REFINEMENT OF THE LOADING CURVE DETERMINATION METHODOLOGY AND MODELING FOR SWISS PWR SPENT FUEL FINAL DISPOSAL CANISTERS

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ABSTRACT

The evaluation in terms of criticality safety of a final disposal concept in the post-closure phase is in general a regulatory requirement in countries that have to dispose of spent nuclear fuel. Nagra, the Swiss National Cooperative for the Disposal of Radioactive Waste, is presently elaborating the criticality safety assessment for the Swiss high-level waste deep geological repository concept. Nagra's safety concept relies on natural and technical barriers. In the initial phase of the repository, a carbon steel canister assures complete containment of the SF. In this context, a criticality safety evaluation methodology for the final disposal concept is developed and investigated at the Paul Scherrer Institute (PSI), in collaboration with Nagra. This research work is organized within the collaborative RD&D project "BUCSS-R", presently in its third phase (2023 – 2027). The methodology devised at PSI pursues a best estimate plus uncertainty assessment approach and includes burnup credit as the basis for the determination of loading curves, in view of the re-packaging of the spent fuel in final disposal canisters.
In the previous phase of the project, phase II (2019 – 2022), a number of methodological and modeling advancements and refinements with respect to phase I (2015 – 2017) have been implemented. These developments include a consistent nuclear data uncertainty quantification, the revision of bounding burnup radial and axial profiles, as well as the analysis of extended sets of fuel assemblies with specific enrichments. The preliminary results, illustrating the effects of these and other recent developments on the preliminary loading curves shapes, are presented in the given paper.

KEYWORDS

Geological disposal, Criticality safety assessment, Burnup credit, Spent nuclear fuel

1. INTRODUCTION

In the years 2014-2017, the first phase of the criticality safety assessment (CSA) project BUCSS-R (Burnup Credit System for the Swiss Reactors–Repository case) has been carried out at the Paul Scherrer Institute (PSI) in collaboration with the Swiss National Cooperative for the Disposal of Radiactive Waste (Nagra). The aim of this project was the development of a burnup credit (BUC) methodology for applications to long-term geological disposal of spent nuclear fuel (SNF) [1]. As a result, exemplary SNF loading curves (LCs) were obtained for the loading of a final disposal canister (ELB) with pressurized water reactor (PWR) fuel assemblies (FAs) from the Swiss PWR spent fuel inventory, based on the preliminary ELB design proposed by Nagra [2]. These LCs indicate the minimum average FA burnup (BU) required for FAs of a given initial fuel enrichment, so that the neutron multiplication factor (k_{eff}) of an ELB loaded with these FAs complies with the imposed criticality safety criterion. The CSA methodology developed within the BUCSS-R project pursues a best estimate plus uncertainty (BEPU) approach complemented by certain conservative assumptions regarding the spatial BU distribution of the FAs.

A second phase (BUCSS-R II) of the project from 2019 to 2022 aimed at a further improvement of the CSA methodology, associated uncertainty quantifications (UQ), a revision of bounding axial and radial BU profiles and thereby refined SNF LCs. Furthermore, simplified long-term post-closure degradation scenarios of the ELB and FAs in terms of criticality safety were investigated [3]. This conference contribution, on the other hand, is presenting the results with a focus on the LCs, associated uncertainties and k_{eff} penalties. Since BUCSS-R II is based on the outcomes of BUCSS-R I, some information necessary for the LC determination is only mentioned here and not described in depth. For more details, the reader be referred to [1] and the references therein.

In the determination of the exemplary LCs, only ELB loadings with 4 similar PWR UO_2 SNF assemblies have been considered, as this configuration has been identified as the most critical among several other studied configurations in BUCSS-R I [1].

