is not independently verified here.

Other aspects of ISG-8, such as the need to account for biases and uncertainties in the calculation of actinide compositions due to code and nuclear data biases, and uncertainties in reactor operating parameters and conditions, are not addressed in this report. Correction factors applied to isotopic calculations will be dependent on the particular physics codes and nuclear data used, and on the supporting experimental assay programs. For this study, isotopic correction factors and conservative depletion analysis parameters were not considered in the calculation of actinide inventories since the same codes were used to compare the different methodologies. In addition, the need to account for the horizontal variation of the burnup within the assembly in ISG-8 is not addressed in the comparisons, although the horizontal effect is believed to be a relatively minor effect for spent fuel storage casks. Since the recommendations of ISG-8 have only been partially implemented in this study (specifically those recommendations most likely to emphasize differences between the ISG-8 and French methodologies), *the amount of burnup credit provided by the ISG-8 methodology presented in this report should only be viewed as a qualitative measure for the purposes of comparing the respective methodologies.*

2.2 FRENCH APPROACH

The French Safety Authority has approved the use of burnup credit for the major actinides.[2] Credit for fission products is not currently allowed. For criticality safety studies, the assembly is assumed to have a uniform axial burnup based on averaging the assembly burnup over the contiguous 50-cm length of the fuel assembly having the least irradiation. No credit for reactivity reduction with cooling time is generally permitted. Since 1997 the decay of ^{241}Pu and buildup of the ^{241}Am progeny during the cooling time is accounted for in some criticality safety assessments.[3] No decay time was assumed in the French methodology as applied in this study.

The burnup credit actinides proposed in the DOE Topical Report, and those allowed by the French Safety Authority, are summarized in Table 1.

Table 1 Actinides considered for burnup credit in criticality safety evaluations

Actinides	DOE topical	French practice
^{234}U	Y	
^{235}U	Y	Y
^{236}U		Y
^{238}U	Y	Y
^{238}Pu	Y	Y
^{239}Pu	Y	Y
^{240}Pu	Y	Y
^{241}Pu	Y	Y
^{242}Pu	Y	Y
^{241}Am	Y	

3 ANALYSIS

3.1 PWR ASSEMBLY AND TRANSPORT CASK MODELS

The criticality calculations were performed using two transport cask models: a 21-assembly stainless steel transport cask design used in the OECD burnup credit criticality benchmark Phase II-B,[4] and a 32-assembly generic burnup credit cask (GBC-32) model that incorporates design features that are anticipated to be representative of the next generation of PWR fuel transport casks in the United States. The OECD and GBC-32 casks use a square assembly lattice arrangement (5 × 5 array, and 6 × 6 array, respectively, with the four corners removed). The GBC-32 cask is illustrated in Figure 1.

The fuel assembly used in the comparisons was based on the Westinghouse 17 × 17 assembly design with an initial enrichment of 3.5 wt % ^{235}U. For the OECD cask studies, the assembly contained 289 fuel pins, with no guide tubes – the same configuration used in the OECD benchmark specifications. For the GBC-32 cask calculations the 17 × 17 assembly model contained 25 instrument tubes, which is more representative of current PWR assemblies. No burnable absorbers were assumed to be present in the assemblies. The interior of the cask was assumed to be flooded with water in all criticality calculations.

