A Comparison of Dose Rate Measurement and Assessment that enabled the Capacity of a Spent Fuel Flask to be increased

Michael H Dean, Anton S Murfin

British Nuclear Group, Risley, Warrington, UK

1. Introduction

BNFL use spent fuel flasks to transport LWR fuel from reactors in Europe and elsewhere to Sellafield, Cumbria, UK for reprocessing. The initial dose rate assessment for a spent fuel flask for a particular European BWR fuel, carried out using the MCBEND Monte Carlo code [1], indicated that only 15 of the possible 16 compartments within the multi-element bottle (MEB) could be used, without exceeding the regulatory criteria [2]. The dose rate is dominated by the neutron component, even though a substantial neutron shielding cover is attached to the flask. The assessment was based on pessimistic assumptions regarding neutron multiplication within the flask and indicated that the top compartment should not contain a fuel assembly. Consequently for the Transport Submission, the assessment was repeated with a steel displacer (to displace the same quantity of water as a fuel assembly) within the top compartment, in order to determine the peak dose rates when 15 assemblies were transported. The displacer is a hollow steel structure of square cross section.

Subsequently, a series of special dose rate measurements was carried out on shipments of flasks carrying 15 fuel assemblies. The purpose of these measurements was to provide further validation of the code and thus enhance the confidence that may be placed in the assumed safety margins for shipments already assessed. When the measurements were compared with calculation, it was confirmed that the calculated dose rates were unduly pessimistic. The degree of pessimism suggested that 16 fuel assemblies could indeed be carried in the flask, with more than adequate margins of safety.

Consequently, shipments containing 16 such fuel elements were made and the special measurements repeated. The new comparison confirmed the predictions made on the earlier exercise with 15 assemblies.

Comparison of measured dose rates with MCBEND calculations thus provided the confidence to increase the flask capacity from 15 to 16 assemblies, without exceeding dose rate criteria or affecting the safety of the shipments. This enabled the number of shipments to be reduced, resulting in cost and dose uptake savings. The reasons for the pessimism in the initial calculations are discussed and a revised assessment showed improved correlation with measurement, providing confidence that the calculational methods provide suitably conservative predictions.

2. Calculations for Transport Submission

The MCBEND calculations carried out for the transport submission were intentionally performed for pessimistic conditions. BWR fuel was assumed to have an enrichment of 3.1 w/o U^{235}/U and to have a burn-up of up to 50 GWd/teU. A minimum cooling period of 6 months was assumed.

The flask under consideration is a wet flask, such that the majority of fuel is under water during transport. However, in order to control internal pressures, an ullage (a void above the water level) is maintained, as a result of which, a proportion of the fuel is exposed above the water. As no neutron shielding materials are built into the flask structure, (apart from some localised NS-4-FR shielding near the lid end of the flask) a wooden neutron shielding blanket is used to minimise neutron dose rates above the exposed fuel, **Fig. 1**.

The flask is a mild steel cylindrical container, within which is a lead liner (encapsulated in stainless steel) to provide the bulk of the gamma attenuation. The MEB is located within the lead liner. A number of annular fins (178 mm deep and 12.7 mm thick) are welded to the steel shell. These are not shown in the **Figs. 1**, **2** and **4**, where the slice is through the gap between two fins. **Fig. 3**, however, shows a slice trough a fin.

A number of pessimistic assumptions were made:

- The boronated stainless steel neutron plates were omitted from the MEB (although the stainless steel compartment walls (housing the fuel assemblies) were modelled)
- The neutron source was enhanced by (1/(1 - $k_{effective}$)) throughout the 15 fuel assemblies, although this is known to be pessimistic for fuel above the water level; $k_{effective}$ being determined for an infinite array of water-filled flasks
- The axial burn-up profile of the fuel was represented with a peak burn-up over the axial centre of the fuel of 60 GWd/teU (representing a burn-up profile peak-to-mean of 1.2). It was assumed that all fuel assemblies would have these parameters.