2. CRITICALITY SAFETY CRITERION

The same criterion for criticality safety as in BUCSS-R phase I has been applied for the derivation of the LCs taking into account BUC. It has originally been adopted from [4] and is formulated as follows:

$$\boldsymbol{k_{eff}\big|_{Bounding\,FA\,pos}(BU) + \Delta k_{eff}^{Ax}(BU) + \Delta k_{eff}^{Rad}(BU) + 2\sigma_{tot}(BU) <} \\ \boldsymbol{< USL = LTB|_{AOA} - \Delta k_{eff}^{AM},} \tag{1}$$

where

$$\boldsymbol{\sigma_{tot}(BU) = \sqrt{\sigma_{ND}^2(BU) + \sigma_{BU-eff}^2(BU) + \sigma_{OP}^2(BU) + \sigma_{TP}^2 + \sigma_{T1/2}^2 + \sigma_{MC}^2},} \tag{2}$$

$$\boldsymbol{\sigma_{ND}^2(BU) = \sigma_{ND}^2{}^{MCNP}(BU) + \sigma_{ND}^2{}^{CASMO}(BU) + 2r\,\sigma_{ND}{}^{MCNP}(BU)\,\sigma_{ND}{}^{CASMO}(BU)} \tag{3}$$

The terms in these formulas are specified in Table I.

Table I. Terms used in the formulation of the criticality safety criterion (σ = standard deviation)

Term	Description
$k_{eff}\big\|_{\text{Bounding FA pos}}$	Neutron multiplication factor of the ELB loaded with the spent SNF placed in the most penalising positions considering the ELB technological tolerances
Δk_{eff}^{Ax}	k_{eff} penalty associated with bounding axial BU profiles
Δk_{eff}^{Rad}	k_{eff} penalty associated with bounding radial BU profiles
USL	Upper Subcritical Limit, for details see [5]
$LTB\big\|_{AOA}$	Lower Tolerance Bound for the particular Area of Applicability (AOA), here limited to LWR fuel. Reported in [5] as **0.99339** for the PSI CSE methodology using MCNPX in conjunction with the ENDF/B-VII.1 library
Δk_{eff}^{AM}	'Administrative margin', usually imposed to cover unknown uncertainties to ensure subcriticality, which is assumed here to be **0.05000** (5000 pcm), i.e. k_{eff} of the system plus calculation bias and uncertainty in the bias must not exceed 0.95. More recently, an administrative margin of 2000 pcm was suggested for very unlikely accident conditions [6].
σ_{ND}	Nuclear data (ND) related uncertainties in k_{eff} emerging from depletion and criticality calculations

σ_{BU-eff}	Uncertainty due to radiation/BU-induced changes/effects
σ_{OP}	Uncertainty due to reactor operating conditions
σ_{TP}	Uncertainties due to tolerances in the technological parameters
$\sigma_{T1/2}$	Uncertainties in k_{eff} caused by uncertainties in the decay constants
σ_{MC}	Statistical uncertainties in the Monte Carlo calculations with MCNP6
σ_{ND}^{CASMO}	Uncertainties in k_{eff} due to ND-related uncertainties associated with the calculation of the SNF composition
σ_{ND}^{MCNP}	ND-related uncertainties in the criticality calculations with MCNP6
r	Pearson correlation coefficient of uncertainties in k_{eff} due to ND-related uncertainties associated with depletion/SNF and criticality calculations, respectively. The correlation coefficient is BU dependent.

The k_{eff} penalties Δk_{eff}^{Ax} and Δk_{eff}^{Rad} are defined as the difference in calculated k_{eff} values considering nominal BU profiles as from the core follow simulations and determined bounding BU profiles. These differences depend on the fuel enrichment, FA-averaged BU as well as on the cooling time.

The listed components of the total uncertainty $\sigma_{tot}\ (BU)$ are assumed to be random (not systematic) and uncorrelated. Furthermore, $\sigma_{tot}\ (BU)$ is assumed to be normally distributed. Under these conditions, the term $2\sigma_{tot}\ (BU)$ in Eq. 1 is supposed to represent a 95% confidence interval for k_{eff}, which is in line with recommendations provided, for instance, in [7][8].

The criticality safety criteria employed here and the calculation methodology applied for the derivation of the exemplary Swiss SNF LCs are in compliance with the recommendations provided in German standard DIN 25712 [9] and US ANSI/ANS Regulatory Guide 8.27 [10].

