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Sci. and Tech. note

Safety Analysis of Spent Fuel Transportation Cask of Bushehr Nuclear Power Plant through the Passing of Fire Tunnel with ANSYS®10.0

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Abstract: The spent fuel assemblies (FAs) of Bushehr Nuclear Power Plant are planed to be transported by TK-13 casks. Each spent fuel transportation cask holds 12 spent FAs and has a thick steel container to provide shielding. The calculations have been performed for FAs with burn ups of 60 MWd/kg and a 3-years cooling period. The ANSYS®10.0 general finite element analysis package was selected for this analysis, since it is an analytical tool, widely used for licensing of spent nuclear fuel casks. The selected model included all the significant heat transfer paths within the casks and between the casks and the external environment. The computational model was subjected to the thermal environment of the tunnel during the fire transient using boundary conditions derived from the results of the fire dynamics simulator computational fluid dynamics code. The model of cask constructed in ANSYS®10.0 consists of a detailed 3-D representation of a symmetric half cross section of the spent fuel transportation cask and a complete cross section of the surrounding tunnel wall. In this model, the cask is oriented horizontally within the tunnel. This orientation gives the cask's outer surface the maximum exposure to the highest temperatures in the fire environment. This includes exposure from the tunnel surfaces by thermal radiation exchange and the flow of hot gases generated by the fire, which results in significant convection heat transfer to the package during the fire transient. The results of this evaluation strongly indicated that neither spent nuclear fuel particles nor fission products would be released from the spent fuel transportation cask. The internal temperature of TK-13 cask which was analyzed through the fire tunnel scenario did not reach the level that could result in rupturing of the fuel cladding.

Keywords: ***Spent Fuel, Cask, Fire Tunnel, Fire Dynamics Simulator (FDS), Fire Tunnel***

1- Introduction

The spent fuel assemblies (FAs) of VVER-1000 Reactors are transported within the TK-13 containers. This shipping cask holds 12 spent FAs and has a thick steel container to provide shielding. The transport container (TK-13) for spent fuel is shown in Fig.1. The scheme of spent FA discharge into container (TK-13) is presented in Fig.2. The axial dimension of the calculational model is assumed to be unlimited. Two cases are considered: dry container and container filled by water fuel without boron. These two cases conservatively characterize the main operational and accidental regimes. The fuel transportation was performed in a dry container and loading of the fuel into the container in water with boric acid concentration of 16000ppm [1].

2- Analysis Approach

In the analytical approach used to evaluate the response of the dry container TK-13 to the conditions of the fire tunnel, a highly detailed three-dimensional (3-D) model was constructed. The ANSYS®10.0 general finite element analysis (FEA) package was selected for this analysis, since it is a widely used analytical tool for licensing analyses of spent nuclear fuel casks. Using this approach, the model included all significant heat transfer paths within the casks and between the casks and the external environment. The flatbed of the truck, which would tend to shield the bottom of the cask from the effects of the fire, was omitted from the analysis. However, the cask was assumed to be located within the tunnel at a vertical height corresponding to the height of the flatbed. This assumption yields the minimum possible distances for thermal radiation exchange with the hottest surfaces in the tunnel environment, and exposes the cask to the hottest air temperature in the tunnel [2-4].

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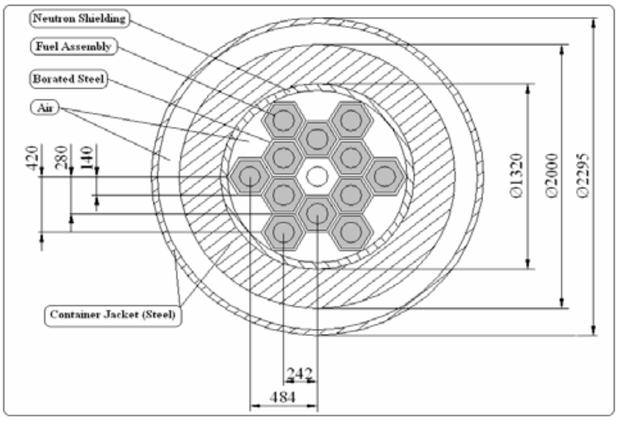
3- Model of Container TK-13 Transportation Cask