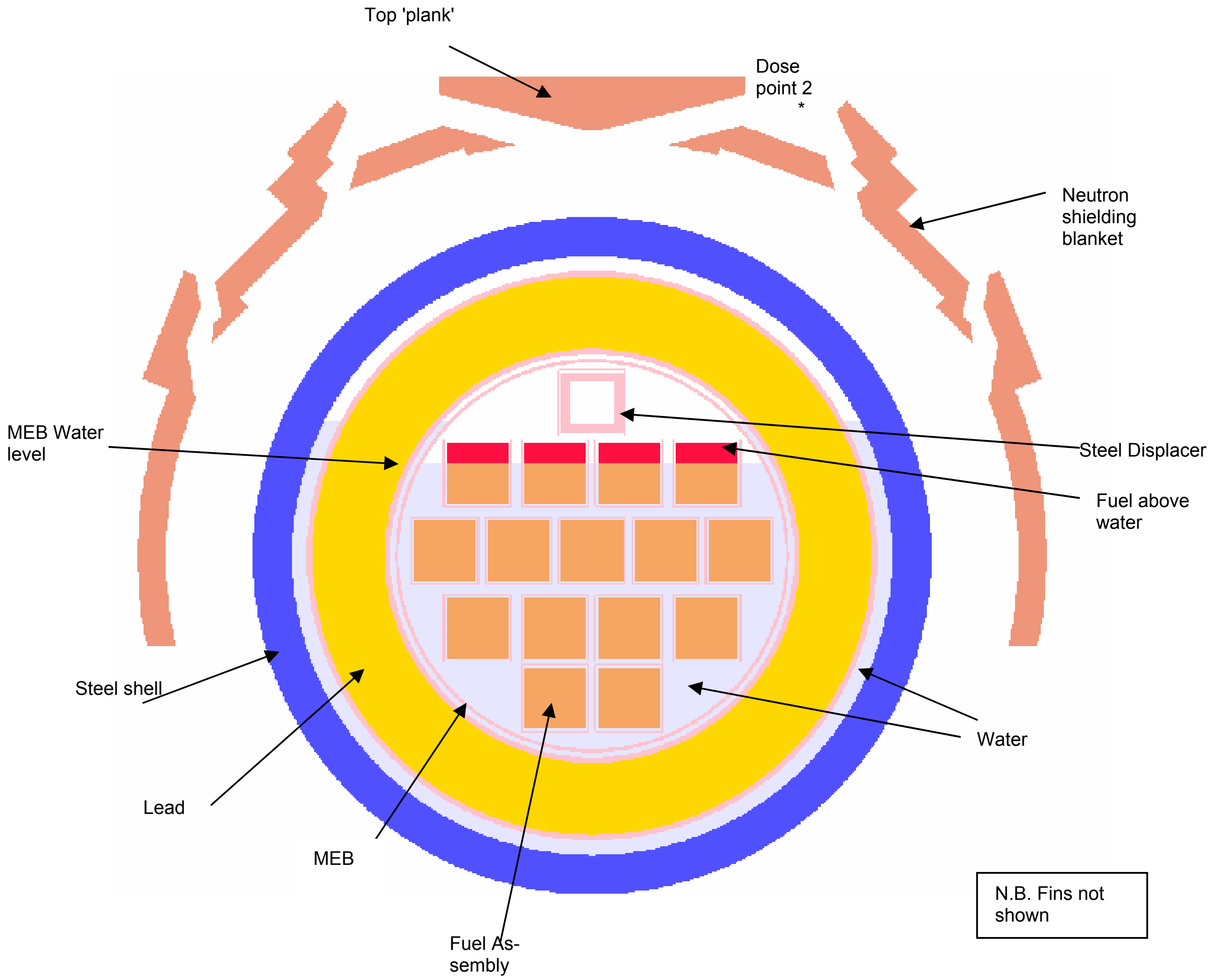

Fig. 1. MCBEND Model of Flask (Slice through axial Centre of Flask)

This pessimism introduced a degree of conservatism into the transport application.

In the transport application, for a flask carrying 15 assemblies, peak dose rates on the axial fuel centre line were for dose point 2, **Fig. 1** and for two metres above the top wooden 'plank', dose point 6 (shown on **Fig. 3**). At the lid end of the flask, the peak dose rate occurred at dose point 14, **Fig. 2**. This is above some localised neutron shielding extending for approximately 200 mm along the length of the flask, beyond the fin region. Overall, the limiting dose rate occurs at dose point 2.

Similar calculations carried out in the initial assessment, for a flask with 16 assemblies, showed that the peak dose rates on contact and at two metres from the flask were a factor of 1.63 (dose point 2) and 1.66 (dose point 6) greater than those for 15 assemblies, respectively. This meant that 16 assemblies could not be carried without reducing source strengths, by resorting to excessive cooling times for the fuel under consideration. It was not possible to enhance the shielding provided by the neutron blanket due to thermal requirements.