3. METHODOLOGY

The CSA methodology developed in this project applies BUC by means of a computational scheme involving depletion (CASMO5), decay (SERPENT2) and criticality (MCNP6.2) calculations, determining k_{eff} eigenvalues of the ELB loaded with the Swiss SNF assemblies, see section 2.3. in [1]. Following the BEPU approach, uncertainties from various sources are quantified and added to the k_{eff} eigenvalues as best estimates. Chapter 5 provides all information regarding the uncertainty assessments.

Although the developed CSA methodology is considered as BEPU, uncertainties concerning the spatial BU distribution within the FAs and their effect on k_{eff} could not be quantified and added to Eq. 2 in the form of a standard deviation. Instead, k_{eff} penalties were calculated separately assuming conservative bounding BU profiles. These penalties, one addressing the axial and one for the radial BU distributions, were then added to the best k_{eff} estimates and the uncertainties, see Eq. 1.

One finding of the previous BUCSS-R phase was the strong impact (Δk_{eff}^{Ax} and Δk_{eff}^{Rad}) of bounding BU profiles as a conservative boundary condition in the pursued BEPU approach on the canister k_{eff} value. The rather coarse method with which, for instance, bounding radial BU profiles have been determined was leading to an excess of conservatism. For this reason, a revision and determination of more realistic yet still conservative set of bounding BU profiles has been recommended. The following chapter addresses this issue.

The models and calculation procedures of BUCSS-R II are based on the developments from BUCSS-R I. Unless explicitly stated otherwise, the same assumptions were made in the second phase of BUCSS-R as in the first one which can be found in [1].

4. CALCULATION ASSUMPTIONS AND UNCERTAINTIES

4.1. Axial Burunp Distribution

Axial BU profiles of the FAs irradiated to different average BUs were retrieved from the PSI CMSYS database. These FA BU profiles consist in the BU values at every axial node of the SIMULATE-3 core-follow simulations. The procedure of determining bounding BU profiles is described briefly here: 1. All BU profiles of interest for which a bounding profile is to be determined are normalized to corresponding average FA BU values. 2. Following standard practice [11], the bounding axial BU profile is then determined choosing the lowest BU values of all the profiles for the first and the last 9 nodes, and the highest normalized BU values of the profiles for the remaining central nodes. 3. The bounding axial profile is re-normalized to conserve the total weight of the BU values at all axial nodes and to maintain the original FA average BU.

At the time of the second phase of the BUCSS-R project, only BU data from power plant operation cycles 01 - 34 were available. These data include FAs of different types: UO_2, Mixed Oxide Fuel (MOX) and Enriched Reprocessed Uranium (ERU). MOX FAs were not considered in BUCSS-R I and II, data from MOX FAs were therefore excluded in the process of determining bounding BU profiles. Fig. 1 (left) shows the normalised axial BU profiles of FAs with a length of 40 axial nodes at the end-of-cycle (EOC). Note that one and the same FA can contribute several profiles to the plot as it can be burned in several cycles. Axial profiles from ERU FAs do not show a different behaviour than those from UO_2 FAs. From cycle 12 until cycle 19, also UO_2 FAs with differing enrichments in their segments were utilized. These FAs featured a fuel enrichment of 1.9 $^{w}/_{0}$ in the first two segments and enrichments of 3.48 $^{w}/_{0}$, 3.5 $^{w}/_{0}$ or 3.59 $^{w}/_{0}$, respectively, in all the other segments. The axial BU profiles of these FAs are marked in black in Fig. 1 (left) and referred to as FAs with “mixed” enrichment in the following.