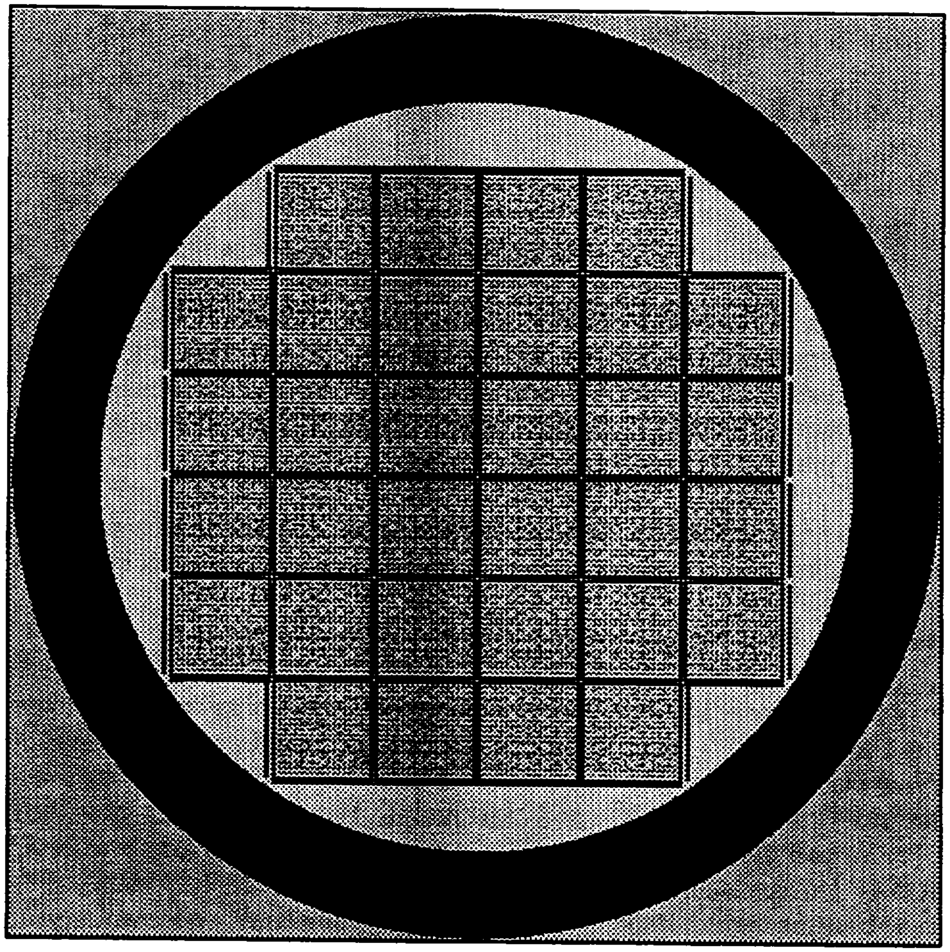

Figure 1 Section view of 32-assembly GBC-32 cask model

3.2 ASSEMBLY AXIAL-BURNUP PROFILES

PWR fuel assembly axial-burnup profiles were required in this study in order to obtain an effective axial burnup for the French burnup-credit approach (based on least irradiated 50 cm of the assembly), and also to obtain the actual, or best-estimate *k*-effective for the system. For this study, assembly profiles taken from the PWR axial-burnup profile database[5] were used as the starting point. The database contains axial-burnup profiles based on reactor physics calculations of core operating cycles from a selection of utilities whose reactors represent the range of commercial PWR fuel lattices. Assembly profiles from the database were averaged to obtain typical profiles over a burnup range from 3 to 40 GWd/MTU. Assemblies with a burnup greater than 40 GWd/MTU, the maximum allowed in ISG-8, were excluded.

A number of assemblies from the database were excluded in the profile averaging due to considerations such as axial enrichment zoning of the assembly, and low-enriched or naturally enriched uranium assembly end regions. The assemblies rejected from the database were the same ones as those rejected in previous work to determine bounding axial profiles.[6] The database contains enrichments from 1.24 to 4.75 wt %. Although ISG-8 limits the enrichment level to no more than 4.0 wt % ^{235}U without a loading offset penalty, assemblies with enrichments above 4.0 wt % were not excluded in this study. Burnup was assumed to be uniform hortizonally across the assemblies. An analysis of the horizontal-burnup effects was not included as part of this study, although this effect is likely minor (< 1 %) for spent fuel storage casks.

3.2.1 Characteristic Profiles

The assemblies in the PWR axial-burnup profile database were grouped to determine representative axial shapes for several burnup ranges. These selected ranges were 37–40 GWd/MTU, 20–25 GWd/MTU, 10–15 GWd/MTU and 3–7 GWd/MTU. Assemblies having burnup values between these groups were not used. The characteristic, or typical profiles, are the average of all of the assembly profiles in the corresponding burnup group. The averaged burnup profiles derived from the selected assemblies in each group are listed in Table 2 and graphed in Figure 2. The average assembly parameters for each group are listed in Table 3. As expected, the average initial enrichment increases with increased burnup. The burnup profiles within each burnup group were not further categorized by enrichment (i.e., all enrichments in the database were used to obtain the average group profiles). In other words, the axial-burnup profiles were based only on assembly burnup.

The characteristic axial profiles derived for these burnup groups are well-behaved, based on composite profiles for a large number of assemblies covering a wide range of operating histories and assembly designs.

3.2.2 Uncharacteristic Profiles

Several calculations were also performed using axial-burnup profiles that were considered to be atypical of the high-burnup Group 1 assemblies (37–40 GWd/MTU). The bounding axial-burnup profile as applied to the ISG-8 methodology in this study is designed to be conservative for both characteristic and uncharacteristic profiles. The calculated k_{eff} is therefore independent of the actual axial profile. However the result using the French methodology is sensitive to the profile near the ends of the assembly. Assemblies which tend to have a small burnup gradient at the end of the assembly will have a higher average burnup in the criticality analysis using the French approach compared with assemblies that have a large burnup gradient, and consequently a lower analysis burnup value. The actual, or best-estimate value of the k_{eff} for the system is also impacted by the axial-burnup profile. Calculating the best-estimate k_{eff} then provides a measure of the safety margin, or "burnup penalty," imposed by the different burnup credit methodologies.

The uncharacteristic assemblies selected from Ref. 5 for this comparison were H. B. Robinson Unit 2 Westinghouse (WE) 15 × 15 assembly D102, and Maine Yankee Combustion Engineering (CE) 14 × 14 assembly N863. Assembly N863 had the smallest burnup gradient near the end region of the assembly out of all 193 assemblies considered in the high-burnup Group 1. The ratio of the burnup averaged over the least irradiated 50 cm of the assembly to that of the entire assembly is about 0.839. Assembly N863 used burnable poison rods (BPRs) during part of the irradiation history. Although it is recognized that ISG-8 does not allow burnable absorbers, the axial-burnup profile for this assembly was selected to provide an estimate of the bounding difference (due to profiles) between the ISG-8 and French burnup credit methodologies. Only the axial profile for this assembly was used in the analysis. The assembly design used to predict the isotopic compositions and for the criticality analysis did not use burnable absorbers. Assembly D102 had the largest burnup gradient, with a burnup ratio value of 0.664. Both assemblies achieved an exit burnup of about 38 GWd/MTU. The assembly data and axial-burnup profiles for these assemblies are listed in Table 4. The initial fuel compositions and burnup used for both assemblies were taken from H. B. Robinson assembly D102, with an initial enrichment of 3.73-wt % ^{235}U. The criticality calculations using the axial profiles from assemblies D102 and N863 were only performed for the GBC-32 cask model (Figure 1).

