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PRESENT STATUS AND FUTURE DEVELOPMENTS OF THE IMPLEMENTATION OF BURNUP CREDIT IN SPENT FUEL MANAGEMENT SYSTEMS IN GERMANY

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Abstract

This paper describes the experience gained in Germany in implementing burnup credit in wet storage and dry transport systems of spent PWR, BWR, and MOX fuel. It gives a survey of the levels of burnup credit presently used, the regulatory status and activities planned, the fuel depletion codes and criticality calculation codes employed, the verification methods used for validating these codes, the modeling assumptions made to ensure that the burnup credit criticality analysis is based on a fuel irradiation history which leads to bounding neutron multiplication factors, and the implementation of procedures used for fuel loading verification.

1. INTRODUCTION

Burnup credit methodologies are implemented in Germany due to significant increases in the initial enrichment of different fuel assembly types:

1. The PWR Nuclear Power Plants (NPP) of the KONVOI type, NECKARWESTHEIM II (GKN II) and EMSLAND (KKE) are increasing their enrichment from 4.0 wt.-% to 4.4 wt.-%,
2. The PWR NPP of the KONVOI type ISAR II (KKI II) is increasing the initial enrichment from 4.0 wt.-% up to 4.6 wt.-%,
3. The BWR NPP GUNDREMMINGEN B and C (GUN B/C) have increased their initial enrichments up to 4.6 wt.-%.

The spent fuel management systems concerned are:

1. The spent fuel storage ponds at plant site,
2. The dry transport casks, meant to be used in future also for interim dry storage at plant site.

The fuel assembly type of the KONVOI plants has a 18x18 lattice with 24 guide thimbles in case of UO_2 fuel and 4 additional water rods in case of MOX fuel. An isolated, water-flooded, unirradiated and unpoisoned fuel assembly of the UO_2 type attains the neutron multiplication factor k_{eff} of 0.95 at an initial enrichment of 4.4 wt.-%. Therefore, all the 4.6 wt.-% enriched fuel assemblies for KKI II are poisoned with a certain number of Gadolinium (Gd) bearing fuel rods.

As is usual with BWR plants GUN B/C has different fuel assembly types in operation. In the criticality safety analysis made by Siemens AG for the increase of the initial enrichment to

4.6 wt.-% an ATRIUM^{TM} 10 design was taken as a basis and it was assumed that the averaged initial enrichment of this type amounts to 5 wt.-%.

2. REGULATORY STATUS AND ACTIVITIES

2.1. Wet Storage of LWR Fuel

In Germany criticality safety design criteria are laid down in Regulatory Guides of the German nuclear technology committee KTA ("Kerntechnischer Ausschuß") and Safety Standards of the German society of standardization DIN ("Deutsches Institut für Normung).

Burnup credit for wet storage of LWR fuel at nuclear power plants has to comply with the newly developed safety standard DIN 25471 [1] passed in November 1999 and to be published shortly. This standard establishes the safety requirements for burnup credit criticality safety analysis of LWR fuel storage ponds and gives guidance on meeting these requirements. In particular, methods acceptable to validation of fuel depletion and criticality calculation codes are specified, parameters affecting the burnup credit are characterized (e.g., axial and horizontal burnup profiles), and methods acceptable to the verification of the fuel loading procedure are specified.

DIN standards are industry codes. Even though not laid down by the law the KTA regulations are commonly regarded as superior to the DIN standards. The basic criticality safety requirements for wet storage of LWR fuel are laid down in the standard KTA 3602 [2]. This standard does not prohibit burnup credit, but requires to give reasons for deviating from the fresh fuel assumption if burnup credit is employed. Therefore, a working group was set up which has the task to revise the standard KTA 3602 in such a way that this standard endorses the new safety code DIN 25471. This working group will probably have finished its work at the end of the year.

2.2. Dry Transport and Storage of LWR Fuel

Licensing evaluations of dry transport systems are based on the application of the IAEA Safety Standards Series No.ST-1 [3].

There are no national regulations that prohibit application of burnup credit to dry-cask transport and storage. However, because of the fact, that burnup credit for dry-cask transport becomes more and more inevitable due to increasing initial enrichment of the fuel, and because of the increasing importance of dry-cask storage in Germany, the necessity of giving regulatory guidance on applying burnup credit to dry-cask transport and storage is seen. It is planned, therefore, to work out criticality safety standards for burnup credit in dry-cask transport and storage on the analogy of the safety standard DIN 25471.

3. CURRENT AND INTENDED LEVELS OF BURNUP CREDIT

3.1. Storage Ponds at the KONVOI Plants

The existing spent fuel storage racks at the KONVOI plants GKN II, KKE, and KKI II are designed to accommodate fresh and spent fuel with a maximum enrichment of 4 wt.-% U-235.

3.1.1. Storage Ponds at NPP GKN II and NPP KKE

In order to minimize the costs of the reracking necessary due to the increase of the enrichment to 4.4 wt.-% only 320 storage cells (5 racks) are equipped with new absorber channels suitable for accommodating fresh 4.4 wt.-% U-235 enriched fuel. These 320 storage positions suffice to accommodate one full core (193 fuel assemblies) plus one reload batch plus all the fuel assemblies which haven't attained the end of their life time. The remaining 448 storage positions (7 racks) are left unchanged and are used as storage region II. Accordingly, in the criticality safety analysis of this region full burnup credit (actinide plus fission product burnup credit, cp. [4]) was applied. Due to the fact that the storage positions of this region are designed to accommodate fresh and spent fuel with a maximum enrichment of 4 wt.-% U-235 only a low burnup credit of 5 MWd/kg U is required. However, the criticality safety analysis includes already plans for a future increase of the storage capacity of this region from 448 positions to 732 positions. The burnup credit required then is given by the loading curve shown in Figure 1.