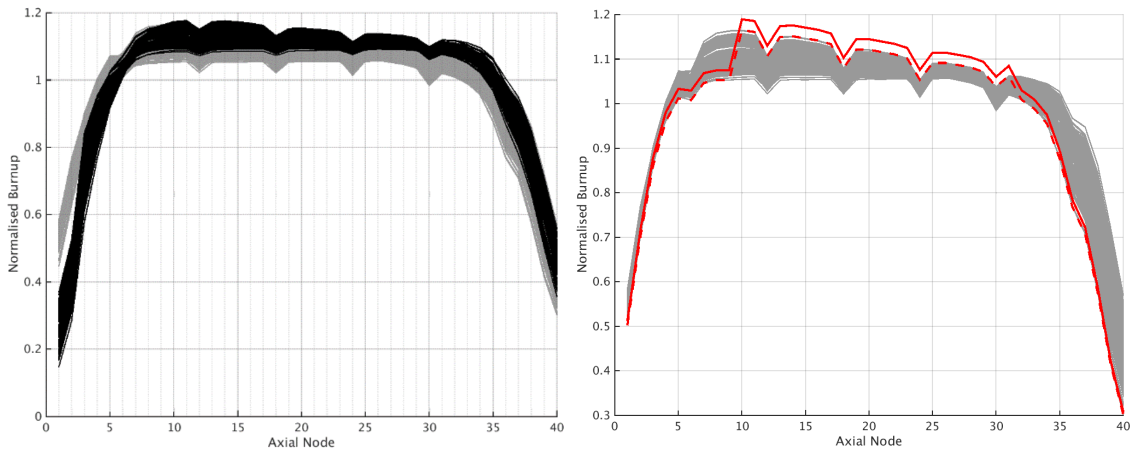

Figure 1. Left: Normalised axial BU profiles of all non-MOX FAs with 40 nodes at EOC up to cycle 34. FAs with mixed enrichment (1.9 w/0 and 3.48 w/0, 1.9 w/0 and 3.5 w/0, 1.9 w/0 and 3.59 w/0) marked in black. Right: All axial BU profiles of FAs with enrichment greater than 4.5 w/0 in grey. In red: Bounding axial profile (dashed: without re-normalisation; solid: with re-normalisation)

While BUCSS-R I applied only two bounding axial BU profiles, one for FAs with 38 segments and one for FAs with 40 segments, BUCSS-R II instead pursued a different approach determining bounding axial BU profiles for the FAs in a enrichment specific manner. Fig. 1 (right), for instance, shows the axial BU profiles of all FAs with enrichment greater than 4.5 $^{w}/_{0}$ (in grey) and the bounding profile based upon this database (in red). k_{eff} penalties associated with this bounding BU profile were then applied in the LC determination for all FAs with enrichment greater than 4.5 $^{w}/_{0}$.

In total, 5 different bounding axial profiles - and based on them, k_{eff} penalties - were determined for the following subsets of the axial BU profile database: Profiles of FAs with 40 axial nodes and enrichment > 4.5 $^{w}/_{0}$, > 4.0 $^{w}/_{0}$ and ≤ 4.5 $^{w}/_{0}$, ≥ 3.5 $^{w}/_{0}$ and ≤ 4.0 $^{w}/_{0}$ as well as profiles with 40 axial nodes and mixed enrichment. Finally, there were also profiles of FAs with 38 axial nodes.This subdivision of available BU profile data has been chosen as an acceptable compromise between an enhanced specificity and sufficient conservativeness of the determination method of bounding axial profiles.

Results of substituting the original BU profile by the penalizing bounding axial BU profiles while keeping the average assembly BU are presented and compared with results from bounding radial BU profiles in chapter 6, see Fig. 4 for the example of a FA with 4.94 $^{w}/_{0}$ enrichment and actinides plus fission products (AC+FP) BUC. The k_{eff} penalties were then applied in the LC determination.

4.2. Radial Burnup Distribution

In BUCSS-R I, bounding radial profiles were determined based on the publicly open information reported in [12]. They were formulated with equations, derived from real measurements, generating a radial BU tilt varying for each pin row. To avoid an overestimation of the BU in regions of higher power by this coarse method a correction factor of 0.93 had to be applied to the determined bounding radial profiles. This implied a lowered FA BU by 7 % introducing an excess in conservatism.