Table 2 Typical axial-burnup profiles based on PWR assembly database

Axial node	Axial height, %	Group 1 37–40 GWd/MTU	Group 2 20–25 GWd/MTU	Group 3 10–15 GWd/MTU	Group 4 3–7 GWd/MTU
1	2.78	0.66694	0.64611	0.58313	0.54324
2	8.33	0.9405	0.9388	0.90303	0.88252
3	13.89	1.0434	1.05293	1.04794	1.04417
4	19.44	1.07189	1.08291	1.09345	1.10351
5	25.00	1.08185	1.09043	1.11046	1.11937
6	30.56	1.07909	1.08458	1.10824	1.11992
7	36.11	1.07792	1.08291	1.11134	1.11637
8	41.69	1.07505	1.08172	1.11283	1.11286
9	47.22	1.07107	1.07958	1.11175	1.11078
10	57.80	1.07206	1.08271	1.11671	1.11008
11	58.33	1.06946	1.08133	1.11337	1.10988
12	63.89	1.06992	1.0818	1.11156	1.10889
13	69.44	1.06864	1.07927	1.10381	1.10473
14	75.00	1.06149	1.06918	1.08245	1.09192
15	80.56	1.04815	1.04882	1.0446	1.05779
16	86.11	1.00342	0.99051	0.95937	0.97614
17	91.67	0.88255	0.8508	0.78871	0.80163
18	97.22	0.6166	0.57559	0.49724	0.4862

Table 3 Parameters for burnup groups derived from PWR assembly database

Parameter	Group 1	Group 2	Group 3	Group 4
Burnup Range (GWd/MTU)	37–40	20–25	10–15	3–7
Number of assemblies in group	193	457	296	64
Average burnup (MWd/MTU)	38595	22230	12757	5830
Average enrichment (wt % ^{235}U)	3.52	3.28	2.93	2.61
Minimum 50-cm BU fraction	0.7971	0.7651	0.7023	0.7062
Minimum 50-cm BU (GWd/MTU)	30764.1	17008.2	8959.2	4117.2

Table 4 Data for assemblies with uncharacteristic axial-burnup profiles

Reactor	H.B. Robinson 2	Maine Yankee
Assembly ID	D102	N863
Fuel Type	W 15 × 15	CE 14 × 14
U-235 wt %	3.73	3.3
No. BP rods	0	8
BP Type		B_4C
Burnup	37814	37626
Axial height %	Axial profile	Axial profile
2.78	0.31488	0.67053
8.33	0.92825	0.93322
13.89	1.07846	1.02433
19.44	1.12253	1.05329
25.00	1.13896	1.06026
30.56	1.13669	1.06185
36.11	1.12818	1.06215
41.69	1.13176	1.06249
47.22	1.13029	1.06312
57.80	1.12513	1.06408
58.33	1.12194	1.06541
63.89	1.12587	1.06702
69.44	1.12096	1.06836
75.00	1.11259	1.0676
80.56	1.09614	1.05918
86.11	1.02752	1.02515
91.67	0.86161	0.92262
97.22	0.29808	0.66935
French Burnup Factor[a]	0.66387	0.83894

[a] Defined as the ratio of the burnup averaged over the least irradiated 50 cm of the assembly to that of the entire assembly.

