Square Arrayed Cask Design Charts for the Transportation of EK-10 Type Spent-Fuel Elements

Ensherah E.M. Ahmed
Atomic Energy Authority

F.A. Rahman, G.F. Sultan
National Center of Nuclear Safety and Radiation Control

E.E. Khalil
Cairo University

ABSTRACT

Both the suitable design pitch at which the spent-fuel elements are stowed in a square arrayed dry cask to be transported for a certain time (depending on the distance between the spent-fuel storage to the reprocessing plant and the mode of transportation) and the real cooling time-for which such spent-fuel elements are left cooled-are obtained as design charts incorporating all these variables taking into consideration the percentage burnup of the spent-fuel elements.

Practical data are selected for a typical spent-fuel element (EK-10 type) of the ET-RR-1 reactor at Inshass. Based on detailed spent-fuel data such as the material content, operational history, cooling time for which the spent-fuel elements have been kept in storage, and the transportation time, the transport package design pitch charts are presented in this investigation.

The calculations were made through the SFTC code, and the results for the design pitch charts of EK-10 type fuel elements are obtained based on the design criteria that the maximum allowed clad surface temperature should not exceed 92°C.

INTRODUCTION

The spent-fuel transport cask design criteria are achieved for a specified fuel element design by realizing the proper cask pitch through the safety margin of the cladding surface temperature for a specified cooling time and a specified transportation time. The cask pitch design criteria are mainly constrained by the nuclear criticality in the smaller-pitch range, whereas the dominant factor affecting the pitch design criteria in the larger pitch range is the cask cost. Also, the cladding surface temperature is limited either by its melting point or by its maximum allowable temperature specified by the fuel element manufacturer. The latter is considered in the present work (which is $T_c > 92°C$). The transport time is also limited by the distance from spent-fuel location to the fuel reprocessing location. The purpose of this study is to investigate the thermal behavior of the spent fuel in the transport cask under normal transporting conditions.

THEORETICAL BASIS

Theoretical analysis was carried out involving the interaction between nuclear and thermal aspects. Nuclear calculations determine the variation of the thermal power profile, which gives the volumetric heat generation source strength. Thermal calculations determine the temperature distributions of the cask spent-fuel elements corresponding to such power levels. The developed model was represented mathematically by the four well-known ordinary differential equations of point reactor kinetics, which are converted to 20 total differential equations and then solved with all heat sources to get the instantaneous effective power (Henry,1958 & ANS,1979). Besides, the analysis presented a developed heat transfer model to treat the heat transfer within the cask (sultan,1992). Based on these models, a two-dimensional code named SFTC is created to evaluate the design criteria of spent-fuel element square array transport dry cask (Ensherah).

INPUT DATA OF ET-RR-1

The Egyptian First Research Reactor ET-RR-1 is a cylindrical tank type, heterogeneous research reactor. The maximum power is 2MWT, and it is delivered to the atmosphere through the secondary cooling circuit. The distilled light water is used as moderator, reflector, and cooling medium (7A,1956). The maximum thermal neutron flux is $1.5x10^{13} n/cm^2.sec$ (Ensherah,1990). The effective core diameter is 645mm. The core contains 52 square fuel positions,51 for fuel elements and the remaining one occupied by a dry channel. The fuel basket is 75 cm in length and contains 16 fuel rods of 10% enriched U-235. The rods are contained in aluminium cladding tubes with an outside diameter of 10 mm (7A,1956).The fuel mass is depleted by reactor operation. When the burnup of the fuel reaches 25%, it is put in spent-fuel baskets where it is kept stored under 3 m distilled water.

RESULTS AND DESIGN CHARTS OF ET-RR-1 SPENT-FUEL ELEMENTS

The results of applying the SFTC code to a spent-fuel basket of ET-RR-1 reactor that is burnt up to 22.47% are shown in figures 1 and 2. These figures are constructed at spent-fuel clad surface temperature of 92°C- as recommended by the Russian documents that it should not exceed 92°C (7A,1956) to present the relationship between the three variables mainly controlling the assessment of a dry cask pitch at different transportation times and different cooling periods. In other words, these design criteria charts shown in the figures are constructed to predict the suitable design pitch at which the spent-fuel element (of EK-10 type and burnt-up to 22.47%) are stowed in a dray cask to be then transported for a certain transporting time (depending on the distance from the spent-fuel storage to the reprocessing plant and on the mode of transportation) and according to the storage cooling time of such spent fuel. Specifically, as seen in figure 1, if the storage cooling time is 75 days (as an example) and such spent fuel is going to be transported to a place that takes the equivalent of 50 days in transportation time (for example) then these charts give the suitable dry cask design pitch on which the spent-fuel stowage is based, so it will be 2 cm design pitch such that the surface temperature should not exceed 92°C. Also, if the cooling time is 91 days and the spent fuel is going to be transported over 70 days, then the clad surface temperature should not exceed 92°C, and the suitable design pitch must be 6.3 cm (as predicted from the design chart shown in the figure.

