Developments in Shielding and Criticality Assessment for Cask Design

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1 INTRODUCTION

British Nuclear Fuels plc has for some years been engaged in the transportation of irradiated nuclear fuel from LWR sites in Japan and Europe, to the Sellafield reprocessing complex in the United Kingdom. This business has used casks which are designed and licenced by the Company. More recently, the Company has also designed a cask to return vitrified waste to the Country of origin for the reprocessed fuel. Consequently, the Company has established a considerable expertise in the design and licencing of transport casks for the transport of fuel and radioactive waste.

The evaluation of a transport cask design requires that a complex iteration is undertaken to optimise, amongst other things, payload, neutron poison distribution and shield design. To continually improve this design iteration, BNFL are engaged in a broadly based development programme of both the philosophy and methodology adopted for the shielding and criticality safety analysis of its transport cask designs. Key aspects of this development programme include :

- development and application of burnup credit philosophy;
- reassessment of anticipated fuel breakup in the event of postulated accident scenarios;
- development of a new integrated suite of shielding and criticality software which may be used for cask assessments.

The objective of this paper is to present recent highlights from this programme which are of relevance to cask assessment.

2 BURNUP CREDIT

At present, within the UK, it is normal practice to ignore any beneficial effects that the burnup of fuel may have on the criticality assessment of a transport cask and its contents. To be exact, the fuel is assumed to have a burnup which maximises its reactivity within the cask. For most fuels this condition corresponds to unirradiated fuel and is hence called the "fresh fuel assumption". In general fuel reactivity decreases significantly with burnup, and so if credit was taken for this burnup it would be possible to carry fuel payloads which otherwise could not be demonstrated to be safely sub-critical. Possible advantages of taking credit for burnup are therefore the ability to transport fuel of higher initial enrichment and/or a greater number of assemblies per cask. This has potential commercial advantages as existing casks can be used to transport a wider range of fuels. It also improves overall safety of fuel transport as less movements are necessary. BNFL have been aware of these advantages for some time (*Clemson and Thorne 1989*); this section will describe recent progress made towards realising these advantages.

2.1 Review of the BNFL approach to burnup credit

From the outset it was identified that a stepwise approach to the modelling of burnup credit would be required in order to take credit only for those aspects of the burnup phenomenon for which BNFL had sufficient validation. At present this means taking credit for fissile depletion and plutonium production only. The poisoning effects of fission products are ignored; however work is described below which has begun to address the necessary validation to take this next step.

2.2 Fissile depletion and plutonium production

A method (*Smith and Watmough 1991)* has been developed which considers fissile depletion and plutonium production based upon the UK codes FISPIN and MONK for inventory prediction and reactivity calculation respectively. The method addressed all the uncertainties inherent within the calculational route eg. uncertainties in fuel composition, fuel burnup, and axial variation of burnup. By making worst case assumptions about the magnitude of these uncertainties, a revised safety criterion for burnup calculations on standard PWR fuel was devised. This safety criterion was that $k+3\sigma < 0.89$, which was a reduction of 0.06 from the normal criterion. Work is in progress to apply the method described above to a licence application to the UK Department of Transport (DTp). The application is based upon a criticality assessment which models a PWR fuel with an artificially high enrichment of 4.1 w/o stored within a type 1196 Multi Element Bottle (MEB) held within an existing cask. The other equally important part of the application, which demonstrates that the fuel within the cask has achieved the minimum burnup determined by the criticality assessment, is being based upon that observed for existing fuel. This approach has the advantage of demonstrating that the hypothetical fuel which could not be transported without taking credit for burnup could be transported by claiming burnup credit. The provisional results of the criticality assessment (*Ziver and Smith 1992*) indicate that the hypothetical fuel is safely sub-critical within a type 1196 MEB provided the fuel has a burnup of at least 22 GWd/teU.

2.3 Fission product poisoning

The stepwise approach to the modelling of burnup credit currently ignores the poisoning effect of fission products. Previous work (*Smith and Watmough 1991)* estimated that the effect of fission products was to cause approximately one third of the total reactivity reduction associated with burnup. Hence fission product poisoning is a significant effect which is worth pursuing but is not the dominant effect. Progress to date in the modelling of fission products has been restricted to upgrading the fission product data in the MONK6 library, to which eighteen nuclides were added. Those were judged to have a significant poisoning effect on irradiated fuel. The data was derived from the JEF-2 evaluations and included those nuclides necessary to participate in the recent OECD burnup credit benchmark calculation (*Tarano and Brady 1991*). It is hoped that these OECD benchmarks in addition to planned experimental validation will, in the next few years, allow this next step in burnup credit to be taken.

3 FUEL BREAKUP IN TRANSPORT PACKAGES

It has been common practice in the UK for many years to assess the effect of loose fuel in the MEB on the overall reactivity of the cask and MEB package. This loose fuel was assumed to have arisen from fuel pins that were either already leaky when placed in the MEB, or that became leaky after an impact corresponding to the 9m drop test. This loose fuel was then assumed to settle at the bottom of the MEB with the MEB in various orientations. This can lead to several situations such as the fragments forming an isolated fissile system with no neutron interaction between the fuel fragments and the elements, a separate fissile system with interaction, or even an intimately mixed system of fuel pins and fuel fragments.