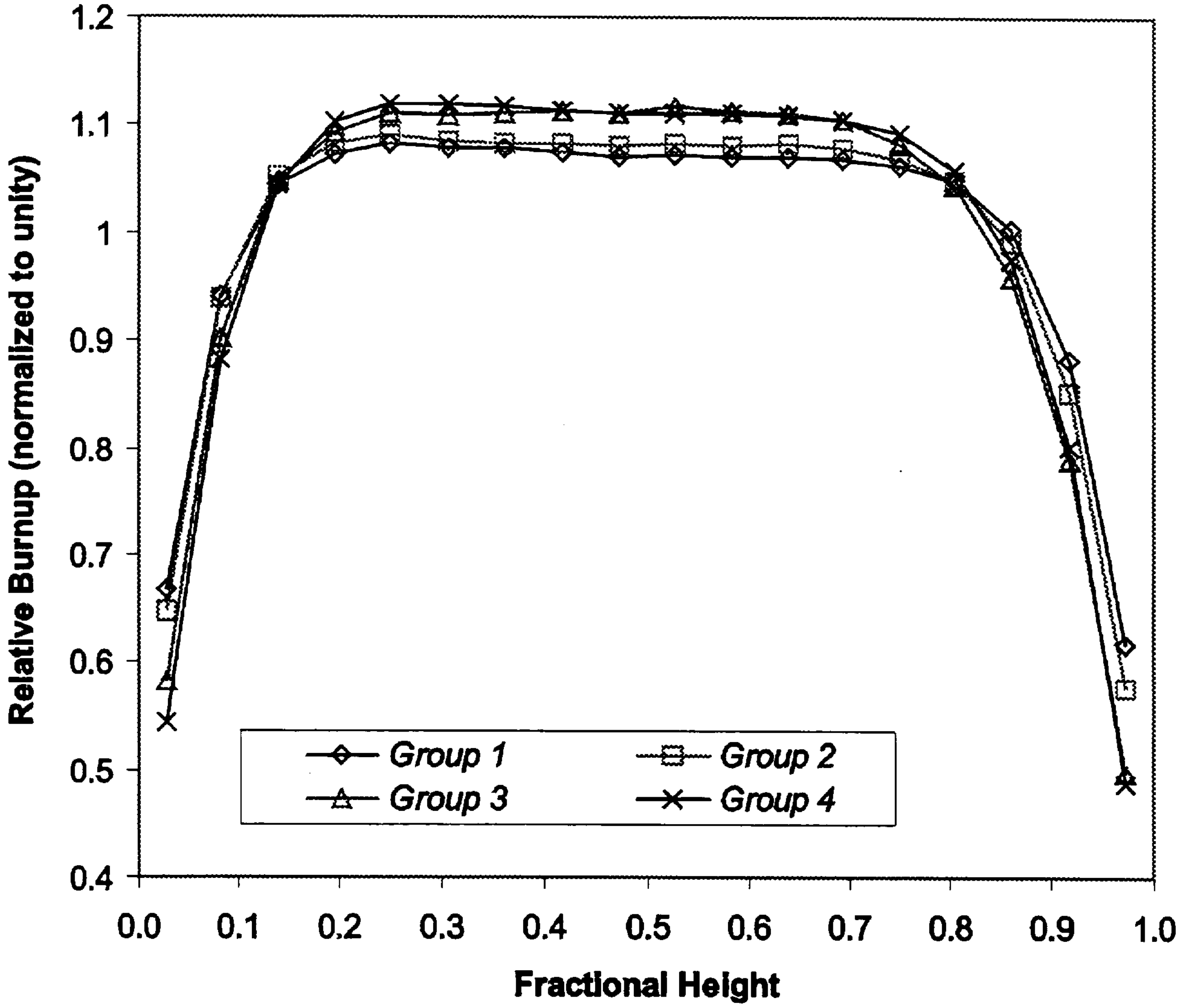

Figure 2 Typical axial profiles based on PWR assembly database

3.3 SPENT FUEL COMPOSITIONS

The fuel assembly isotopic compositions used as the basis for comparing burnup credit using ISG-8 and French Safety Authority practices were calculated using the ORIGEN-ARP sequence of the SCALE code system.[7] ORIGEN-ARP uses the ORIGEN-S isotope generation and depletion code and pre-calculated burnup- and problem-dependent cross-section libraries. For this study the basic ARP cross-section library generated for a 17 × 17 Westinghouse PWR was used. The ARP library extends to initial ^{235}U enrichments of 5.0 wt %, and a maximum burnup of 60 GWd/MTU.

The irradiation times assumed for each burnup group were selected to maintain an average assembly power of about 25 MW/MTU. For calculations involving axial-burnup profiles, the axial zone power was scaled accordingly to the normalized axial burnup for that zone. Following a depletion calculation using ORIGEN-S for an axial zone, the fuel inventories for the zone were read from the binary composition interface and converted to units of atom density (atoms/barn-cm). The nuclides allowed in the burnup credit analysis (see Table 1) were then written in a format suitable for execution using the CSASI control module[8] of SCALE. CSASI prepares self-shielded macroscopic cross sections for each mixture in the problem. The cross- section identifiers for each of the fuel mixtures were subsequently renumbered according to the axial zone position, and used in a KENO V.a criticality calculation for the cask models. The KENO V.a calculations used the cross sections available in the 44GROUPNDF5 library.

For comparison with the burnup credit results, calculations were performed using the initial fresh fuel compositions. The fresh fuel results represent the reference used for comparison with the burnup credit results. In addition, "best-estimate" k_{eff} calculations were also performed. These calculations are useful in estimating the subcritical margin for the system.

Both the ISG-8 and French methodologies require the use of conservative modeling of both the irradiation history and burnup parameters (e.g., fuel temperature, moderator density, etc.) to predict the actinide compositions, and the use of correction factors to the isotopic concentrations that account for biases and uncertainties in depletion calculations (e.g., f-BUC factors recommended in the DOE Topical Report). For the purposes of this study the spent fuel compositions applied to both burnup credit methodologies were taken directly from the depletion calculations without any corrections. The isotopic correction factors are assumed to affect the amount of burnup credit provided by both methodologies by a similar amount, because the ability of current codes to predict the major actinides is well established.

The isotopics for the ISG-8 calculations were obtained for a cooling time of 5 years, as recommended in the guidance. The calculations using the French Safety Authority methodology applied the fuel isotopics at discharge (no cooling time), with no credit for the decay of ^{241}Pu to ^{241}Am.

4 RESULTS AND DISCUSSION

The amount of burnup credit, defined here as the relative difference in the calculated k_{eff} using burnup credit compared with that obtained using unirradiated fuel compositions, is assessed using the ISG-8 and French actinide-only burnup credit methodologies. Calculations were performed using characteristic axial PWR burnup profiles obtained from averaging the profiles of many assemblies having a wide range of operating histories. The results for two cask designs are presented. In addition, uncharacteristic axial-burnup profiles which represented the extremes in terms of the burnup gradient in the assembly end regions were also evaluated for the high-burnup regime in this study.

It is emphasized that the calculations using the burnup-credit methodologies do not apply conservative modeling methods for calculating fuel inventories, nor do they apply isotopic correction factors to the calculated inventories. Additionally, consideration of the horizontal burnup distribution, required by ISG-8, is not included. Consequently, the results should only be used qualitatively for the purposes of comparing the respective burnup credit methodologies.

4.1 CHARACTERISTIC AXIAL-BURNUP PROFILES

4.1.1 OECD Cask Model

The KENO V.a results for the OECD cask model are listed in Table 5 for the four burnup groups using the actinide-only burnup credit methodologies of the ISG-8 guidance and the current French practice. The best-estimate k_{eff} values were calculated using the averaged axial profiles determined for the PWR assemblies in each of the groups (see Table 2) and taking credit for all actinides and fission products in the fuel that have associated cross section data in the 44GROUPNDF5 library used in the KENO V.a analysis. A comparison of the different methodologies is plotted in Figure 3 as the relative change in k_{eff} compared to the reference, or fresh fuel value (i.e., $\Delta k/k$), defined as $(k_{fresh} - k_{credit})/k_{fresh}$.

The results indicate that the current French approach to burnup credit is consistently more restrictive (i.e., more penalizing) and provides less burnup credit than the ISG-8 approach for the assemblies and burnup ranges (up to 40 GWd/MTU) considered. For the PWR transport casks and configurations evaluated, ISG-8 provides about 2% more burnup credit compared to the French approach.

4.1.2 GBC-32 Cask Model

The KENO V.a results for the GBC-32 cask model are given in Table 5. The results are similar to those for the OECD cask model. ISG-8 provides about 2% more burnup credit than the French approach for the burnup range and assembly types studied. The amount of burnup credit using the different methodologies is compared in Figure 4.

The actual k_{eff} values calculated for the GBC-32 cask are compared in Figure 5 for uniform fresh fuel compositions, and using the actinide-only ISG-8 and French burnup credit methodologies. In addition, best-estimate values based on the characteristic (averaged) axial-burnup profiles (Table 2) and comprehensive representation of all fission products and actinides with associated cross-section data are presented for comparison. The figure shows that the

k_{eff} values calculated using the burnup-credit methodologies are similar, and lie nearly midway between the fresh fuel results and the best-estimate results, that is, the amount of burnup credit is nearly equal to the burnup penalty, or subcritical margin, as established from the best-estimate values.