According to Fig.1, the containers TK-13 include 12 FA and outer diameter is 2295mm. The thickness of steel that surround the cask was 340mm. A thin plate from borated steel surrounded the FAs for shielding and neutron absorber purpose. The model utilized SOLID70 and SHELL57 thermal elements for conduction, SURF152 surface effect elements for convection, and SHELL57 elements in conjunction with AUX-12 generated MATRIX50 super elements for radiation interaction. The model and meshing of container TK-13 that was prepared in ANSYS®10.0 software are shown in Figs. 3 and 4b. The material properties from the cask vendor's safety analysis report (SAR) were verified and used in the analysis. The model explicitly represents the geometry of the cask, including the internal geometry of the fuel basket, all gaps associated with the basket, as well as the integral neutron absorber plates. The model used 40,489 SOLID70, 8-node brick elements and 4,776 SHELL 57, 4-node quadrilateral thermal elements to represent the structural components. A total of 7,165 SURF152 elements were used to cover thermal radiation between the container surfaces and the tunnel, and convection heat transfer at the container surfaces. The model of the container TK-13 transportation cask consists of a detailed three-dimensional representation of a half cross section of symmetry for the cask geometry and its supporting components. Fig. 4a, c [2, 3, 5].



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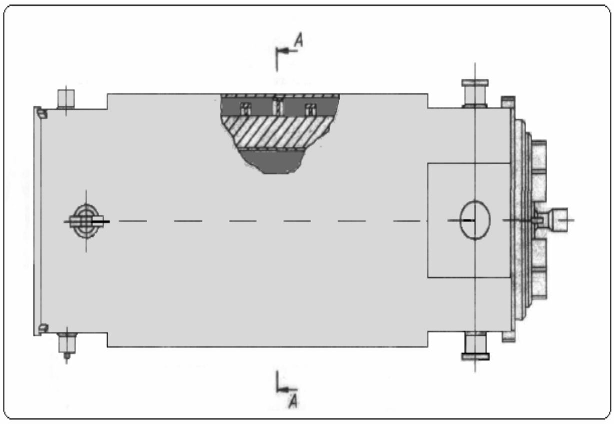

Fig 1. Container TK-13 for spent fuel transportation [1].

4- Model of Tunnel Fire

In this research, the results of fire dynamics simulator (FDS) code were used to predict the range of temperatures presented in the tunnel during the fire event. FDS is a computational fluid dynamics (CFD) code that numerically solves a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat

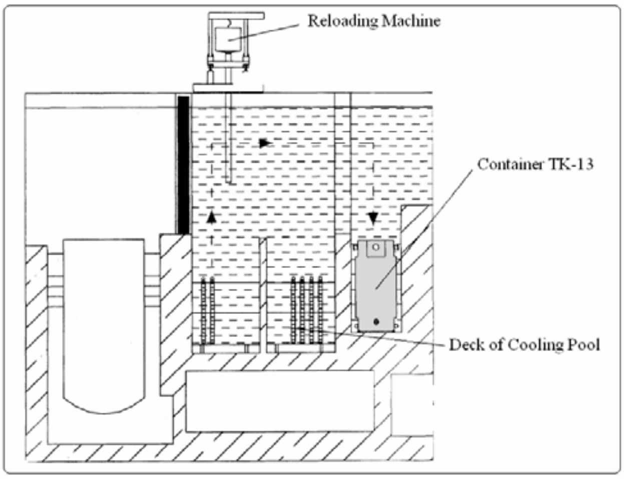

Fig 2. Scheme of spent FA discharge into container TK-13 [1].

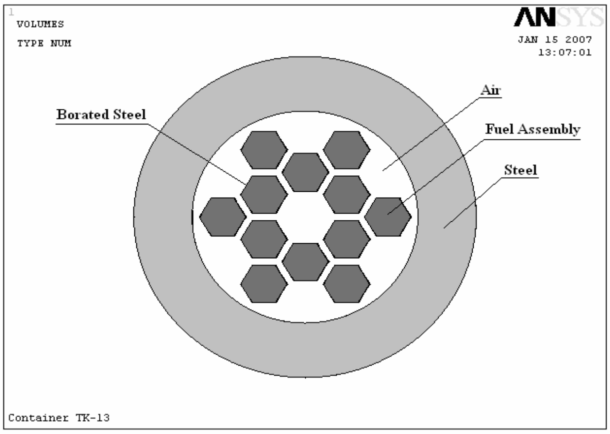

Fig 3. The model of container TK-13 in ANSYS®10.0.