In the second phase of the BUCSS-R project, on the other hand, BU data from the PSI CMSYS database were available. The radial BU profiles of all FAs in the database were normalized at each axial level to the average BU of the corresponding axial node. Based on the normalized radial BU profiles, 2-dimensional gradients were calculated for every axial node. The profile with the steepest gradient among all FAs and all axial nodes was then identified. This radial profile shows the lowest BU and, thus, the highest concentration of fissile material in one of its sides/corners, which in turn is the most critical aspect considering an ELB loading with 4 similar FAs oriented so that the fissile material is concentrated close to the centre of the ELB. In this procedure, unlike in determination of bounding axial profiles, only FAs at their end-of-life (EOL), i.e. at the end of their operational use, have been considered. Fig. 2 shows an illustration of the bounding radial BU profile for the 15 x 15 pin layout of the FAs.

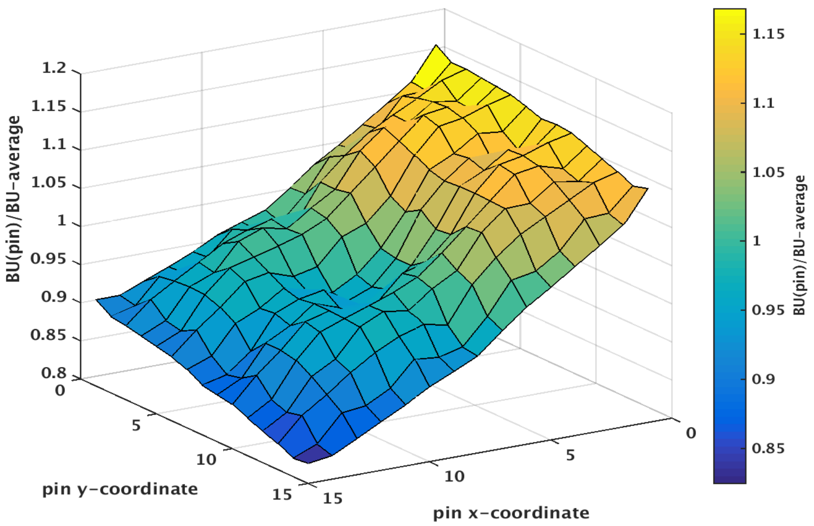

Figure 2. Illustration of the bounding radial BU profile (for the sake of better visibility, gaps in the profile at the position of the guide tubes were filled with 2-d interpolated values).

Upon determination of the conservative bounding radial BU profile, new BUCSS-R calculations were carried out employing the bounding profile in the depletion step of the calculation sequence. The bounding radial BU profile is applied to all FAs and all axial nodes of a FA in the same way, multiplying the average BU of each axial node with the matrix elements of the bounding radial profile to get the corresponding pin BUs. As for the bounding axial BU profiles, this conservative assumption is not part of the BEPU approach of BUCSS-R, but complements it. The criticality calculations later in the BUCSS-R sequence were then performed simulating the most critical FA configuration, i.e. the FAs were oriented so that the corner of the FAs with the lowest BU – and thus the highest amount of fissile material – is the closest to the centre of the ELB. The resulting k_{eff} values were then compared with the ones considering only a planar radial profile, giving k_{eff} penalties for FAs with different enrichment, BU and decay time. Fig. 4 (middle), for example, shows the k_{eff} penalties for FAs of 4.94$^{w}/_{0}$ enrichment in the AC+FP case.

5. UNCERTAINTY ASSESSMENTS

In order to determine the total uncertainties $\sigma_{tot}\ (BU)$ as described in Eq. 2, all contributions had to be quantified. The quantification of ND-related uncertainties σ_{ND} in the computed k_{eff} values, emerging from depletion and criticality calculations, has been reviewed within BUCSS-R II. An in-depth treatment of the new ND-UQ is provided in [13]. Results of an ELB loading with SNF of 4.94 $^{w}/_{0}$ ^{235}U initial enrichment and considering AC+FP as the most conservative case are given in the second column of Table II. Values for σ_{OP} and σ_{BU-eff} were adopted from [14]. All other uncertainties, $\sigma_{T1/2}$, σ_{TP} and σ_{MC}, are minor contributors to σ_{tot} and were adopted from BUCSS-R I. σ_{tot} was then used in the determination of the LCs based on Eq. 1. Table I gives an overview about the BU dependent uncertainty components to σ_{tot} .