The cost savings due to application of burnup credit are about 4 million € per storage pond for the present reracking stage (exchange of 320 absorber channels). This amount includes the material savings due to the reduction of the number of absorber channels to be replaced as well as the cost savings due to the reduction of the waste to be managed (decontamination and disposal of the absorber channels replaced).

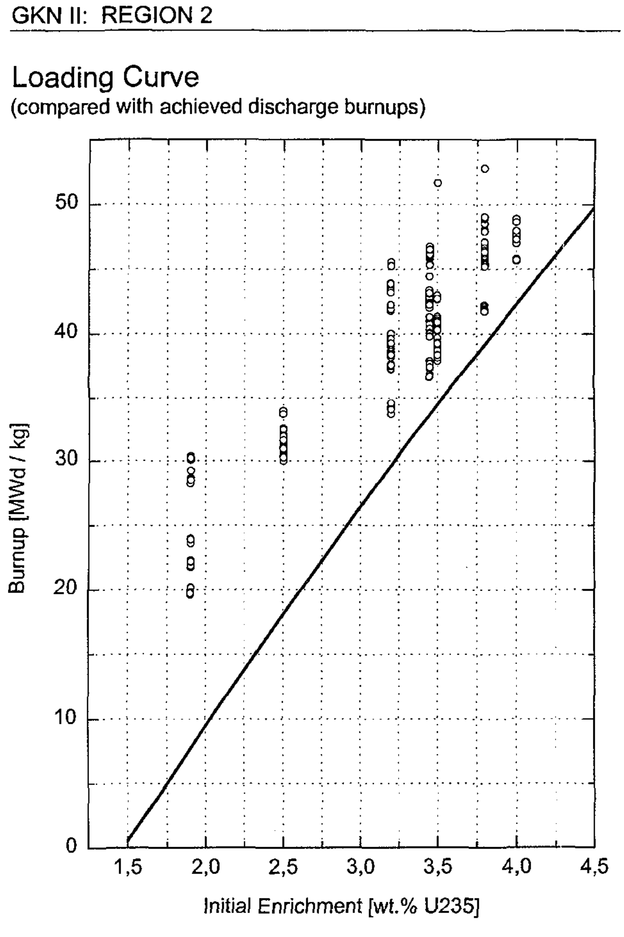

FIG. 1. Storage Pond at NPP GKN2: Loading Curve Referring to the Planned Future Increase of the Region II Storage Capacity.

3.1.2. Storage Pond at NPP KKI II

Due to the fact that each and every 4.6 wt.-% U-235 enriched fuel assembly is poisoned with Gd bearing fuel rods no reracking is required for the storage pond at NPP KKI II. In order to be able to demonstrate this it was necessary to apply the "integral burnable absorber burnup credit level" [4] as an "actinide plus fission product burnup credit level". The following isotopes were included:

1. Actinides: U-235, U-236, U-238, Np-237, Pu-239, Pu-240, Pu-241, Pu-242, and Am-243.
2. Fission Products: Mo-95, Tc-99, Rh-103, Cs-133, Cs-135, Nd-143, Nd-144, Nd-145, Nd-146, Nd-148, Nd-150, Pm-147, Sm-149, Sm-150, Sm-151, Sm-152, Sm-154, Eu-153, Gd-155, Gd-156, Gd-157, as well as the isotopes of the burnable absorber of course.

The methodology applied is similar to the methodology used for wet storage of BWR fuel (see below). Approval of this methodology was obtained in 1999.

3.2. Storage Pond at NPP GUN B/C

In the criticality safety analysis made under the assumption of 5 wt.-% U-235 enriched fuel the "integral burnable absorber burnup credit level" [4] was applied as an "actinide plus fission product burnup credit level". The following isotopes were included:

1. Actinides: U-234, U-235, U-236, U-238, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, and Am-241.
2. Fission Products: Rh-103, Cs-133, Cs-135, Nd-143, Nd-145, Sm-149, Sm-150, Sm-151, Sm-152, Eu-153, as well as the isotopes of the burnable absorber (Gd) of course.

The methodology applied is described in more detail in Reference [5]. Approval of this methodology was obtained in 1999.

3.3. Dry Transport and Storage of LWR Fuel

Limited burnup credits based on the "actinide only level" [4] have been approved for dry transport of LWR fuel. The licensing is based on either the French approach or a fuel assembly minimum average burnup as set forth below.

The standard casks used for shipping and dry storage of spent LWR fuel are the CASTOR casks developed by the Gesellschaft für Nuklear-Behälter (GNB), Essen, Germany.

The cask CASTOR V/52 is licensed to accommodate spent BWR fuel with average initial enrichments up to 4.6 wt.-% ^{235}U. The licensing evaluation of this cask is based on:

1. The fresh fuel approach for initial enrichments less or equal to 4.2 wt.-% ^{235}U,
2. The "uranium plus plutonium isotopes only" burnup credit for initial enrichments greater than 4.2 wt.-% ^{235}U.

If the initial enrichment is greater than 4.2 wt.-% ^{235}U it has to be ensured that the fuel to be loaded is irradiated (this is ensured by checking the cesium γ dose rate) and has a minimum average burnup of 5 MWd/kg U (this is ensured through the analysis of each fuel assembly's exposure history).

