Burnup Credit development and implementation in the Slovak Republic

Vladimír Chrapčiak, VUJE, Slovakia, chrapciak@vuje.sk
Juraj Václav, UJD, Slovakia, juraj.vaclav@ujd.gov.sk

INTRODUCTION

Improved calculation methods allow to take credit for the reactivity reduction associated with fuel burnup. This means reducing the analysis conservatism while maintaining an adequate criticality safety margin. Application of burnup credit (BUC) requires knowledge of the reactivity state of the irradiated fuel for which BUC is taken. The isotopic inventory and reactivity has to be calculated with validated codes.

We use in Slovakia Gd2 fuel with maximal enrichment of fuel pins 4.4%. Our transport and storage basket KZ-48 with boron steel is licensed for fresh fuel with enrichment 4.4%. In near future (2011 or 2012) we will use a new fuel with maximal enrichment of fuel pins 4.9%. For this fuel we plan to use existing KZ-48 with BUC application.

In cooperation with Slovak Nuclear Regulatory Authority (UJD) we have started several years ago process of BUC implementation in Slovakia for VVER-440 reactors.

We have already prepared methodology according IAEA methodology. We have validated computational systems (SCALE 5.1 already, SCALE 6 in progress). UJD will prepare regulation about BUC application in Slovakia. Last item is preparation of safety reports (for transport and storage) for the new fuel with average enrichment 4.87% in basket KZ-48 with BUC application.

CURRENT STATUS

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ISFSF in Jaslovské Bohunice has capacity 14 112 assemblies. 12 502 assemblies are in Slovakia (in reactors + pools at reactor + ISFSF) at the end of year 2009. We will load 469 assemblies Gd2 fuel with maximal enrichment 4.4% and later assemblies Gd2 fuel with maximal enrichment 5%. It means that in ISFS we will have 12 971 assemblies with licensed enrichment and 1141 assemblies (in 24 baskets KZ-48) with maximal enrichment 5%. We will use BUC application for 24 baskets KZ-48.

In cooperation with UJD we have started several years ago process of BUC implementation in Slovakia for VVER-440 reactors.

We have participated on meetings about BUC under IAEA, OECD/NEA and AER to know theoretical background. We have participated in project COVERS, in which one task was BUC. We have prepared in cooperation with UJD two tasks about BUC implementation in Slovakia - first is already finished (years 2005 - 2007), second is in progress (years 2008 -

2010). Under those tasks we have developed methodology for BUC and we have validated the SCALE 5.1 system as very good tool for VVER-440 fuel and BUC application. We have received the SCALE 6 system from OECD/NEA databank and verification is in progress (criticality calculations are already verified and inventory calculations in next year). Three Slovak's organizations (VUJE, JAVYS, and UJD) are members of International consortium for a new chemical investigation of nuclide composition of VVER-440 spent fuel to receive more data for validation of nuclide composition calculation (project ISTC #3958).

BUC METHODOLOGY

We have developed methodology according IAEA and OECD/NEA recommendation.

All criticality and inventory calculation is possible to carry out only with verified and validated codes. In Slovakia we have already verified the SCALE 5.1 system, the verification of the SCALE 6 system is in progress.

Validation

Criticality validation can be achieved through evaluation of experimental data which are representative with respect to the spent fuel of interest. Available experimental data are in "International Handbook of Evaluated Criticality Safety Benchmark Experiments":

- critical experiments with fresh fuel in systems same or similar to spent fuel configuration of interest (for the VVER-440 fuel with hexagonal geometry),
- reactivity worth measurement on individual nuclides and spent fuel composition.

The "final" $k_{ef} = k_{ef}^{calc} + 2\sigma_{MC} + 2\sigma + \Delta k^{unc}$

Where k_{ef}^{calc} – result of calculation

σ^{MC} – Monte Carlo numerical error

σ - statistical tolerance

Δk^{unc} – impact of uncertainties (may be =0 if uncertainties are in k_{ef}^{calc})

Inventory validation can be achieved through evaluation of experimental concentrations of selected isotopes. Available experimental data are usually non public. Parts of chemical assay data available in open literature have been compiled in the SFCOMPO data base. Unfortunately, the SFCOMPO database doesn't include chemical assay of VVER-440 fuel. Old measurement for VVER-440 fuel is in Russian literature, the newest measurements were done in the ISTC #2670 project (already done) and in the ISTC #3958 (in progress).