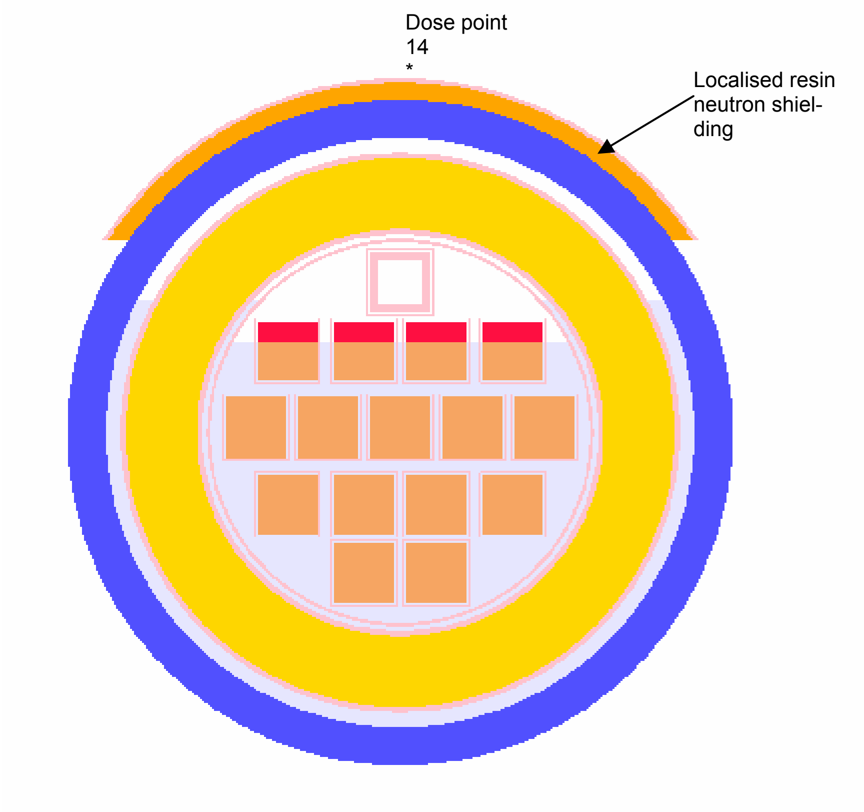

Fig. 2. MCBEND Model of Flask (Slice through Lid end of Flask)

3. Measurement Exercise

In order to determine the degree of conservatism in the calculational methods, and possibly to increase the flask capacity from 15 to 16 fuel assemblies, a special measurement exercise was carried out on flasks carrying spent fuel:

- On a flask carrying 15 assemblies and, subsequently
- On a flask carrying 16 assemblies.

There could also be scope for reducing cooling times, should there be adequate pessimism in the calculations.

The measurements were carried out at the BNFL Marine Terminal, Barrow-in-Furness, Cumbria, UK. Neutron and gamma ray dose rates were measured at various points around the flask, at the axial fuel centre-line and towards the lid end. Measurements were carried out on contact and at two metres from the flask. The centre-line dose points are shown in **Fig. 3**, the neutron dose points being displayed by a circle representing the polythene sphere of the neutron detector. A series of measurements were made at two metres from the side of the flask to identify the maximum dose rate at two metres from the edge (of the transport vehicle). A similar set of dose points were adopted towards the lid end but this conference paper concentrates on the more restrictive centre-line dose rates.