transport from fires. The longitudinal figure and cross section of the fire tunnel are shown in Figs. 5 and 6 respectively. The maximum temperatures calculated in the FDS model were ~1000°C in the flaming regions of the fire. The model indicated that the hot gas layer above the cask had an average of 500°C. Temperature on the tunnel wall surface were calculated to be in excess of ~800°C where the fire directly impinged on the ceiling of the tunnel. The average tunnel ceiling temperature was 400°C. Figs. 8, 9 and 10 are showing the evolution of the surface temperatures on the tunnel walls, floor and ceiling during and immediately after the gasoline fueled fire. The above mentioned temperature profiles were located along the axial length of the portion of the tunnel included in the model. The peak tunnel surface temperature, peak gas temperature, and associated gas velocities over time simulation with FDS were selected from a location approximately 100m downstream of the fire source. As a conservative simplification of the finely detailed meshing of the fluid nodes in the FDS simulation, the tunnel air volume was divided into three sections of an upper, middle and lower region. The analysis was carried out for a 7hour fire and 23hour post fire cool down duration, as predicted by the FDS analysis results [6-8].

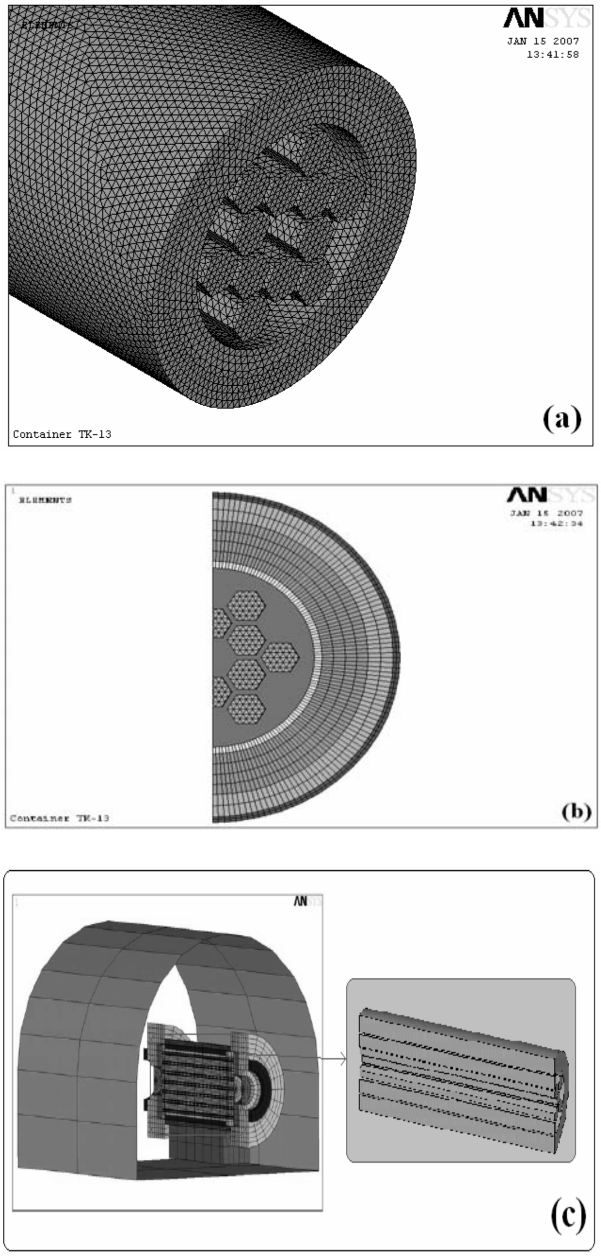

Fig 4. TK-13 Transportation cask.
(a) the meshing model
(b) half cross section
(c) component and environmental conditions.

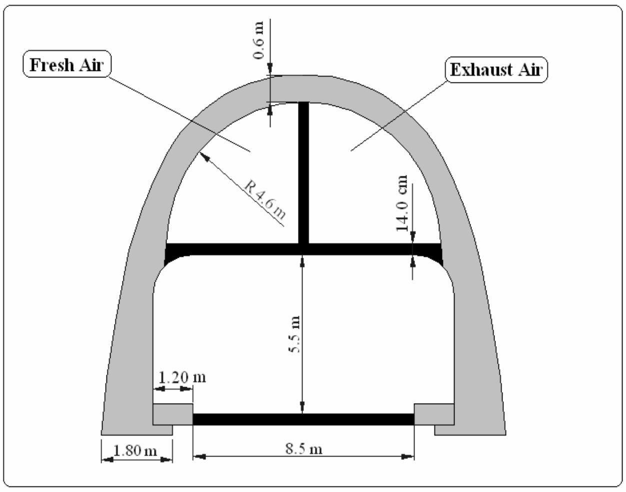

Fig 5. Fire tunnel typical cross section [2].