Several additional calculations were performed to evaluate the relative importance of ^{241}Am as a burnup credit actinide in the ISG-8 calculations (^{241}Am is not included in the French methodology), and the differences in decay time assumed by ISG-8 and French practice. The buildup of ^{241}Am from the decay of ^{241}Pu (14.4 y half-life) is a significant contributor to the decrease in k_{eff} during the initial 5 years of cooling time. The elimination of ^{241}Am as a burnup credit actinide in the ISG-8 calculations resulted in an increase in the calculated k_{eff} for the transport casks of between 1 and 2% for the higher burnup assembly group. The increase in the ISG-8 k_{eff} results caused by excluding ^{241}Am significantly reduced the differences observed between the ISG-8 and French burnup credit methodologies. ISG-8 calculations that included ^{241}Am but assumed no cooling time yielded similar results, confirming buildup of ^{241}Am during the cooling time as the dominant contributor to the difference.

Table 5 Criticality results for characteristic PWR assembly axial-burnup profiles

Burnup group	Group 1	Group 2	Group 3	Group 4
Average burnup (GWd/MTU)	38.6	22.2	12.8	5.8
Average BU/ Least 50-cm BU	0.797	0.765	0.702	0.706
21-Assembly OECD Benchmark Cask (k_{eff} ± 1 σ) Fresh fuel (3.5 wt %) k-effective = 1.0630 ± 0.0011				
French	0.8938 ± 0.0009	0.9735 ± 0.0009	1.0192 ± 0.0010	1.0366 ± 0.0010
ISG-8	0.8711 ± 0.0009	0.9432 ± 0.0010	1.0043 ± 0.0012	1.0247 ± 0.0010
Best-estimate	0.7551 ± 0.0009	0.8618 ± 0.0010	0.9359 ± 0.0010	0.9746 ± 0.0010
32-Assembly GBC-32 Cask (k_{eff} ± 1 σ) Fresh fuel (3.5 wt %) k-effective = 1.1034 ± 0.0011				
French	0.9451 ± 0.0009	1.0205 ± 0.0009	1.0590 ± 0.0010	1.0778 ± 0.0011
ISG-8	0.9049 ± 0.0011	0.9784 ± 0.0012	1.0406 ± 0.0010	1.0592 ± 0.0010
Best-estimate	0.7835 ± 0.0011	0.8968 ± 0.0011	0.9732 ± 0.0010	1.0139 ± 0.0010

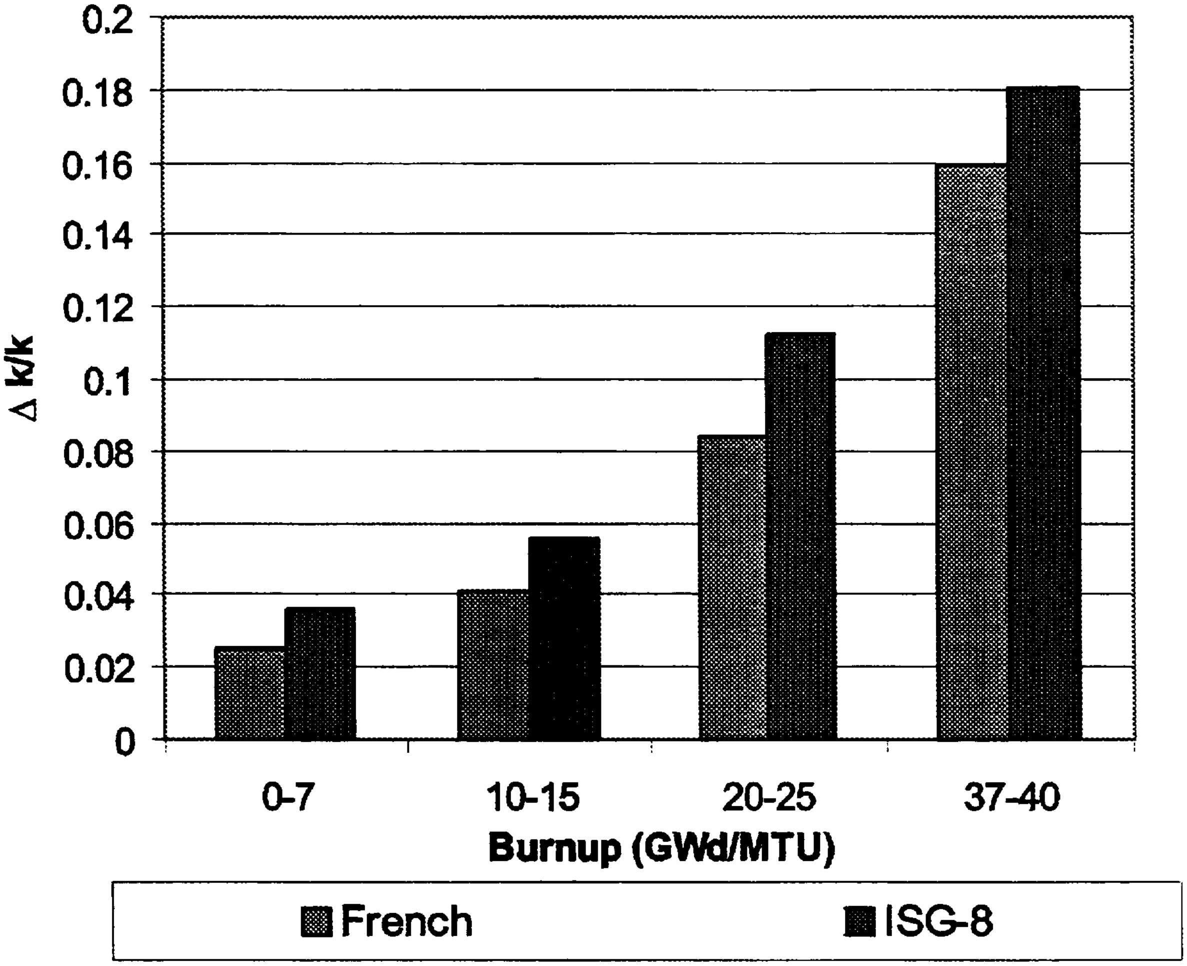

Figure 3 Comparison of burnup credit for OECD cask model using French and ISG-8 methodologies