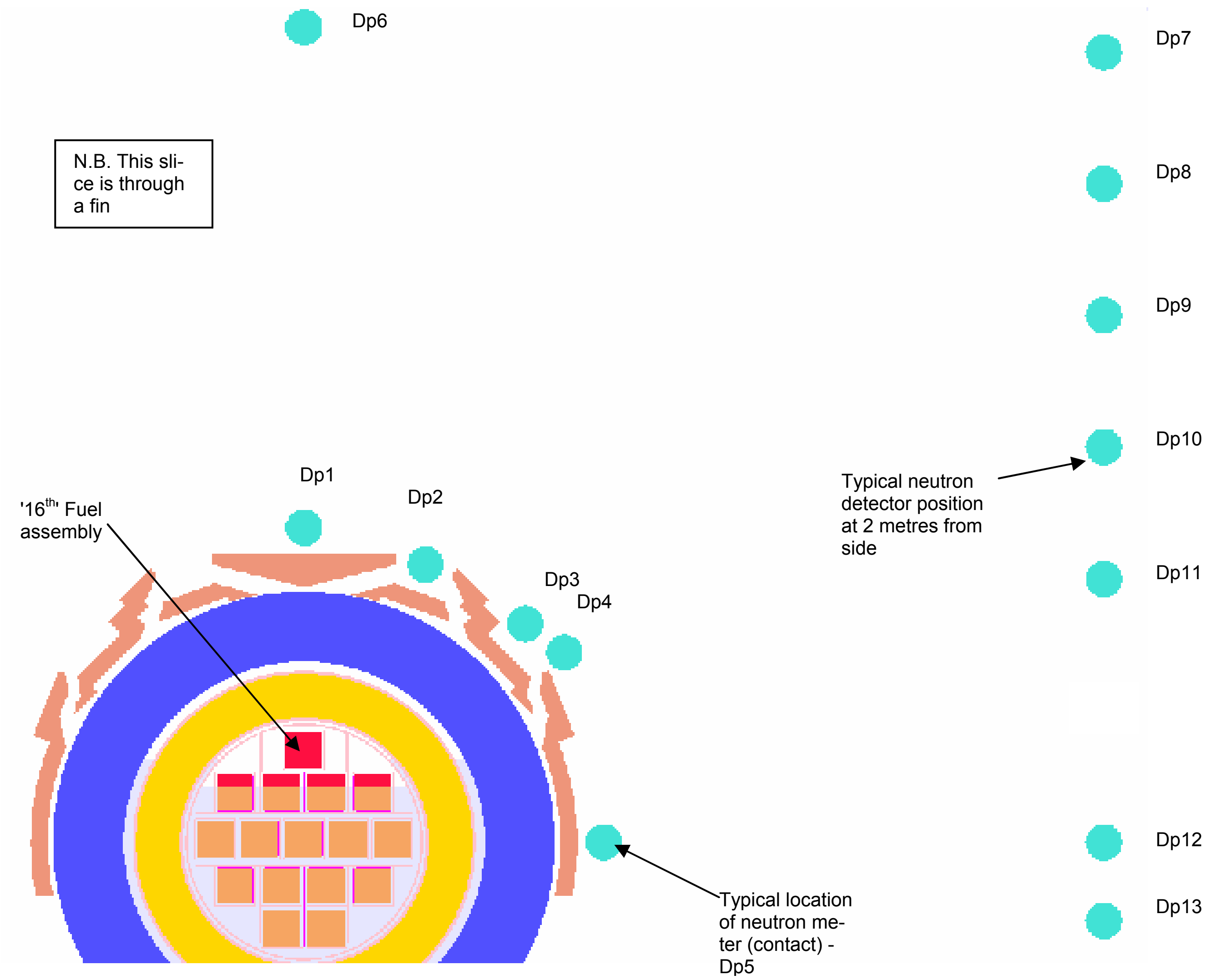

Fig. 3. MCBEND Flask Model (Slice through Flask axial Centre) 16 Assemblies - Neutron Dose Points (Dp) Shown, Boronated Stainless Steel Plates included

4. Comparison between Calculation and Measurement

In the comparison exercises, the MCBEND calculations were based on BWR fuel with an enrichment of 3.1 w/o U^{235}/U, a burn-up of 42 GWd/teU and a cooling of 5 years, more typical of the fuel actually carried in the flasks being measured. Calculated dose rates were scaled to allow for the actual burn-up and cooling of the assemblies that were transported (burn-up varied from 40 to 43 GWD/teU and cooling varied from 5.6 to 6.6 years).

Neutron, primary gamma, secondary gamma and activation gamma dose rates were determined by calculation. (Activation gamma dose rates were for the fuel assembly end fittings). For the purposes of presentation, the total calculated neutron plus gamma dose rates are compared to the total measured dose rates for 13 locations.

A comparison between calculation and measurement with 15 fuel assemblies (Section 4.1) indicated that there was sufficient conservatism to carry 16 assemblies. This was confirmed in Section 4.2 in the comparison between calculation and measurement for 16 assemblies. The paper then concentrates on a revised comparison between calculation and measurement with 16 fuel assemblies present.

In the revised calculations (Section 4.3), the boronated stainless steel plates were explicitly represented. Also, the neutron enhancement was represented in a less pessimistic way, with different neutron enhancement in the dry parts of the flask to the wet parts, as described in [3], which showed that this technique gave dose rates close to those calculated with more rigorous methods. Separate values for neutron enhancement were derived from a MONK [4] criticality calculation.