GNB applies this "uranium plus plutonium isotopes only" burnup credit concept also to the CASTOR V/19 cask used for shipping and dry storage of spent PWR fuel. This cask is licensed for a maximum averaged enrichment of 4.45 wt.-% U-235 with:

1. The fresh fuel approach for initial enrichments less or equal to 4.05 wt.-% ^{235}U,
2. The "uranium plus plutonium isotopes only" burnup credit for initial enrichments greater than 4.05 wt.-% ^{235}U.

For an enrichment in excess of 4.05 wt.-% the required minimum averaged burnup of 10 MWd/kg U must be ensured on the basis of the irradiation history of the fuel assemblies from the reactor records. Additionally prior to cask loading γ dose rate measurement on each fuel assembly must be performed to ensure loading of irradiated fuel only.

4. CALCULATION CODES

The standards which have to be applied to the calculation codes used and the verification of these codes are laid down in the safety codes KTA 3101.2 [6], DIN 25471 [1], and DIN 25478 [7].

4.1. Depletion Codes and Verification Methods Applied

The depletion code systems mainly used in Germany in conjunction with burnup credit are:

1. The Siemens KWU standard design procedures SAV90 [8] and SAV95 [9] including the depletion codes FASER, MICBURN/CASMO-3G [10-11], and KORIGEN [12],
2. CASMO-4 [13-14] (as well as earlier versions of CASMO – those earlier versions make use of MICBURN to independently perform the integral burnable absorber burnup calculations),
3. The sequence controller SAS2H of the SCALE system [15] running the codes BONAMI-S, NITAWL-II, XSDRNPM-S, and ORIGEN-S.

The Siemens procedures SAV90 and SAV95 are usually used for burnup credit applications to PWR wet storage systems [16]. The depletion codes FASER and MICBURN/CASMO-3G within SAV90 and SAV95, respectively, are applied to determine the isotopic densities at the time of shutdown. To get cooling time dependent isotopic densities the depletion code KORIGEN is used with the cross-section sets generated by FASER or CASMO. The broad and comprehensive verification of the SAV90 and SAV95 procedures is based on observation and evaluation of normal power operation, special measurement programs (reactivity coefficients and equivalents describing the behavior of the reactor, short-term and long-term transients), and analysis of chemical assay data [9, 16]. Among the numerous chemical assay data against which SAV90 and SAV95 were verified are the data from the ARIANE programme [16-17]. It is intended to verify SAV95 also against the outcomes of the REBUS programme [18].

The code CASMO-4 or versions of CASMO prior to version 4 are usually employed for burnup credit applications to BWR wet storage systems [5]. CASMO is a widely used code which is extensively verified against in-core measurement data and chemical assay data (as for instance from the ARIANE programme [17]) as well as critical experiments.

The SAS2H sequence of the SCALE system [15] is usually used for burnup credit applications to dry transport casks. This sequence was verified against numerous experimental data resulting from dissolution experiments and in-core measurement data [19-20]. It is intended to verify SAS2H also against the outcomes of the REBUS programme [18].

Some other depletion codes used in Germany (for instance for WWER fuel depletion calculations) are described in [21-22].

4.2. Criticality Calculation Codes and Verification Methods Applied

The criticality calculation codes mainly employed in Germany are:

1. The KENO module of the SCALE package [15] (usually used with the aid of the criticality safety sequences CSAS25, CSAS2X, CSAS26, and CSAS26X running the codes BONAMI-S, NITAWL-II, and in case of CSAS2X and CSAS26X also XSDRNPM-S for cross-section processing and then the Monte Carlo code KENO V.a or, in case of CSAS26 and CSAS26X, KENO VI),
2. The MCNP code [23],
3. The CASMO code already described above.

The KENO code as well as the MCNP code are verified against a large number of critical experiments and critical configurations:

1. Verifications of fresh fuel and net fissile content burnup credit calculations [4]: Evaluation of critical experiments covering a broad range of systems and fissile material types including homogeneous high- and low-enriched U-235 systems, heterogeneous low-enriched U-235 systems, U-233 systems, and Pu-systems: See [24-26],
2. Verifications of actinide-only burnup credit applications: Evaluation of critical experiments on mixed uranium-plutonium systems: See [24-28],
3. Verifications of integral burnable absorber burnup credit applications: Evaluation of critical experiments on integral burnable poisons: See [26-27],
4. Verification of actinide plus fission product burnup credit applications: Evaluation of reactor critical configurations: See [27, 29],
5. Verification of the temperature dependence of the neutron multiplication factor: See [30],
6. Verification of LWR spent fuel assembly storage pool and cask analysis: See [26, 28].

To evaluate the impact of different cross-section processing methods on the neutron multiplication factor of a spent fuel system comparisons between KENO - used with CSAS25 in conjunction with the ENDF/B-V derived 44-group library 44GROUPNDF5 of the SCALE system [15] - and the MCNP version MCNP4B2 [23] – used with continuous-energy neutron cross-section data available from several libraries [23] – were drawn using the burnup credit benchmark problems specified in [31]. As can be seen from Figures 2 through 4 [16] and in more detail from [31], the KENO and MCNP results are in good agreement.