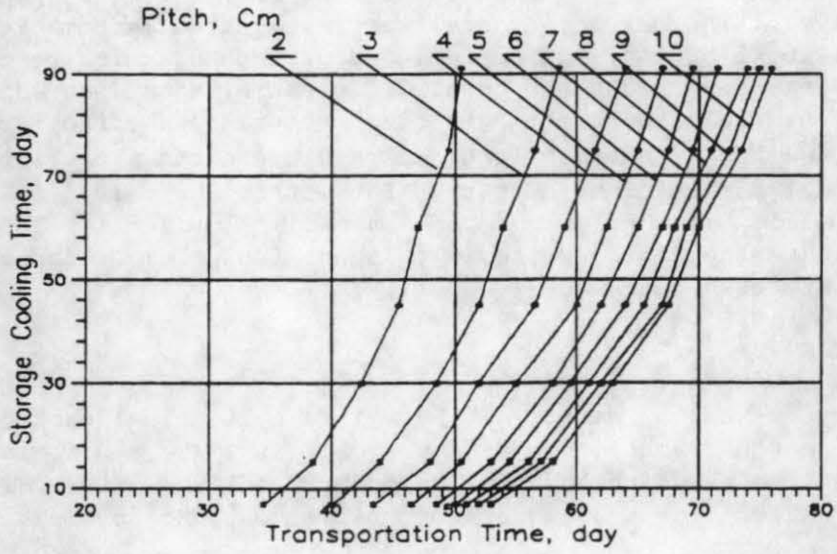

Fig.1. Spent-Fuel Cask Pitch as a Function of Transportation Time for Several Spent-Fuel Cooling Times

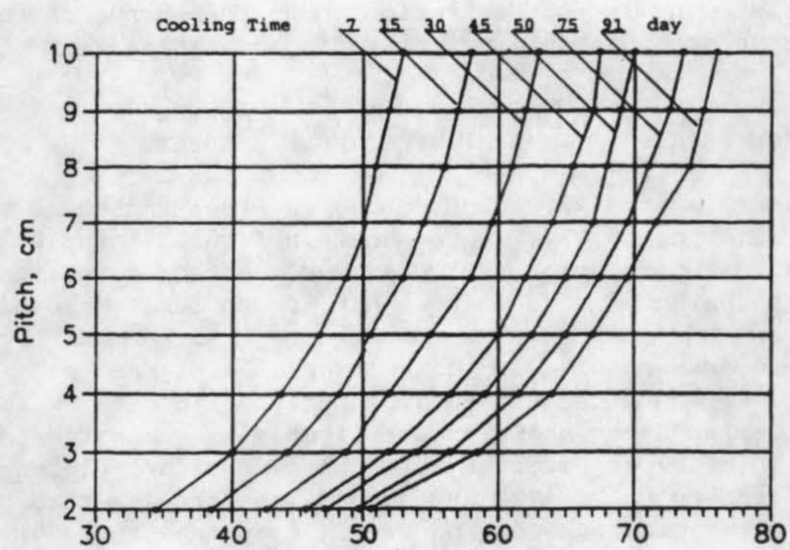

Fig. 2. Cask Design Criteria Chart for the ET-RR-1 Spent-Fuel Rods Burnt Up at 22.47% Arrayed in a Square Lattice Pitch Dry Cask

On the other hand, if such spent-fuel under investigation is going to be stowed on a certain specified pitch (controlled by other factors, such as cost benefit analysis or industrial technology) of a dry cask to be transported for a certain time, then for its maximum clad surface temperature not to exceed 92°C, such spent-fuel should be cooled for the time indicated by the interception of the three variables on this chart. For example-as shown in figure 2-at dry cask pitch of 4 cm and at transportation time of 55 days, the cooling time should not be less than 40 days to agree with safety requirements of 92°C maximum clad surface temperature. It is worth noting that these design charts shown in figures 1 and 2 are constructed according to the case study of ET-RR-1 fuel elements spent at 22.47% burnup. But the SFTC two-dimensional code could be extended to construct other design charts for any dry cask suitable to transport any type of spent-fuel elements at any percentage burnup and for power or research reactors (Ensherah, 1995).

CONCLUSIONS

By applying the code to the EK-10 type spent-fuel elements of the ET-RR-1 reactor, the following conclusions can be drawn:

1. From the thermal point of view, a cooling time of 90 days is enough for the spent fuel to be then safely transported.
2. For the safety requirement constraining the maximum allowable clad surface temperature, and for cooling time of 90 days, the safe transportation time ranges from 51 to 55 days for a square arrayed dry cask of small pitched range (2-4 cm).
3. For large pitched range (7-10 cm) of square arrayed dry cask, the safe transportation time ranges from 72 to 76 days for EK-10 type spent-fuel elements after left cooling in the storage pool for 90 days.

REFERENCES

A.F.Henry, "The Application of Reactor Kinetics to the Analysis of Experiments," Nuc. Sc. & Eng., Vol.3, p.52-70 (1958).

A N S " Decay Heat Removal in LWR," An A N S Report, ANS-5.1 (1979).

Design Description of the UA-RR-1 , The WWR-S Reactor Catalogue NO. 7 A, Moscow (1956).

Ensherah, E. Ahmed, et al. "SFTC:A Two-Dimensional Computer Code for Thermal Analysis of Spent-Fuel Transport Dry Cask," to be published.

Ensherah, E. Ahmed, et al. "Probabilistic Safety Analysis for ET-RR-1 Reactor," AREAEA/Int. Rep. 128, Cairo Egypt(1990).

Ensherah E.M. Ahmed and F.A. Rahman, "A 3-Dimensional Code for Thermonuclear Package Design to Transport Spent-Fuel Elements," PATRAM'95, Las Vegas, Nevada, USA (1995).

G.F.Y.Sultan, "Heat Transfer of Spent-Fuel Transport Cask," M.SC. Thesis, Fac. of Eng., Cairo Univ., Egypt (1992).