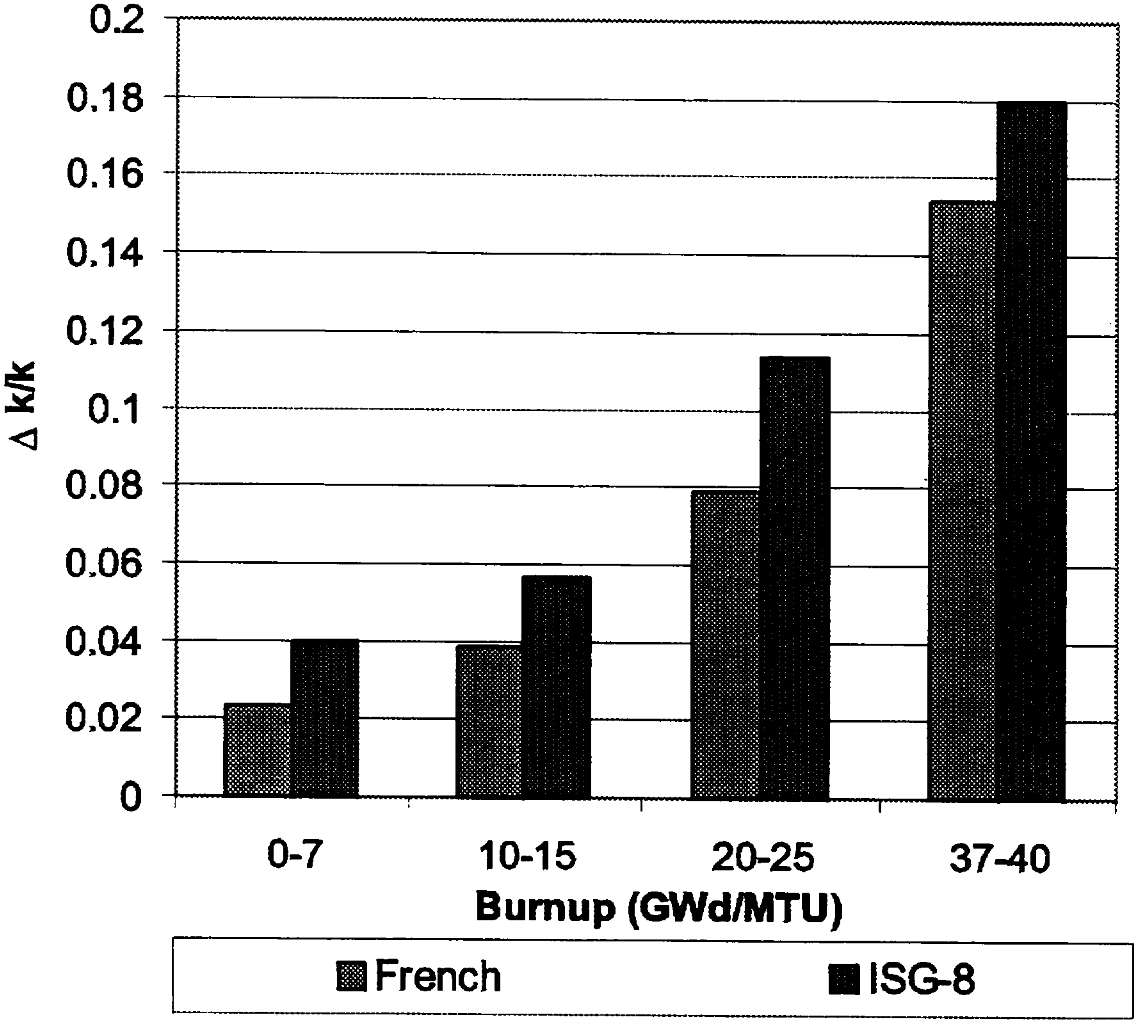

Figure 4 Comparison of burnup credit for GBC-32 cask using French and ISG-8 methodologies