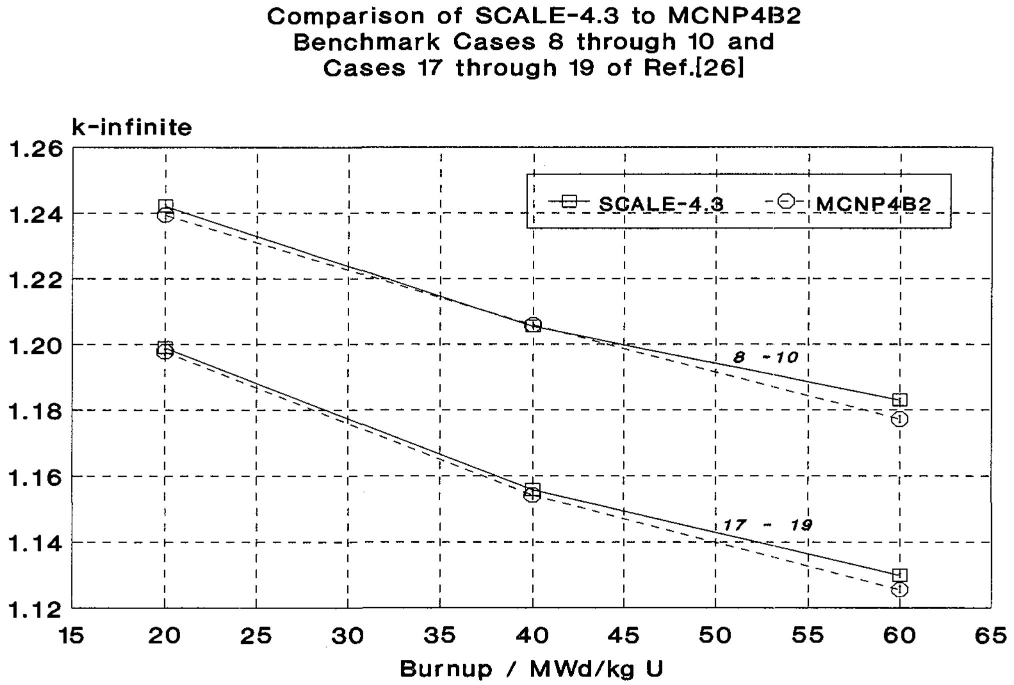

FIG. 2. Comparison of SCALE-4.3 to MCNP4B2 for Benchmark Problems Specified in [31].

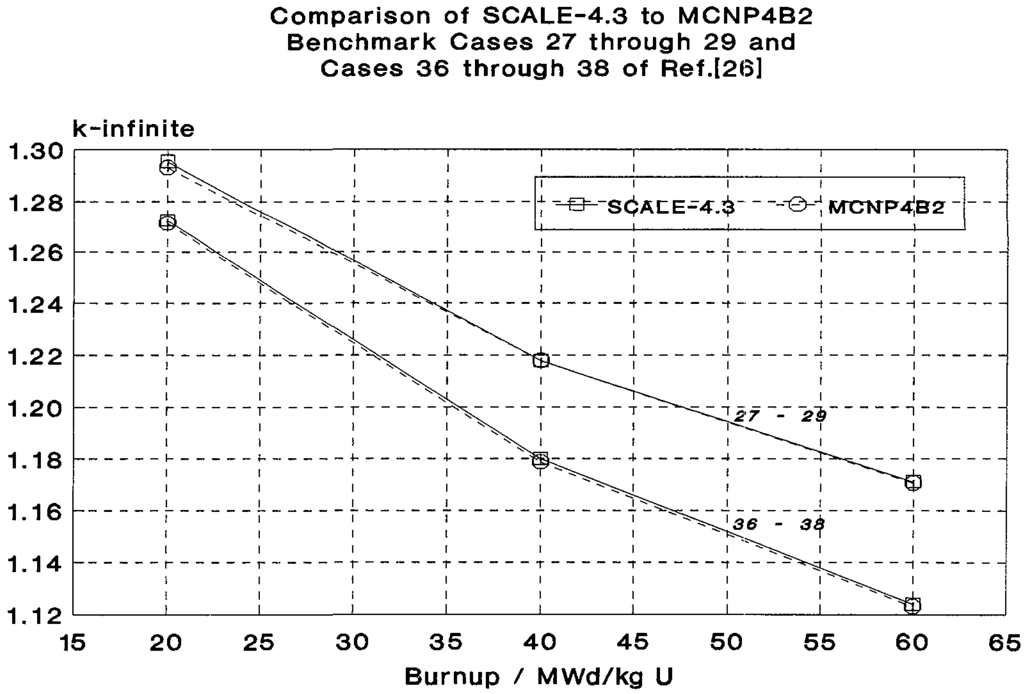

FIG. 3. Comparison of SCALE-4.3 to MCNP4B2 for Benchmark Problems Specified in [31].