The two most important parameters when considering such systems are the amount and concentration of fuel fragments in the sludge. The released fuel is treated and often referred to as a homogenous sludge rather than a mixture of small fuel fragments in water. The amount of fuel considered to make up this sludge (*Banks 1982*), was found to be 4% of the total fuel inventory of the MEB. The optimum concentration of the UO_2 fuel fragments (*Clemson and Watmough, 1989*) was found to be 1.5 g/cm^3. Many BNFL assessments have modelled fuel sludge in this way.

3.1 Reason for revising the fuel breakup figure

It has been considered for some time that the value of 4% fuel breakup may be unnecessarily pessimistic. In many cases this does not lead to a criticality problem so the fact that the value is high is unimportant. However for some transport packages, especially those with a high reactivity without fuel breakup or with compartments within the MEB where the sludge can form geometrically favourable conditions, using a value of 4% can lead to difficulties in demonstrating the criticality safety of the package. This in turn can lead to expenditure on items such as boronating the water or a re-design of the MEB which could be safely avoided if a less pessimistic value was assumed.

3.2 Basis of revised fuel breakup figure

The previously used breakup figure of 4% of the MEB contents has a number of components : -

- 2% for leaky fuel which is assumed to break easily on impact due to localised secondary hydriding.

  The Japanese authorities have now imposed a limit on each cask of one leaky fuel assembly containing not more than 5 leaky pins. Hence it is reasonable for transport of Japanese fuel to replace the 2% of the total fuel load with the 5 pins figure.

- 1% for pins which are assumed to have been leaky but re-sealed in the reactor although hydriding could still have embrittled the pin.

  It was shown by *Ikeda 1992* that the re-sealing of leaky fuel pins does not occur. The Japanese have also confirmed that they have never experienced such a phenomenon. This 1% figure will therefore be omitted for the assessment of Japanese fuels.

- 1% for "unknowns".

  The 1% for "unknowns" is intended to include such aspects as sound irradiated rods failing on impact. It has been suggested *(Wolfenden et al. 1987)* that damage to sound irradiated rods resulting from the standard 9 metre drop test is no worse than that for un-irradiated rods. However for pessimism this 1% figure will be retained.

  So for Japanese fuels, the fuel breakup figure now becomes 1% of the total fuel load plus 5 pins.

3.3 Recommendations resulting from the fuel damage review

The above arguments result in a much reduced fuel breakup figure which for a typical transport package leads to a mass of UO_2 released of around 50Kg as compared to previously a value of about 200Kg. This value was used in the assessment of the 1147m transport package which has been accepted by the Department of Transport. In that assessment, it is shown that the effect of the optimised sludge on the overall reactivity of the transport package is virtually undetectable.

From this work, the following new recommendations are made:

- In assessing transport packages containing Japanese fuel the breakup figure should be 1% of the total fuel load plus 5 pins.
- The above value could also be used for fuels other than Japanese fuels if there is similar experimental evidence or reasoning to justify the assumption.
- In view of the higher reactivities associated with higher enriched fuels the effect of additional missing pins caused by fuel leakage and hence increased moderation in the element may be much more important than the reactivity of the released fuel itself.
- The question of assessing fuel breakup should be kept under review. It is anticipated that with the lower fuel breakup values being used it will be found that the effect of released fuel will be insignificant and may be disregarded by comparison with other effects.

4 SOFTWARE DEVELOPMENT

The software used for shielding and criticality analysis of transport casks, that is predominantly the MCBEND and MONK packages are also the subject of continuing development by BNFL and the UKAEA. Specifically the two packages are at present being combined into a single package which will maintain the features of the separate software packages whilst also permitting the features to be shared. As such a single geometry model will be prepared which will be able to be used for both shielding and criticality analysis, hence reducing the overall cost of design assessment.

The merging of the software will result in substantially lower development and maintenance costs for the software. Validation costs will also be much reduced by the sharing of validation between the two packages, while overall safety will improve as the total amount of validation from the previous two codes will now be used to validate a single code.

5 SUMMARY

This paper has presented recent highlights from the shielding and criticality methods development programme that are of relevance to cask design. Specifically, the following points emerge :-

- the preparation of a licence application based upon UK methods and data used in a standardised fissile depletion and plutonium production model has been completed;
- the assumptions used in the modelling of granules of broken fuel within the transport package following a postulated impact accident have been revised thereby allowing less pessimistic assessments to be performed;
- enhancements are being made to the software used for shielding and criticality analysis enabling a more cost effective design service to be provided.

These ongoing developments clearly show the activity to extend the scope of assessments while increasing the physical realism of the models. Through these developments BNFL continues to offer a comprehensive and cost effective shielding and criticality analysis service as part of its worldwide fuel transport business.

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