Lessons Learned from International Investigations of Burnup Credit Criticality

OEDC/NEA Working Party on Nuclear Criticality Safety
Expert Group on Burnup Credit Criticality (EGBUC)

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This summary report defines, discusses and makes recommendations related to the physics and analysis of burnup credit criticality on the basis of the combined experience of the OECD/NEA Expert Group on Burnup Credit Criticality (EGBUC) members over the past 15 years. The report emphasizes the relevance of EGBUC benchmark evaluations and comparisons in deriving these conclusions. This report addresses systems containing irradiated Light Water Reactors (LWRs) including Pressurized Water Reactors (*PWRs)*, Boiling Water Reactors (*BWRs)* and water-cooled, water-moderated energy reactors *VVER (Russia-design PWRs).* Studies for PWRs included the use of Mixed-Oxide (MOX) fuels.

The purpose of this presentation is to assess and document the conclusions of the EGBUC members and their experience regarding the importance of various parameters for the implementation of burnup credit as a criticality safety strategy in establishing the safety basis/argument for nuclear material storage, transportation and reprocessing of irradiated LWR (*PWR, BWR and MOX)* fuel. This report also attempts to establish practical rules and identify applicable tools when appropriate. Lessons learned regarding any inconvenience or problem encountered in the experience of performing the international comparison problems will be presented and discussed.

Validation issues are three-fold and are of concern for each fuel type. There is the basic issue related to nuclear data including the efficacy of cross-section data for fission products important to the determination of reactivity in used fuel and the decay data used for the calculation of irradiated fuel isotopics. Direct measurements of the reactivity and composition of used fuel have also been identified as necessary. Lastly, there is the issue of verifying by measurement the burnup (exposure) to be attributed to individual fuel assemblies. Since many of the experimental programmes are not yet in the public domain, mechanisms for disseminating results for the validation of commonly used code/data packages are very valuable. The Experts

Group on BUC has been an important example of how this can be realised. The Working Party for International Cooperation on Nuclear Data Evaluation, JEFF Project also provides a forum for feeding back the lessons learnt from new validation programmes through improvements to nuclear data libraries. Discussions at IAEA Technical Meetings on Burnup Credit are a further useful medium for dissemination, as are various conferences and journals covering criticality safety, notably the ICNC.

Studies of burnup credit for fuel irradiated in PWRS of western design have dominated the work of the EGBUC. The principal concerns address the impact of the axial distribution of burnup across the fuel and how this affects reactivity in the fuel assembly and storage/transportation cask. The effect is dependent on the calculational model (how the axial distribution is represented in the models) as well has how the associated spectral shifts affect the worth of absorbers in features integral to the fuel and the storage/transportation cask. A subgroup within the EGBUC has made duplicate studies for VVER designs. In 1996 the Nuclear Research Institute at Rez (NRI) presented an international VVER Burnup Credit Calculational Benchmark Proposal to participants of the Atomic Energy Research (AER) research activity of the countries operating VVERs. The specification of the benchmark was based on the work of the EGBUC. This benchmark effort supports the use of the BUC methodology development in the VVER environment by demonstrating similar results and sensitivities as identified in the similar studies of western PWRs.