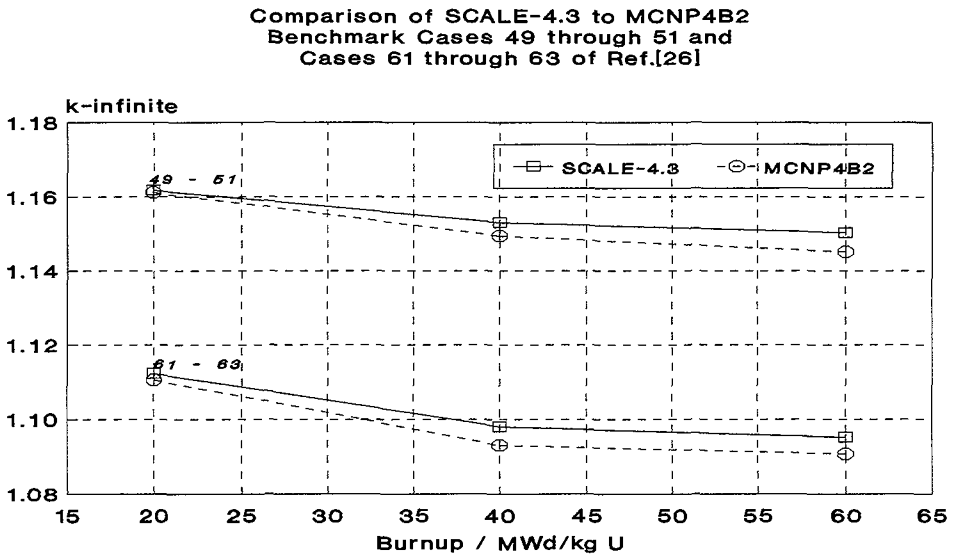

FIG. 4. Comparison of SCALE-4.3 to MCNP4B2 for Benchmark Problems Specified in [31].

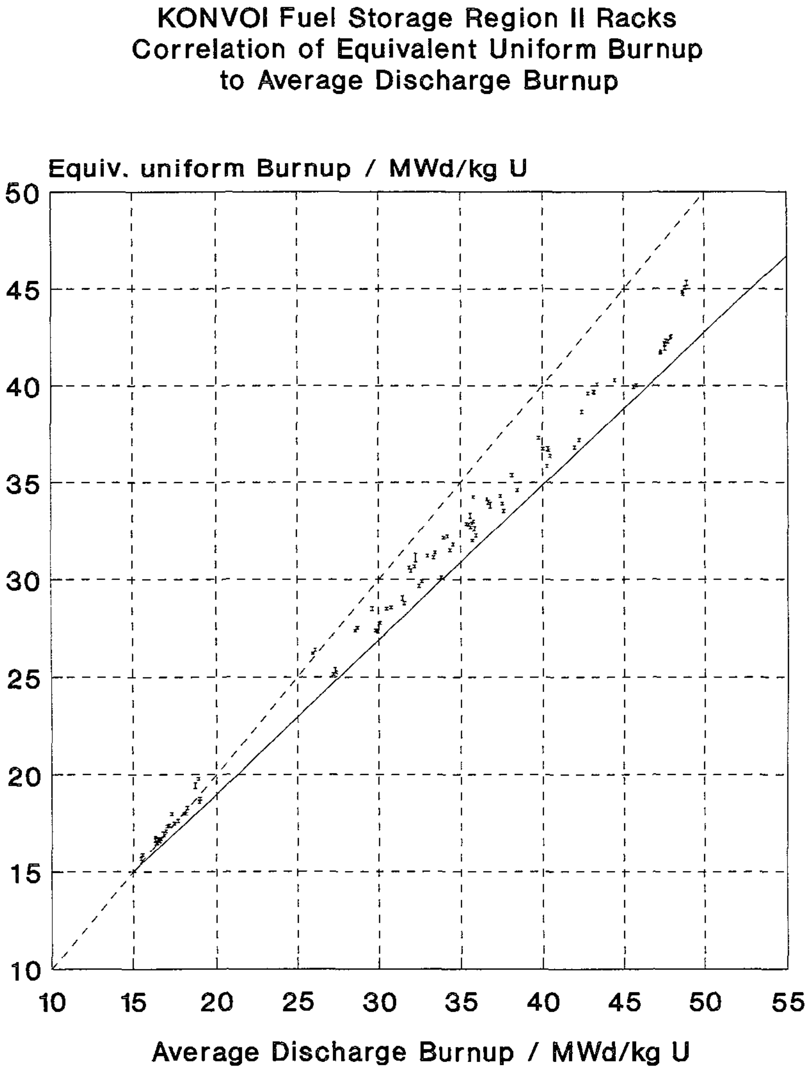

FIG. 5. Effect of Axial Burnup Shapes on Burnup Credit.

5. PARAMETERS AFFECTING BURNUP CREDIT

5.1. Reactivity Effect of Axial Burnup Profiles of PWR Fuel Assemblies

Siemens KWU has collected a big lot of axial burnup profiles based on in-core measurement data from different PWR NPP all over the world. All these data have been evaluated – for each plant separately – using the methods described in [32]. Figure 5 shows for example results obtained for NPP GKN II. This figure shows the "equivalent uniform burnup" as a function of the average burnup of the fuel assemblies. The equivalent uniform burnup is the uniform burnup (uniform burnup means constant burnup over the full active length of the fuel assemblies) which leads to the same neutron multiplication factor of the spent fuel management system of interest as obtained by considering the real axial burnup profile. If the equivalent uniform burnup is less than the average burnup of the profile then the difference Δk between the neutron multiplication factor obtained with the profile and the neutron multiplication factor obtained by assuming a uniform distribution of the average burnup of the profile is positive. If this difference, known as the "end effect", is positive it has to be covered by the loading curve Figure 1. To get an enveloping loading curve the equivalent uniform burnups of a big lot of axial profiles are estimated – each small bar in Figure 5 represents one analyzed profile (the fact that an analyzed profile is represented by a bar in Figure 5 is due to the fact that a Monte Carlo criticality calculation code was applied to determine the neutron multiplication factors). From the results obtained an enveloping correlation between equivalent uniform burnup and average burnup can be derived. This correlation represented in Figure 5 by the solid line (the dashed line corresponds to zero end effect) can be used:

1. First, to correct a loading curve based on the assumption of uniform burnups,
2. Secondly, to segregate non-acceptable axial profiles from acceptable ones: An axial profile is acceptable only then if the related equivalent uniform burnup is not beneath the correlation curve.