Table II. Uncertainty components and total uncertainty evaluations (4.94 w/0 enr.; AC+FP)

Exposure (GWd/t)	σ_{ND}	σ_{OP}	σ_{BU-eff}	σ_{TP}	$\sigma_{T1/2}$	σ_{MC}	1*σ_{tot}	**2***σ_{tot}
0	0.00853	0.00000	0.00000	0.00010	0.00015	0.00025	0.00853	0.01707
17.61	0.00737	0.00100	0.00200	0.00010	0.00015	0.00025	0.00771	0.01542
33.82	0.00672	0.00400	0.00200	0.00010	0.00015	0.00025	0.00808	0.01616
50.47	0.00614	0.00500	0.00700	0.00010	0.00015	0.00025	0.01057	0.02115
61.92	0.00590	0.00500	0.00700	0.00010	0.00015	0.00025	0.01044	0.02087
72.75	0.00585	0.00500	0.00700	0.00010	0.00015	0.00025	0.01041	0.02082

6. LOADING CURVES - UPDATE

LCs for discharged SNF provide the information of how much average BU of an individual FA is required to to ensure undercutting the USL for a full loading of the ELB with 4 similar FAs. This information is provided for different initial enrichments and can serve as acceptance criterion for ELB loadings. The USL is, according to Eq. 1 and the values for $LTB\big|_{AOA}$ and Δk_{eff}^{AM} specified in Table I, calculated as

$$\boldsymbol{USL = LTB|_{AOA} - \Delta k_{eff}^{AM} = 0.99339 - 0.05000 = 0.94339} \tag{4}$$

The LC is determined by solving Eq. 1 for different enrichments and taking once only actinides into account and another time also fission products. Minimum average BU values are, like the $\boldsymbol{k_{eff}}$ penalties addressing axial and radial BU profiles, calculated at decay times of 0, 5, 20000, 30000, 40000 and

50000 years, based on results obtained in BUCSS-R I. The highest of these values is taken as safety criterion and becomes part of the LC. Furthermore, in order to safely cover variations in the operating conditions such as the positioning of the FAs inside the core, the data points of the LC were calculated for a sample of FAs large enough to obtain useful upper tolerance limits (UTLs) with 95% confidence and 95% coverage for every initial enrichment.

Fig. 3 finally shows all calculated minimum average FA BUs in the shape of two LCs, the upper one for the AC only case and the lower one for the AC+FP case. Integrated into the plots are also 95% confidence intervals (CIs) for the true mean of the minimum average BU required, displayed as grey bands.

For an initial enrichment of 4.94 $^{w}/_{0}$ only data from 4 FAs were available, so that no meaningful statistical quantities such as confidence intervals or an upper tolerance limit could be derived. The updated LC also includes data points for initial fuel enrichments which were not yet taken into account in BUCSS-R I, namely for 3.8 $^{w}/_{0}$, 4.42 $^{w}/_{0}$, 4.52 $^{w}/_{0}$, 4.72 $^{w}/_{0}$ and 4.9 $^{w}/_{0}$, enhancing a priori the robustness of the LC. Also the significantly higher number of calculated data points and the derived statistical quantities further increase the confidence in the LCs.