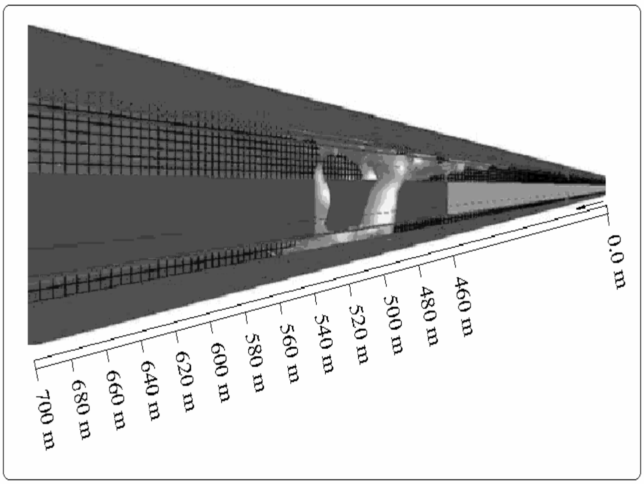

Fig 6. Typical view of the longitudinal fire tunnel [2].

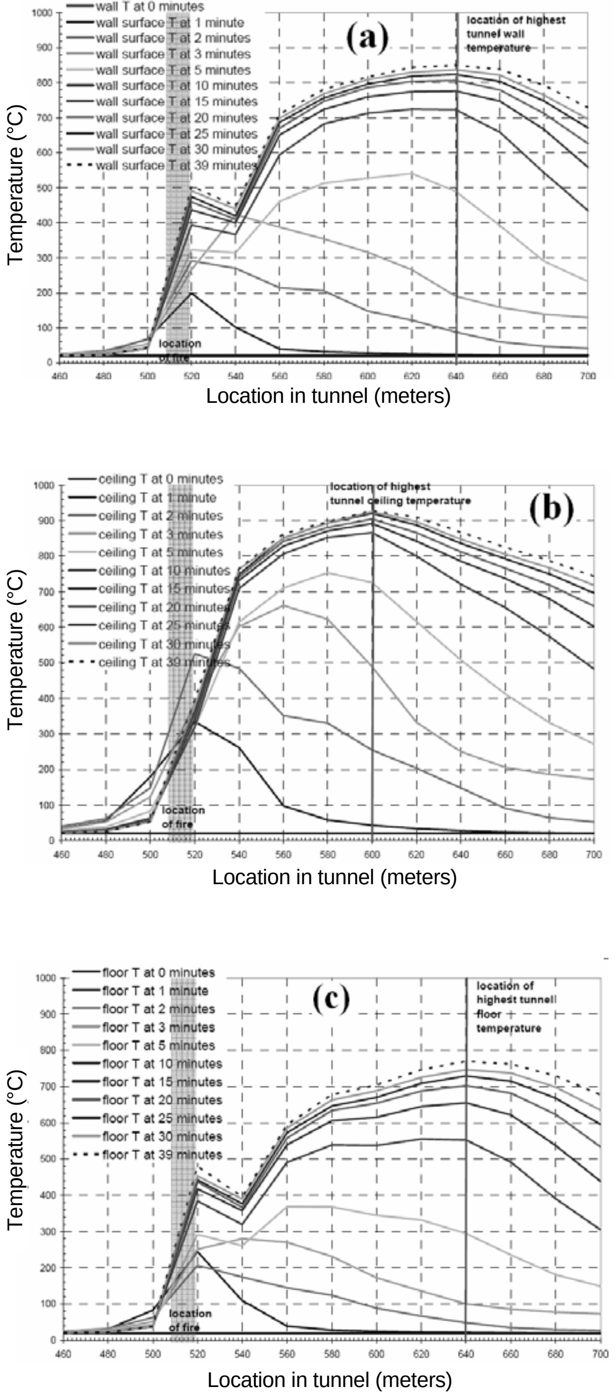

Fig 7. The temperature behavior of fire tunnel:
(a) mid-line,
(b) ceiling centerline, and
(c) floor centerline

5- Boundary Conditions for Cask

Peak tunnel surface temperatures, peak gas temperatures, and associated gas velocities with respect to time from simulation with FDS were selected from a location approximately 100m downstream of the fire source. The defined regions are based on the geometry of the tunnel and the position of the cask within the tunnel. The hot normal conditions for transport are used as initial conditions. A heat generation rate equivalent to a decay heat load of 2.5 (kW) is applied, with appropriate peaking factor, over the active fuel region. The ambient temperature boundary condition for these analyses is specified as 54°C [4, 9].