5.2. Reactivity Effect of Horizontal Burnup Profiles

Horizontal burnup profiles are covered by the linear model shown in Figure 6. This model gives the difference ΔB between the horizontally averaged burnup of one half of the fuel assembly and the horizontally averaged burnup B_{av} of the entire fuel assembly as a function of B_{av}. The averaged burnup B_{avH} of the higher burned half and the averaged burnup B_{avL} of the lower burned half of the fuel assembly are bounded by the equation $\Delta B = B_{avH} - B_{av} = B_{av} - B_{avL}$. The linear model shown in Figure 6 covers the horizontal profiles presented in [33] as well as horizontal profiles calculated with the SAV90 system described above [8-9].

Results obtained for the difference Δk between the neutron multiplication factor obtained with the model Figure 6 and the neutron multiplication factor obtained for the averaged burnup B_{av} are shown in Figure 7. These results refer to the KONVOI storage region II represented by the loading curve shown in Figure 1.

6. VERIFICATION OF FUEL LOADING PROCEDURES

6.1. Wet Storage of LWR Fuel

According to the safety code DIN 25471 [1] fuel assembly burnup determination based on reactor records without any additional measurements is acceptable. A fuel handling error has to be excluded by virtue of the double contingency principle (i.e., at least two unlikely, independent and concurrent incidents must occur before a misplacement of a fuel assembly that does not meet the region II loading criterion into a region II storage cell can occur).

To meet the double contingency principle NPP GKN II, e.g., is establishing the following procedure: To prevent fuel handling errors an interlock logic protected against malfunction is used for the loading machine hindering this machine from handling operations which are not laid down in a "handling sequence plan" established by an authorized person and checked by an empowered person according to the quality assurance requirements. The "handling sequence plan" is generated with the computer code ALFA [34] which uses appropriate interlock logic schemes to prevent fuel handling errors already at the planning stage. Fuel handling operations cannot be executed until the "handling sequence plan" is installed in the control unit of the fuel handling machine by an authorized person.

A similar procedure is intended to be used for the wet storage pond of NPP KKE.

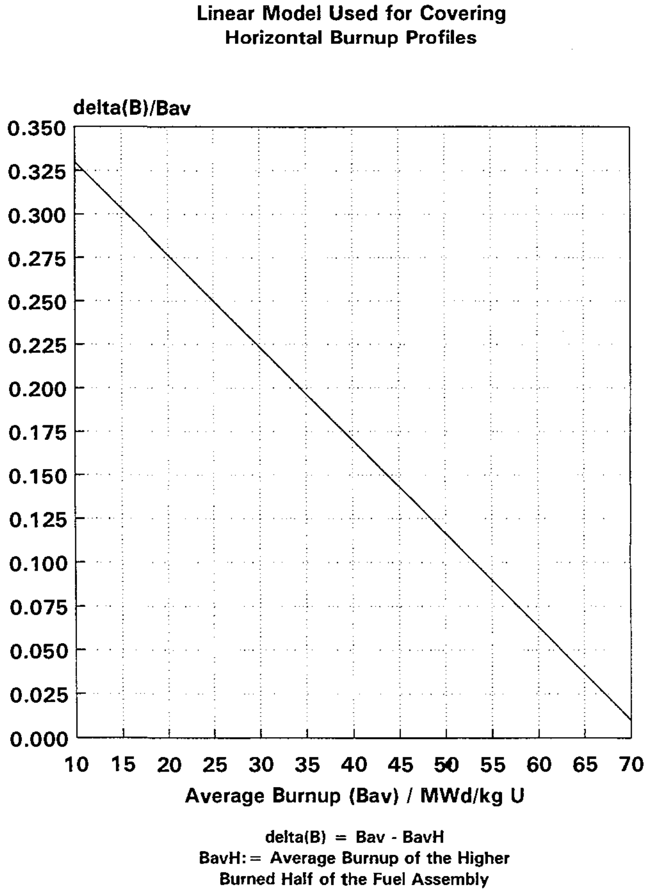

FIG. 6. Linear Model Used for Horizontal Burnup Profiles (See Equation (16) in Reference [32]).

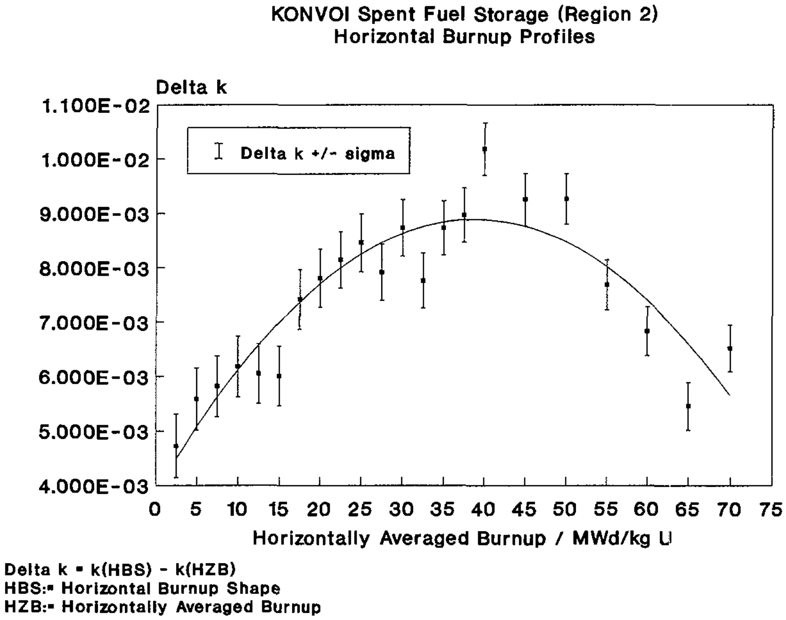

FIG. 7. KONVOI Storage Region II: Effect of Horizontal Burnup Profiles (cp. [32]).