The results of inventory validation are correction factors (CF) for each nuclide. The concentration used in criticality calculation is corrected:

$c^{crit} = c^{inv} * CF$

Where c^{crit} – nuclide concentration used in criticality calculation

c^{inv} – nuclide concentration as result of inventory calculation

CF – correction factor

The CF is:

Fissile materials:

- if $c^{inv} > c^{exper}$, then CF = 1

- if $c^{inv} < c^{exper}$, then $CF = c^{exper}/c^{inv}$, (CF > 1)

Non fissile materials:

- if $c^{inv} < c^{exper}$, then CF = 1
- if $c^{inv} > c^{exper}$, then $CF = c^{exper}/c^{inv}$, (CF < 1)

List of nuclides

The different levels of burnup credit commonly used are characterized as follows:

- Net-fissile-content level: Credit is taken for the:
  - Reduction of the net fissile content due to build-up and burnup of the different fissile nuclides, (U235, Pu239, Pu241),
  - Reduction of the U238 content.
- Actinide-only level: Net fissile content level plus credit for the build-up of neutron absorbing actinides (U234, U235, U236, U238, Np237, Pu238, Pu239, Pu240, Pu241, Pu242, Am241, Am243).
- Actinide-plus-fission-product level: Actinide-only level plus any number of fission products the use of which can be verified (FP: Mo95, Tc99,Ru101, Rh103, Ag109, Cs133, Nd143, Nd145, Sm147, Sm149, Sm150, Sm151, Sm152, Eu151, Eu153, Gd155).

Cooling time

The nuclide concentration is permanently changing. For interim storage the real cooling time is 1 to 100 years. The reactivity slightly decreases. It means that the most conservative is the shortest cooling time.

Core parameters by irradiation

A loading criterion must cover the variety of the irradiation histories of the fuel loaded in the system. The task to determine a loading criterion thus implies the need for looking for a bounding irradiation history given by those reactor operation conditions (depletion conditions) leading, at given initial enrichment and given burnup, to the highest reactivity of the spent nuclear fuel.

The reactor operation conditions (depletion conditions) for the VVER-440 fuel are characterized by the following parameters:

- Fuel temperature
- Moderator temperature/density
- Soluble boron
- Specific power and operating history

The depletion parameters are related to neutron spectrum hardening. Spectrum hardening results in an increased build-up rate of plutonium due to increased neutron capture in U238 and leads therefore to a higher Pu239 fission rate and hence, at given power, to a lower U235 fission rate. Spectrum hardening has therefore the effect of increasing the reactivity of the spent fuel.

Axial and radial burnup profile

The non-uniformity of the axial distribution of the burnup and hence the non-uniformity of the axial distribution of the isotopic composition impacts the reactivity of a spent fuel management system. The reactivity effect of an axial burnup profile, often named as “axial end effect” or “end effect” only, is usually expressed as the difference $\Delta k_{AX}(e, B, t)$ between the system’s neutron multiplication factor obtained with the axial burnup profile and the system’s neutron multiplication factor obtained by assuming a uniform distribution of the averaged burnup of the profile.

Whether the reactivity effect $\Delta k_{AX}(e, B, t)$ is positive or not depends on the reactivity importance of the centre region of the active fuel zone relative to the bottom and top end regions of the active fuel zone. The lower the relative reactivity importance of the centre region is, the higher is the reactivity effect $\Delta k_{AX}(e, B, t)$. Because the relative reactivity importance of the centre zone is determined by the axial distribution of the isotopic number densities, the reactivity effect $\Delta k_{AX}(e, B, t)$ is dependent on:

- the initial enrichment,
- the reactor operation conditions (depletion conditions) determining the neutron spectrum in the core and hence, due to the energy dependence of the neutron cross sections, the change in the isotopic concentrations with increasing burnup,
- the average burnup,
- the cooling time.

The VVER-440 assembly has different water/uranium ratio in pins and therefore pins in corner are in different neutron spectrum, the nuclide composition in pins is different, but this effect is very small.

By burnup credit application is necessary to take into account axial profile, but radial profile is possible to omit.

Others

Others possible impacts are control rods (absorption of thermal neutrons results hardening of spectrum) and burnable poison. In Slovakia the operational position of working group is 225 cm and therefore impact of control rods is possible to omit. Older fuel is without burnable poison and newer fuel is with Gd_2O_3.

LEGISLATION

The UJD started its efforts in implementation of BUC in Slovakia in 2002. Although we had (and still have) limited personal and financial resources we have found great support in the IAEA and we have started co-operation with VUJE Company.

From 2005 to 2007 we realized first part of a research task about implementation of BUC for storage and transportation of VVER-440 spent fuel. As a result of this partial task a methodology for calculation validation has been approved. In 2008 we started second part of this research task and we will finish it in 2010. Having finished the work a complex

methodology for calculation validation will be finalized. The methodology will also include accessible Russian measurements and results coming form ISTC #2670 and #3958 projects.
The methodology will contain calculation of actinides and selected fissile products and the UJD will issue it as a guide for operators in 2011. In addition, most probably in 2011, the UJD will issue an amended regulation on spent fuel handling, which will also contain de jure recognition of the methodology.
It may also be mentioned, that BUC has been partially used in safety report of transport container C-30.

CONCLUSION

The BUC implementation is a very important process. In Slovakia we pay strong attention to the correctness of the calculations, safety and costs.

We have very good tools (the computational systems SCALE 5.1 and SCALE 6 and BUC methodology) to prepare all necessary analysis in required quality.

Last item is preparation of safety reports for the new fuel 4.87% in basket KZ-48 with BUC application for transport and storage.

In 2011 the legislative requirements on usage of BUC will be fulfilled.

In October 27 - 30 2009 will be held in Cordoba BUC workshop. Slovakia was chosen to report national program.

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