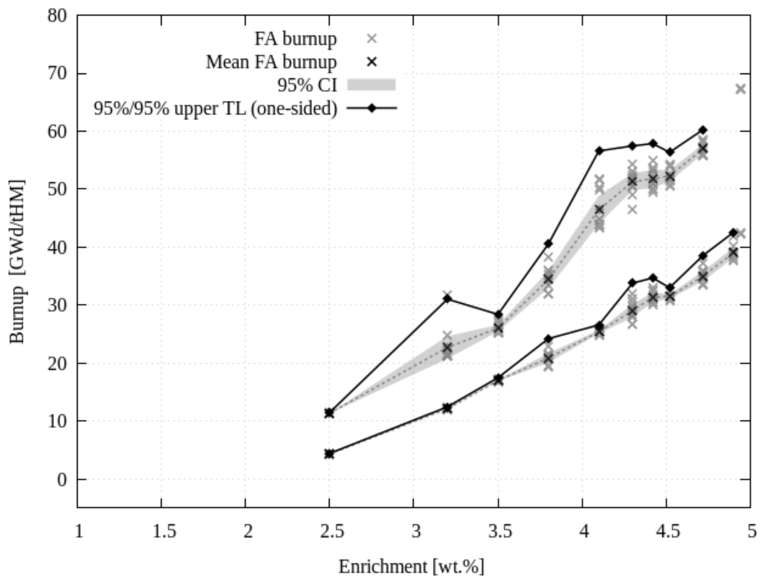

Figure 3. Updated preliminary LCs including all conservative effects for discharged SNF. Upper curve: AC only; Lower curve: AC+FP.

It can be noted, that, with a few exceptions in the AC only case, the values of the new LC are systematically lower than those of the previous LC. Reason is a - in total - lower sum of uncertainties and penalties from bounding radial and axial BU profiles obtained in BUCSS-R II. Fig. 4 compares total uncertainties, penalties from bounding radial BU and penalties from bounding axial BU profiles, respectively, from BUCSS-R I and BUCSS-R II, for the example of a FA with 4.94 $^{w}/_{0}$ initial enrichment and the AC+FP case.

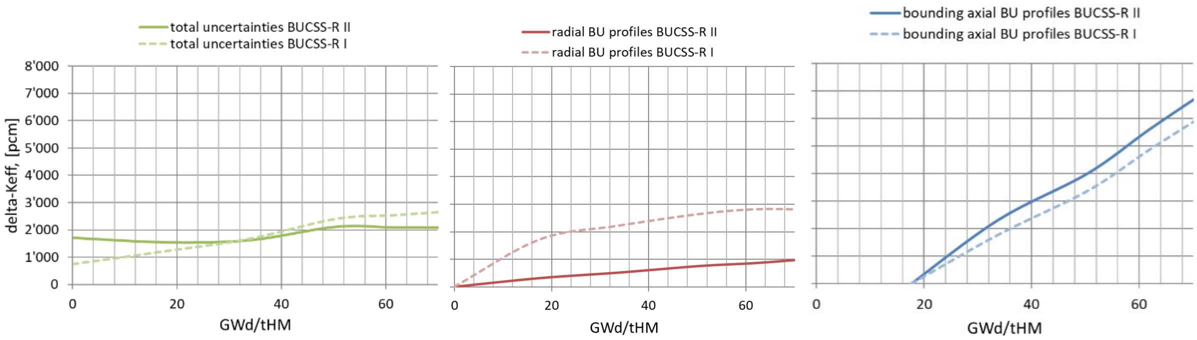

Figure 4. Comparison of total uncertainties in the canister k_{eff} (left), k_{eff} penalties due to bounding radial (middle) and axial (right) BU profiles, obtained in BUCSS-R I and II, respectively. For UO_2 FAs with 4.94 $^{w}/_{0}$ initial enrichment, AC+FP case.

Regarding the k_{eff} penalties from bounding axial BU profiles, it has to be noted, that the difference in the values obtained within BUCSS-R I or II emerges from the correction of a detected error in the implementation of the procedure determining the bounding axial profile. The differences are therefore not to be seen as an effect of the different method to take into account bounding axial BU profiles. In fact, the method of enrichment specific bounding axial BU profiles was leading to negligible differences in the associated penalties as compared to BUCSS-R I.

7. DISCUSSION AND OUTLOOK

Within BUCSS-R II, the ND-UQ has been refined and improved, as well as the bounding axial and radial BU profiles. These refinements were leading to more realistic yet still conservative potential BU requirements for ELB loadings meeting the USL. A comparison of the updated with the previous LC clearly shows the effects of the refined uncertainty contributions and BU profile assumptions.