6.2. Dry Transport of LWR Fuel

Verification of the loading procedure by measurement is required as set forth below:

1. If the licensing is based on the fuel assembly minimum average burnup approach described in section 3.3 only a qualitative burnup verification measurement is necessary, as already described in section 3.3. The required minimum level of burnup is verified from the reactor records,
2. If the licensing is based on the French approach a quantitative burnup verification measurement is required. The NPPs Grohnde and Brokdorf, e.g., use the French PYTHON device [35] for this purpose.

7. SUMMARY

Application of the "actinide plus fission product burnup credit level" to wet LWR storage ponds at plant site is now introduced in Germany. A criticality safety standard is established in this matter, the methodologies used are well established and approvals of these methodologies are obtained.

Further development of the burnup credit methodologies applied to dry-cask transport is required due to increasing initial enrichment of the fuel. Dry-cask storage has to be included due to its increasing importance in Germany. One of the most important steps on the road to full burnup credit will be the evaluation of the outcomes of the REBUS programme [18].

REFERENCES

[1] DIN 25471, Kritikalitätssicherheit unter Anrechnung des Brennelementabbrandes bei der Lagerung und Handhabung von Brennelementen in Brennelementlagerbecken von Kernkraftwerken mit Leichtwasserreaktoren (Criticality safety taking into account the burnup of fuel elements when handling and storing nuclear fuel elements in fuel pools of nuclear power stations with light water reactors), DIN Deutsches Institut für Normung e.V., Berlin, to be published shortly.

[2] KTA 3602, Lagerung und Handhabung von Brennelementen, Steuerelementen und Neutronenquellen in Kernkraftwerken mit Leichtwasserreaktoren, Kerntechnischer Ausschuß (KTA), Sicherheitstechnische Regel des KTA, Carl Heymanns Verlag KG Berlin und Köln.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the safe transport of radioactive material - 1966 Edition, Safety Standards Series No. ST-1/Requirements, STI/PUB/998, Vienna (1996).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, "Implementation of burnup credit in spent fuel management systems", Proceedings of an Advisory Group meeting held in Vienna, 20-24 October 1997, IAEA-TECDOC-1013, April (1998).

[5] NEUBER, J.C., "Criticality Analysis of BWR Spent Fuel Storage Facilities Inside Nuclear Power Plants", Proceedings of the "Sixth International Conference on Nuclear Criticality Safety", ICNC'99, September 20-24 (1999) Versailles.

[6] KTA 3101.2, Auslegung der Reaktorkerne von Druck- und Siedewasserreaktoren, Teil 2: Neutronenphysikalische Anforderungen an Auslegung und Betrieb des Reaktorkerns und der angrenzenden Systeme, Kerntechnischer Ausschuß (KTA), Sicherheitstechnische Regel des KTA, Carl Heymanns Verlag KG Berlin und Köln.

[7] DIN 25478, Einsatz von Berechnungssystemen beim Nachweise der Kritikalitätssicherheit (Application of Computer Codes for the Assessment of Criticality Safety), Deutsche Norm, Beuth Verlag GmbH Berlin.

[8] KOEBKE, K., AMBROSIUS, G., HETZELT, L., MERK, S., WINTER, H.J., The Core Design Procedure SAV90 for Pressurized Water Reactors, Kerntechnik 57 (1992) 37-40.

[9] BERGER, H.-D., NEUFERT, A., HETZELT, L., "Advanced PWR Core Design by Siemens/ KWU: Method – Experience", Proceedings Technical Meeting of the "Fuel Assembly" and "Reactor Physics and Calculational Methods" Groups of the German Nuclear Society (KTG), Forschungszentrum Karlsruhe, 3/4 February (1998) 41 – 49.

[10] EDENIUS, M., GRÄGG, C., MICBURN-3, Microscopic Burnup in Burnable Absorber Rods, Studsvik Nuclear, STUDSVIK/NFA-89/12, November (1989).

[11] EDENIUS, M., FORSSÉN, B.H., CASMO-3, A fuel Assembly Burnup Program, Studsvik Nuclear, STUDSVIK/NFA-89/3, December (1989).

[12] FISCHER, WIESE, Verbesserte konsistente Berechnung des nuklearen Inventars abgebrannter DWR-Brennstoffe auf der Basis von Zell-Abbrand-Verfahren mit KORIGEN, KFK 3014, January (1983).

[13] CASMO-4, A Fuel Assembly Burnup Program, User's Manual. STUDSVIK/SOA-95/1.

[14] CASMO-4, A Fuel Assembly Burnup Program, Methodology STUDSVIK/SOA-95/2.

[15] "SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation", NUREG/CR-0200, Rev. 6; NUREG/CR-6182, Vol. 1; ORNL/NUREG/CSD-2/R6, V. 1-3; ORNL/TM-12663/V1.