6- Results

The most temperature sensitive components of the transport systems that were evaluated included the spent fuel cladding, closure seals, impact core materials, and neutron shield core materials, due to the lower temperature limits of these components in comparison with other cask components. The results of the analyses for the cask were evaluated primarily in relation to the predicted peak temperatures for these components in the transient. Fig. 7 presents the TK-13 transportation cask component temperatures predicted by the ANSYS®10.0 model, as a function of time, for 30 hours (with the assumption of approximately 7hour fire duration). The figure shows that peak fuel cladding temperatures are predicted to occur at approximately 25hours after fire cessation (32hours after ignition) and increase as high as 475°C. This is 95°C below the regulatory limit. The initial fuel cladding temperature spike shown shortly after the fire duration (~10hour) was the fuel in the outer periphery of the cask, in a region up toward the lid, initially rising in temperature faster than those residing in the core of the cask. However, by this time the fire has just ended and the flux begins to dampen and spread as component temperatures begin to redistribute in this location causing the peak fuel temperature to jump from one assembly to another. As such, the peak reported cladding temperatures begin to drop for a brief period, before rising again and hitting their peak in the core of the cask. The peak fuel clad temperature is therefore enveloped in the data presented as it moves from assembly to assembly within the fuel cask, during the transient.

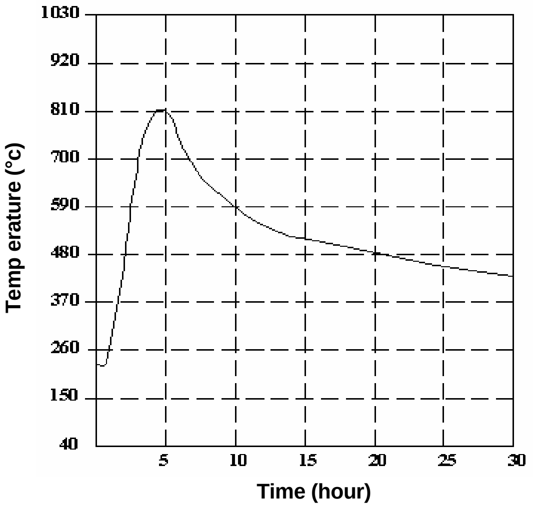

Fig 8. Average temperature of inner surface of container TK-13.

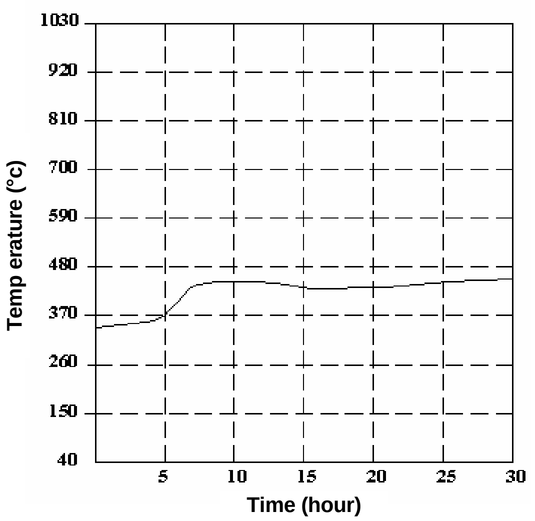

Fig 9. Average temperature of spent fuel in container TK-13.

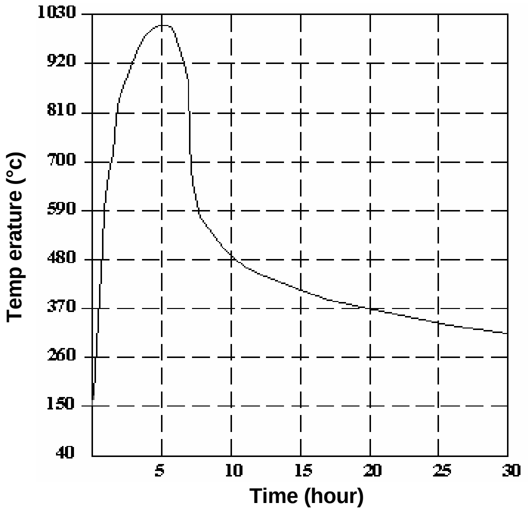

Fig 10. Average temperature of outer surface of container TK-13.

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