The PWR studies performed by the EGBUC have resulted in the identification of specific improvements needed in nuclear data for europium and gadolinium isotopes, the compilation of available spent fuel assay measurements, need for new critical experiments to address validation issues, the compilation of axial burnup distribution data and the development of statistical techniques to evaluate the effects of these distributions. Phase I and Phase II studies performed by the EGBUC included both criticality and depletion benchmarks for pressurized water reactors (PWRs). A set of selected nuclides including 7 major actinides (U-234, 235, 236, and 238; Pu-239, 240 and 241), 5 minor actinides (Pu-238 and 242; Am-241 and 243; Np-237) and 15 fission products (Mo-95; Tc-99; Ru-101; Rh-103; Ag-109; Cs-133; Sm-147, 149, 150, 151 and 152; Nd-143 and 145; Eu-153; and Gd-155) were used in these studies. The results showed no trends in standard deviation among participants with burnup or cooling time in the criticality analyses. Consistently the largest deviations among participants were for the fresh fuel cases. In the depletion analyses, there was evidence of a significant trend in the standard deviation among participants for the residual U-235 (the trend was small for most other isotopes). A number of nuclides have been identified for additional study based on the sensitivity of k to the observed standard deviations: Pu-239, Gd-155, U235, Pu-241, Pu-240 and Sm-151. Much of the differences are assumed to be in the basic nuclear data. Both 2-D and 3-D models have been used to evaluate the impact of axially distributed burnup. It was determined that 70% of the total fissions occur in the upper 40cm of fuel that illustrates the potential importance of this parameter. Good agreement was seen among the participants relative to the calculated “end effect”. It has been noted by the group that the effect on k is strongly a function of the system being evaluated and may be even more important under postulated accident conditions that result in axial heterogeneity. Two remaining issues associated with the axial effect continue to be investigated in the expert group: (1) limited availability of measured axial profile data and detailed power history data in the open literature, and (2) defining/performing analyses to determine the sensitivities due to different axial burnup profiles across the full range of burnups.

The EGBUC has extended its study to address fuels for Boiling Water Reactors and investigated the sensitivity to the void density distribution, enrichment splits and use of integral absorbers prevalent in fuels for this reactor type. BWRs were addressed in the Phase III studies and included both criticality and depletion benchmarks. For the most part the results are consistent with those for PWRs: the largest deviations among participants are for the fresh fuel cases, and deviations are higher for distributed burnups versus modeling the average burnup. Larger void fractions (i.e., use of a 70% uniform void distribution) tended to increase the deviation among participants. The complex geometry of the BWR fuel assemblies added complexity to the depletion calculation. The Phase III depletion benchmark was intended to compare the predictability of current computer code and data library combinations for the atomic number densities of an irradiated BWR fuel assembly model. The fuel assembly was irradiated under specific power of 25.6 MW/tHM up to 40 GWd/tHM and cooled for five years. The void fraction was assumed to be uniform throughout the channel box and constant, at 0, 40 and 70%, during burnup. The calculated atomic number densities of 12 actinides and 20 fission product nuclides were found to be for the most part within a range of +/−10% relative to the average, although some results, especially ^{155}Eu and gadolinium isotopes, exceeded the band, which will require further investigation. Pin-wise burnup results agreed well among the participants. The results in the infinite neutron multiplication factor k_{eff} also agreed well with each other for void fractions of 0 and 40%; however some results deviated from the averaged value noticeably for the void fraction of 70%. The k_{eff} benchmarks were intended to confirm the predictive capability of the current computer code and data library combinations for the neutron multiplication factor (k_{eff}) of a layer of irradiated BWR fuel assembly array model. The effects of following parameters are investigated: cooling time, inclusion/exclusion of fission product nuclides and axial burnup profile, and inclusion of axial profile of void fraction or constant void fractions during burnup. Axial profiles of fractional fission rates were also compared. The relative dispersion of *keff* values calculated by the participants from the mean value is almost within the band of ±1 %Δk/k. The deviations from the averaged calculated fission rate profiles are found to be within ±5 % for most cases.

MOX fuel derived from commercial grade material and weapons grade materials have also been addressed by the EGBUC for PWRs. The importance of curium isotopes in the evaluation of the reactivity of irradiated MOX fuels was identified. Inclusion of curium isotopes in MOX fuel can increase the reactivity of the system by up to 1000pcm. By taking into account all the reactivity components, total burn-up reactivity credits of approximately 24 %, 32 % and 20 % dk/k can be obtained for first generation MOX, weapons disposition and later generation MOX fuels respectively. In particular, the largest burn-up credit gain can be seen for weapons disposition MOX fuel. For all three MOX fuels, the contribution of the major fission products and cooling time (extending from 1 year to 5 years) to the total burn-up credit was found to be around 9-11 % and 6 % dk/k respectively.

The presentation will summarize the activities of the EGBUC, highlight the current findings by reactor and fuel types and address the future goals of the group. Current studies directed at the evaluation of burnup credit in a geologic repository timeframe and environment will be described.

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