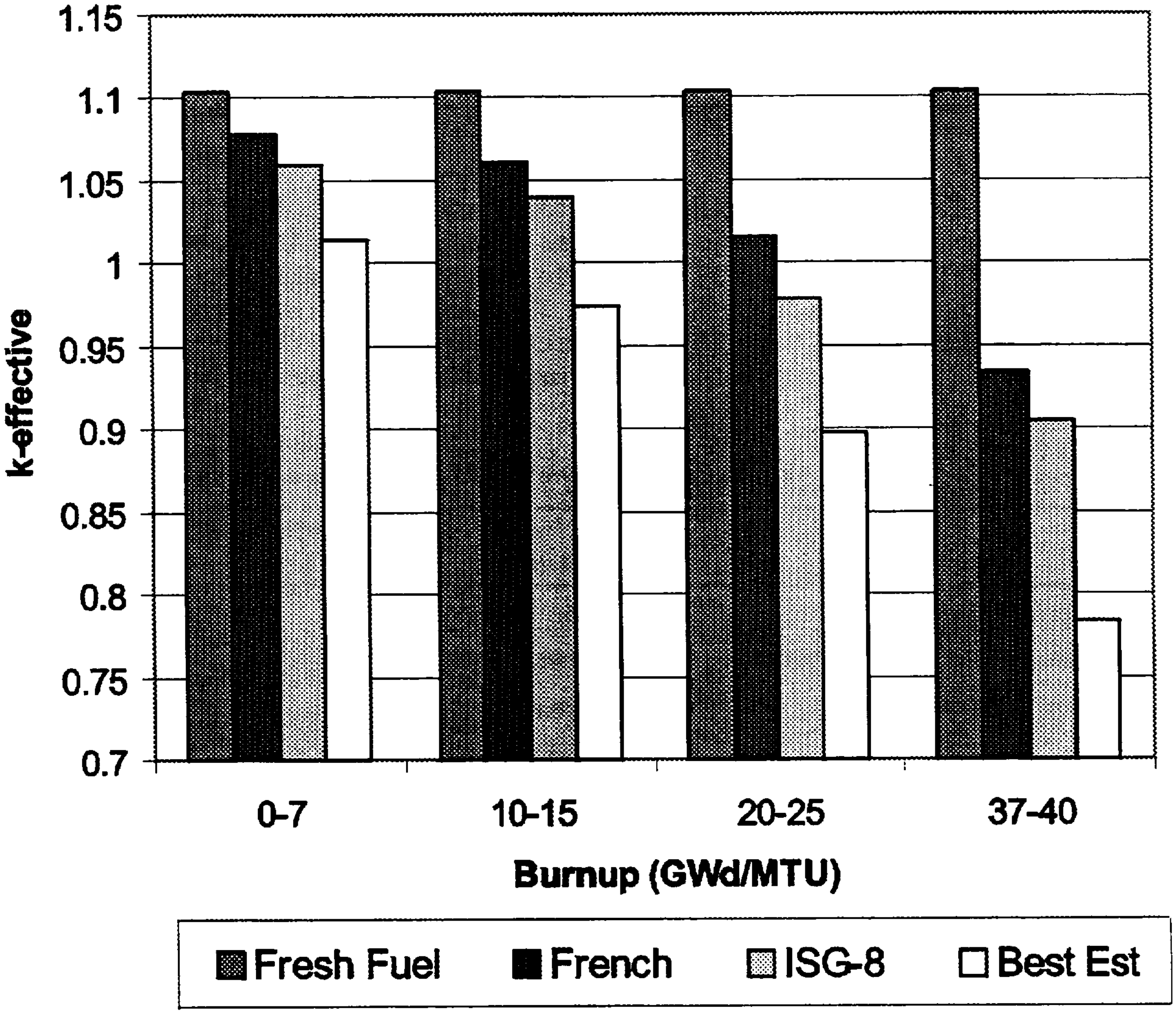

Figure 5 Comparison of calculated k-effectives for GBC-32 cask model using various methodologies

4.2 UNCHARACTERISTIC AXIAL-BURNUP PROFILES

The results for the uncharacteristic, high-burnup assemblies N863 and D102 are listed in Table 6 and are plotted in Figure 6. The results for the two assembly profiles only change for the French methodology and the best-estimate calculations, because the ISG-8 calculations have applied a bounding axial profile that is independent of the actual assembly profile.

The results show that the ISG-8 approach still yields a larger amount of burnup credit than the French approach for either of the two extreme burnup profiles assessed. The amount of credit provided by the two methods is very similar for assembly N863 (with a relatively small gradient); the assembly D102 profile (with a large gradient) resulted in significantly less credit using the French approach. If viewed from the perspective of subcritical margin (i.e., comparison of the French and ISG-8 results with the best estimate results rather than fresh fuel results), the amount of margin provided by both burnup credit methods is larger for assembly N863 than D102.

Table 6 Criticality results for uncharacteristic PWR assembly profiles in GBC-32 cask

	$k_{eff} \pm 1\ \sigma$	$k_{eff} \pm 1\ \sigma$	Burnup Credit ($\Delta k/k$)[a]	Burnup Credit ($\Delta k/k$)
Assembly profile	D102	N863	D102	N863
French burnup factor[b]	0.66387	0.83894		
Fresh fuel (3.75-wt %)	1.1145 ± 0.0011	1.1145 ± 0.0011		
French	0.9813 ± 0.0011	0.9423 ± 0.0010	0.1195	0.1545
ISG-8	0.9213 ± 0.0011	0.9213 ± 0.0011	0.1734	0.1734
Best-estimate	0.8479 ± 0.0011	0.7901 ± 0.0009		

[a] Defined as $(k_{fresh} - k_{credit})/k_{fresh}$.

[b] Defined as the ratio of the burnup averaged over the least irradiated 50 cm of the assembly to that of the entire assembly.