4.1 Flask containing 15 Assemblies - with Pessimism included

The initial comparison demonstrated that there was sufficient conservatism in the calculation approach adopted for the Transport Submission to allow 16 assemblies to be transported. No changes were made to the pessimism in the calculations present in those for the Transport Submission. The C/M values (dose rate calculation to measurement) for the key dose points were 3.38 for contact dose rates (dose point 2) and 2.10 for two metre dose rates (dose point 6). These C/M values leave ample scope for the dose rate increases arising from carrying 16 assemblies (increases of 1.63 and 1.66, respectively, as described in Section 2).

4.2 Flask containing 16 Assemblies - with Pessimism included

No changes were made to the pessimism in this second comparison but the C/M values were 4.69 for contact dose point 2 and 2.78 for the two metre dose point 6. These results confirmed that there was sufficient pessimism in the Transport Submission to allow 16 assemblies to be carried.

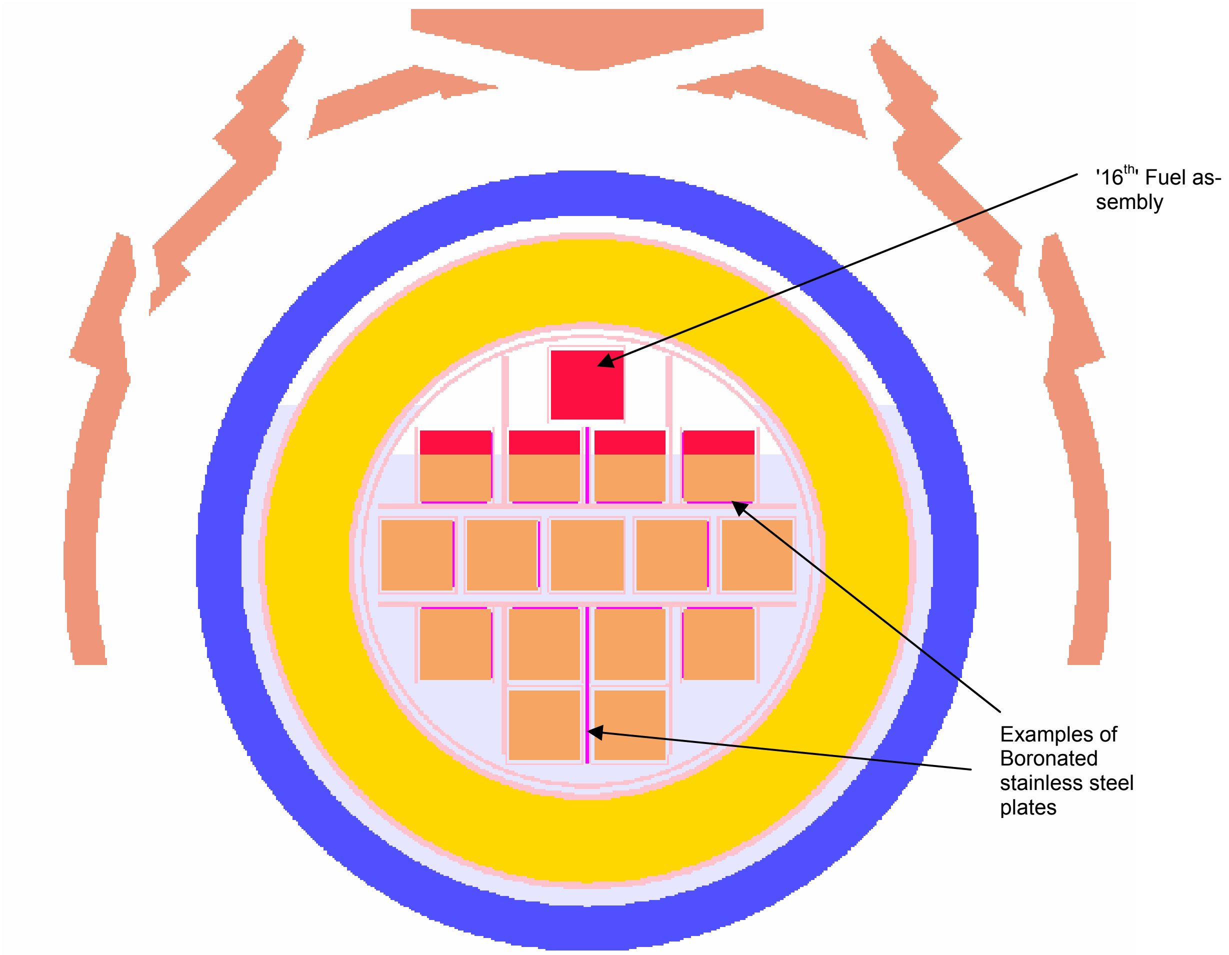

Fig. 4. MCBEND Flask Model (Slice through Flask axial Centre) 16 Assemblies, Boronated Stainless Steel Plates added