[16] NEUBER, J.C., "Criticality Analysis of PWR Spent Fuel Storage Facilities inside Nuclear Power Plants", International Symposium on Storage of Spent Fuel from Power Reactors, IAEA, Vienna, 9 - 13 November 1998, IAEA-TECDOC-1089, Vienna July (1999) 257-278.

[17] BASSELIER, J., LIPPENS, M., ABELOOS, C., "A Detailed Investigation of the Source Term Devoted to UO_2 and MOX High Burnup LWR Fuel through the ARIANE International Programme", Proceedings Technical Meeting of the "Fuel Assembly" and "Reactor Physics and Calculation Methods" Groups of the German Nuclear Society (KTG), Forschungszentrum Karlsruhe, 3/4 February (1998) 161 - 169.

[18] BASSELIER, J., MALDAGUE, T., RENARD, A., AID ABDERRAHIM, H., BODART, S., D'HONDT, P., VAN DER MEER, K., RYPAR, V., SVOBODA, C., VASA, I., "Critical Experiment with Spent Fuel for Burn-up Credit Validation (REBUS International Programme)" Proceedings of the "Sixth International Conference on Nuclear Criticality Safety", ICNC'99, September 20-24 (1999) Versailles.

[19] HERMAN, O.W., et al., Validation of the Scale System for PWR Spent Fuel Isotopic Composition Analyses, ORNL/TM-12667, Oak Ridge National Laboratory, March (1995).

[20] DEHART, M.D., HERMAN, O.W., An Extension of the Validation of SCALE(SAS2H) Isotopic Predictions for PWR Spent Fuel, ORNL/TM-13317, ORNL, September (1996).

[21] NEUBER, J.C., "Present Status and Future Developments of the Implementation of Burnup Credit in Spent Fuel Management Systems in Germany", INTERNATIONAL ATOMIC ENERGY AGENCY, "Implementation of burnup credit in spent fuel management systems", Proceedings of an Advisory Group meeting held in Vienna, 20-24 October 1997, IAEA-TECDOC-1013, April (1998) 39-49.

[22] HESSE, U., GMAL, B., VOGGENBERGER, Th., BALEANU, M., LANGRENBUCH, S., "KENOREST- A New Coupled Code System based on KENO and OREST for Criticality and Burnup Inventory Calculations", to be presented on the TCM on "Evaluation and Review of the Implementation of Burnup Credit in Spent Fuel Management Systems, July 10-14 (2000) Vienna.

[23] BRIESMEISTER, J.F., Ed., MCNP - A General Monte Carlo N-Particle Transport Code, Version 4A, LA-12625, 1993; Version 4B, LA-12625-M, March (1997).

[24] EMMET, M.B., and JORDAN, W.C., Guide to Verification and Validation of the SCALE-4 Criticality Safety Software, NUREG/CR-6483, ORNL/TM-12834, November (1996).

[25] DEHART, M.D., BOWMAN, S.M., Validation of the SCALE Broad Structure 44-Group ENDF/B-V Cross-Section Library for Use in Criticality Safety Analyses, NUREG/CR-6102, ORNL/TM-12460, September (1994).

[26] NEA NUCLEAR SCIENCE COMMITTEE, International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03/I through VII.a, NUCLEAR ENERGY AGENCY, OECD Paris.

[27] BOWMAN, Stephen M. , DEHART, Mark D., and PARKS, Cecil V., Validation of SCALE-4 for Burnup Credit Applications, Nuclear Technology Vol. 110 (1995) 53–70.

[28] NEUBER, J.C., TIPPL, W., Validation of SCALE-4.4/KENO V.a/VI and the ENDF/B-V Derived Cross Section Library 44GROUPNDF5 (Rev. 9) for High Density Fuel Storage Configurations, Siemens AG, Power Generation Group (KWU), Calculation Report NDM3/99/E6499, Offenbach, August 17 (1999).

[29] DEHART, M.D., Scale-4 Analysis of Pressurized Water Reactor Critical Configurations: Volume 1 — Summary, ORNL/TM-12294/V1.

[30] NEUBER, J.C., TIPPL, W., Integration of WORKER into NITAWL-II, Siemens AG, Power Generation Group (KWU), Technical Report KWU BT33/94/E097, Offenbach December 22, (1994).

[31] BOWDEN, Russel L., THORNE, Peter R., "OECD/NEANSC Burnup Credit Criticality Benchmark Results of Phase IV-A, Draft Version 1, May (1999).

[32] NEUBER, Jens-Christian, "Burnup Credit Applications to PWR and BWR Fuel Assembly Wet Storage Systems", Proceedings of the "1998 International Conference on the Physics of Nuclear Science and Technology", Long Island, New York, October 5-8 (1998).

[33] U.S. DEPARTMENT OF ENERGY, Topical Report on Actinide-Only Burnup Credit for PWR Spent Nuclear Fuel Package*s*, DOE/RW-0472 Rev. 1, May (1997), Rev. 2, September (1998).

[34] JOHANN, H.-G., NEUBER, J.C., "The Neckarwestheim Fuel Handling Procedure", presented on the TCM on "Evaluation and Review of the Implementation of Burnup Credit in Spent Fuel Management Systems, July 10-14 (2000) Vienna.

[35] LEBRUN, A., BIGNAN, G., RECROIX, H., HUVER, M., "Characterization of Spent Fuel Assemblies for Storage Facilities Using Non Destructive Assay", International Symposium on Storage of Spent Fuel from Power Reactors, IAEA, Vienna, 9 - 13 November 1998, IAEA-TECDOC-1089, Vienna July (1999) 247-255.