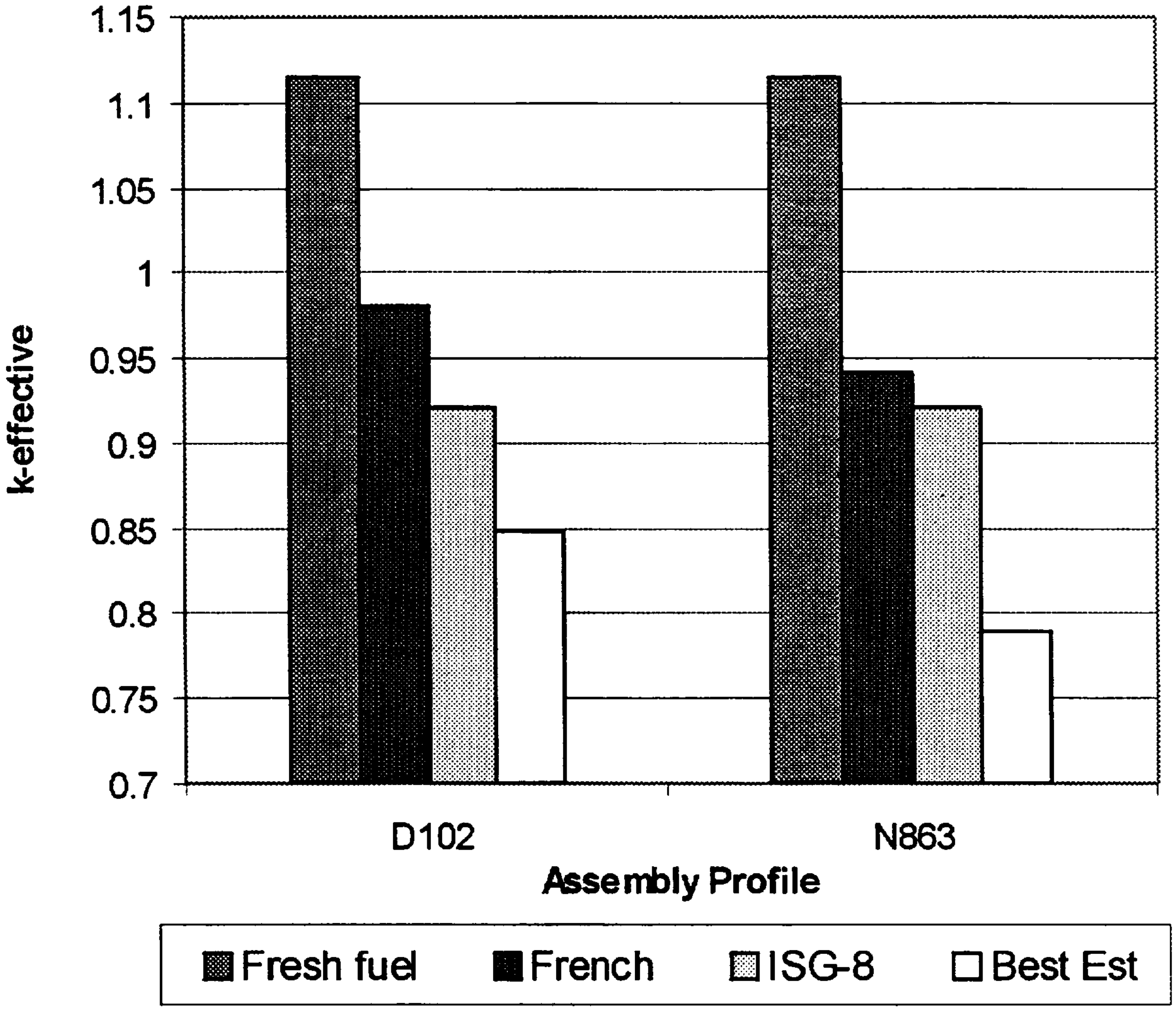

Figure 6 Comparison of calculated k-effectives for uncharacteristic profiles and GBC-32 cask.

5 CONCLUSIONS

The methodologies for actinide-only burnup credit in ISG-8 and current French practice generally lead to similar levels of burnup credit. For the assembly types allowed within the recommendations of ISG-8, the French approach is slightly more restrictive for all burnups and axial profiles considered. The differences between the OECD and GBC-32 cask designs did not have a significant impact on the predicted level of burnup credit. ISG-8 provides typically 2% more burnup credit in terms of k_{eff} than the French approach for typical PWR axial-burnup profiles. A significant part of the difference between the two methodologies is attributed to ^{241}Am buildup in the ISG-8 calculations, whereas ^{241}Am is excluded as a burnup credit actinide in the French calculations. The buildup of ^{241}Am from the decay of ^{241}Pu (14.4 y half-life) is a significant contributor to the decrease in k_{eff} for actinide-only calculations for spent fuel with a cooling time of 5 years. The elimination of ^{241}Am as a burnup credit actinide in the ISG-8 calculations resulted in an increase in the calculated k_{eff} of the transport casks of between 1 and 2% for the higher burnup assembly groups, significantly reducing the differences between the two methodologies.

Analyses using two uncharacteristic or atypical axial profiles resulted in significantly less burnup credit being provided by the French approach relative to ISG-8 for profiles having a large burnup gradient near the end of the assembly. In all cases and assembly profiles considered, the ISG-8 approach afforded a larger degree of burnup credit than the French methodology.

The burnup credit calculations based on the current French practice of using a uniform burnup to represent the fuel assembly were significantly more straightforward than using the bounding 18-axial-zone profiles proposed in the DOE Topical Report. The lack of any symmetry in the bounding profiles and explicit axial zoning in the central region of the assembly (which can be accurately simulated with a uniform axial burnup) results in a significant overhead in terms of complexity, model preparation, data management, and computational time. Note that the French are currently investigating use of a more complex approach similar to ISG-8[2] as a means to increase the burnup credit provided.

The results presented here are only intended to provide an approximate measure of the amount of burnup credit provided by the ISG-8 guidance with respect to current French practice. The results are based on an analysis of averaged, well-behaved PWR assembly axial profiles, and provide a limited analysis of atypical profiles. The amount of burnup credit and the subcritical margin provided by the respective methodologies will vary depending on the degree of deviation from the typical profiles used in this study. Individual assemblies may exhibit different subcritical margins than those presented here, particularly for assemblies with atypical end-region profiles which have a significant effect on the amount of burnup credit and subcritical margin provided using the current French approach.

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11. ABSTRACT ***(200 words or less)***

This report has been prepared to qualitatively assess the amount of burnup credit (reactivity margin) provided by ISG-8 compared to that provided by the burnup credit methodology developed and currently applied in France. For the purposes of this study, the methods proposed in the DOE Topical Report have been applied to the ISG-8 framework since this methodology (or one similar to it) is likely to form the basis of initial cask licensing applications employing limited burnup credit in the United States. This study limits the scope of the comparison to several of the fundamental burnup credit parameters: the nuclides credited in the analysis, the axial-burnup profile, and the cooling time. An investigation of other parameters, such as horizontal burnup effects and isotopic correction factors to account for biases and uncertainties in calculated actinide compositions, were beyond the scope of this review. This report compares the amount of burnup credit provided by the respective methodologies for typical axial-burnup profiles derived from averaging actual PWR axial burnup distributions. In addition, a limited assessment of several atypical axial burnup distributions is also included.

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