Although significant improvements could be achieved, further developments and refinements of the LC determination are still possible. The identified potential improvements shall be outlined in this section. The list of possible improvements of BUCSS-R will, however, not be complete. Some more possible ways to improve the reference BUCSS-R methodology were presented in [1].

First of all, it has to be noted that the determination of both, bounding axial as well as radial, BU profiles in BUCSS-R II was exclusively based on CMSYS data of utility operational cycles 01 – 34. It can therefore not be excluded, that taking into account data from later cycles, once they are available, would lead to more conservative and hence more penalizing bounding BU profiles. No margin whatsoever, e.g. in the shape of a conservative correction factor for determining the bounding BU profiles, to compensate for this limitation has been applied in BUCSS-R II.

Furthermore, only data from FAs operated in one single Swiss power plant were considered in the bounding BU profile determination. The implications of this limitation as well as possible solutions for this potential issue, in view of the fact that different FA designs are used in the Swiss NPPs, are currently under discussion.

Considering only axial BU profiles from FAs at their EOL in the determination of a bounding axial reference profile would mark a next step for a further development of BUCSS-R. In fact, already the bounding *radial* reference profile of this study has been determined limiting the selection process to radial profiles only from FAs at their EOL. In this sense, a modification of the – still enrichment specific – bounding axial BU profiles taking into account only FAs EOL would be consistent with the procedure determining the bounding radial BU profile.

The procedure of determining bounding axial BU profiles described in section 3.2. includes the renormalization of calculated bounding axial profiles in order to maintain the FA-averaged BU. This step increases the BU and in turn decreases the amount of fissile material at the end of the FAs with the potential of lower calculated k_{eff} values for the loaded ELB. It is currently unclear, if this procedure step leads to a significant underestimation of k_{eff} within this methodology, eventually compromising the currently assumed conservativeness of the entire procedure. A possible solution would be the omission of this step in case it increases the FA-average BU.

The determined bounding radial BU profile, on the other hand, is currently applied to all FAs independent from their initial enrichment and to all axial nodes. This circumstance represents an excess in conservatism, although this excess is estimated to be rather moderate. A future update of k_{eff} penalties associated to bounding radial BU profiles could take into account also initial enrichment, axial elevation as well as different degrees of BU (at EOL).

The ELB model used for determining the LCs assumes – although filled with water – the full structural integrity of the ELB, i.e. corrosion of any ELB system elements and associated formation of corrosion products are not taken into account. This is an unrealistic assumption considering the design lifetime of the ELBs and the entire safety assessment period of the final disposal repository. Furthermore, other results obtained within BUCSS-R II clearly show the strong effect of magnetite formations on the canister reactivity [3]. Integral part of BUCSS-R III will be therefore the integration of degradation scenarios and a corresponding update of the exemplary LC.

Results from a scoping analysis of k_{eff} uncertainties due to variations in reactor operational parameters and BU induced changes of the geometry in [14], based on a KKG fuel rod sample from a 15 x 15 FA irradiated during 3 cycles up to the sample final BU above 50 GWd/tHM, have been accepted for use in this study. However, a more comprehensive investigation of such uncertainties, covering more representative FAs, various initial enrichments and more assembly-averaged BU values, is intended.

Until now, no calculation biases have been taken into account in the depletion step of the BUCSS-R computation scheme. For this reason, a comprehensive review and summary of all verification and validation studies relevant for the BUCSS-R methodology is planned in the third phase of the project. Based on that, further actions regarding an adaption of the CSA method need to be discussed.

8. CONCLUSIONS

The robustness of the exemplary LCs could generally be enhanced due to the calculation of around 10 data points per initial fuel enrichment, the determination of basic statistical quantities (mean, UTL, CI) based on them and the addition of data points for initial enrichments not yet accounted for in BUCSS-R I.

The exemplary LCs are based on the preliminary and conceptual ELB design proposed by Nagra [2]. The results, together with other findings of BUCSS-R II [3], serve as feedback for Nagra guiding further development of the conceptual ELB design in order to improve its performance.

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