Criticality evaluation of a transport cask of irradiated nuclear fuel samples according to the IAEA Regulations for the Safe Transport of Radioactive Material

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Safe transport of radioactive materials to Post Irradiation Examination (PIE) facilities is one of the most important issues. Criticality safety requirements for packages containing fissile material are provided by the International Atomic Energy Agency (IAEA) Regulations for Safe Transport of Radioactive Material (SSR-6). The general relationship for establishing the acceptance criteria in the criticality safety of a cask is:

$$k_{eff} + n\sigma \leq 1 - \Delta k_m - \Delta k_u \qquad (1)$$

where k_{eff} is the calculated multiplication factor; n is the number of standard deviations considered (2 and 3 are common values); σ is the standard deviation of the k_{eff} value obtained with Monte Carlo analysis; Δk_m is a required margin of sub-criticality; and Δk_u is an allowance for the calculational bias and uncertainty. The parameter of Δk_u is sum of two separate parts, Δk_c and Δk_b; the first is determined by benchmark calculations and the latter is related to the manufacturing tolerances as well as material composition uncertainties. Here, Δk_m=0.05 was used, which is recommended by most authors. The right-hand side of Eq. (1), which is the maximum Upper Subcritical Limit (USL), is given by:

$$USL = 1 - \Delta k_m - \Delta k_u = 0.95 - \Delta k_c - \Delta k_b \qquad (2)$$

In this study, criticality evaluation was carried out for a cask containing irradiated Tehran Research Reactor (TRR) mini plates and fuel rod samples of Bushehr Nuclear Power Plant (BNPP) with shorter active length (about 56 cm height) based on SSR-6 requirements. It was assumed that five mini plates and six fuel rod samples were irradiated in the research reactor. The fuel samples within the capsule are assumed to be irradiated for enough period of time until they reached the maximum burnup. Then, the fuel samples and the capsule are allowed to be cooled inside the adjacent reactor pool before transportation to a PIE facility by the cask.

To determine Δk_c and verify that the computer code accurately predicts the k_{eff}, a set of calculational benchmark problems were employed in this work for bias and uncertainty of the k_{eff}. For Δk_b, a set of calculations were carried out to determine uncertainty of tolerances associated with diameter and thicknesses as well as the material specifications.

The effective multiplication factor of the single cask and the cask array under Normal Condition of Transport (NCT) and Hypothetical Accident Conditions (HAC) were calculated using MCNP code. Considering bias and uncertainties, the USL which determines the minimum effective multiplication factor for the sub-criticality of the system was specified. Regarding the results, the criticality margin of the single and the array under NCT and HAC was far from the USL and therefore the cask can be transported with the assured safe margin.

References

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