4.3 Flask containing 16 Assemblies - Reduced Pessimism

The MCBEND model was modified to:

- Incorporate the boronated stainless steel neutron plates in the MEB in addition to the stainless steel compartment walls, **Fig. 4**.
- The neutron source was enhanced by separate values of $(1/(1 - k_{effective}))$ for the dry parts of the upper five fuel assemblies and the remaining wet parts of the fuel assemblies. The two values of keffective were obtained from a MONK calculation, using the 'component multiplication' feature. This technique was shown to be a good approximation to a rigorous method for spent fuel in [3].

The C/M values are 2.64 for contact dose point 2 and 1.78 for two metre dose point 6. The reduction in the two values from Section 4.2 confirms that some pessimism in the Transport Submission was due to the two above effects. However, a degree of pessimism still remains and could enable cooling times to be reduced, possibly on a case by case approach. Dose point 6 remains the peak two metre dose rate throughout and is pessimistic compared to any side dose rate at two metres from the transport vehicle. Transport regulations [2] indicate that the dose rate at two metres from the side of the transport vehicle should be less than 100 µSv/h. If the two metre dose point directly above the flask can be ignored, with further analysis, cooling times could be reduced further.

Dose Point	C/M Value ((Calculated/Measured) Total Dose Rate)		
	15 Assemblies	16 Assemblies	16 Assemblies Reduced Pessimism
1	1.64	1.65	0.96
2	3.38	4.69	2.64
3	2.31	2.78	1.52
4	1.50	1.81	1.05
5	1.59	1.90	1.25
6	2.10	2.78	1.78
7	2.95	2.18	1.72
8	3.65	2.40	1.68
9	2.64	2.63	1.88
10	2.54	2.36	1.64
11	1.26	3.74	1.58
12	2.28	1.81	1.49
13	-	1.31	1.17

5. Conclusions and Recommendations for Further Work

Comparison of measured dose rates with MCBEND calculations have provided the confidence to increase the flask capacity from 15 to 16 assemblies, without exceeding dose rate criteria or affecting the safety of the shipments. This has enabled the number of shipments to be reduced, resulting in cost and dose uptake savings.

The values of C/M are generally very similar with 15 and 16 assemblies present. The reasons for the pessimism in the initial calculations have been discussed but the revised assessment does show closer correlation with measurement, providing confidence that the calculational methods provide suitably conservative predictions.

Some pessimism remains, particularly for the peak dose rate, dose point 2. This could be due to the complicated geometry of the neutron shielding blanket and the streaming paths associated with this area.

Fuel assemblies with reduced cooling compared to the Transport Sumission may be carried on a case by case basis by taking account of the remaining pessimism or by only considering two metre dose points at the side of the vehicle.

A new version of MCBEND (Version 10), shortly due to be available, will enable a rigorous treatment of induced fission to be carried out within the MCBEND calculation and avoid the need for separate (or indeed any) neutron scaling factors to account for neutron enhancement, that have had to be derived from a separate criticality calculation. It is intended to repeat the Section 4.3 analysis with the new version of MCBEND, as a method of demonstrating its effectiveness.

References

[1] ANSWERS Software Service, Serco Assurance (2002). MCBEND. A Monte Carlo Program for General Radiation Transport Solutions', ANSWERS/MCBEND(94)15, Updates for Version 9E RU2, January 2002.

[2] IAEA (2000). IAEA Safety Standards Series, No. TS-R-1 (ST-1, Revised) “Regulations for the Safe Transport of Radioactive Material”, International Atomic Energy Agency, Vienna, 1996 Edition (Revised).

[3] RAMTRANS, Vol. 13, No. 3 - 4, pp. 269 -274 (2002), Nuclear Technology Publishing, 'Using 'Component Multiplication' in MONK to reduce Pessimism in the Dose Rate Assessment for water-filled (ullaged) Transport Packages', M H Dean

[4] ANSWERS Software Service, Serco Assurance (2001). MONK. A Monte Carlo Program for Nuclear Criticality Safety and Reactor Physics Analyses, ANSWERS/MONK(98)6, Updates for Version 8B, June 2001.

Acknowledgements

The author acknowledges the help provided by Stephen Spedding, BNFL Marine Terminal, Barrow-in-Furness, Cumbria, UK for his help in making arrangements to enable the dose rate measurements to be carried out.