Verification Plan for the Concrete Temperature of the MACSTOR/KN-400 Module under Transient State Considering Actual Operating Conditions

Kyung-Ho Lee, Jeong-Eun Park*
KHNP Co., Ltd. Nuclear Engineering & Technology Institute, Daejeon, Korea
*KHNP Co., Ltd. Wolsong Nuclear Power Site, Gyeongjoo, Korea**
E-mail: suhong@khnp.co.kr

1. Introduction

This paper covers a verification plan of the results of heat transfer analysis in the MACSTOR/KN-400 on a transient state basis. The transient state reflects several natural environment parameters such as solar loads and daily temperature variations. These factors seriously affect analysis results in terms of concrete temperature and temperature gradients. There are two objectives to verifying the heat analysis results under transient state. First, there is the need to meet the request of the regular body to confirm that concrete temperature stays below the level of the design criteria. Second, it is necessary to recognize how much conservative the analysis is. In actual operating conditions, concrete temperature would be reduced by less conservative conditions.

2. The Descriptions of Storage Module

The layout of the MACSTOR/KN-400 is shown in Figure 1. Heat generated by the spent fuel stored in the MACSTOR modules goes out through the storage cylinders. The temperature of the air surrounding the storage cylinders increases and its density decreases. The density difference causes the air to move upwards along the storage cylinder. At the top of the modules, there are twelve openings through which the hot air can escape to the environment. The air going out of the module is replaced by air coming in through the ten air inlets located at the bottom of the module. This is called natural convection. The mass flow rate of the air due to natural convection is relatively small compared to forced air cooling, but enough to maintain approrpriate cooling of the spent fuel and the concrete structure .

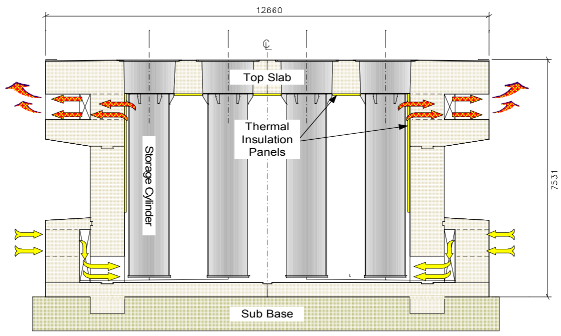

Figure1. MACSTOR/KN-400 layout

3. Design Requirements

3.1 Allowable concrete temperature

ACI-349[1] was applied to the design requirements of the MASTOR/KN-400. ACI-349stipulates that average concrete temperature under normal condition shall not be over 65℃.

3.2 Design parameters of storage module and spent fuel

Average burnup	7,800MWd/MTU
Heat release and cooling time of average fuel bundle	6.08W/6years
Maximum fuel burnup	12,083 MWd/MTU
Module capacity	24,000 bundle
Number of storage cylinders/baskets	40/400
Total average module power	145.9kW

4. Operating Conditions

In the heat transfer analysis, environmental conditions such as solar loads and daily temperature variations at the Wolsong site were taken into account in the transient analysis. Environmental conditions reflect the real situations of the conditions of heat transfer in the module. Solar loads in the horizontal and the latitude are shown in Figure 2. Ambient temperature varies over one day as shown in Figure 3. In the day time, the highest solar loads are expected to be reached, while no solar loads are considered in the remaining periods. One of the key factors in transient analysis is daily temperature variation of 10℃. These affect the temperature gradient of the concrete module due to the variations of outside concrete temperature. The temperature of the outside concrete surface is increased during mid-day time by solar loads while the inside temperature as affected by decay heat from the fuel basket is usually constant. Therefore, temperature gradient due to environmental conditions is called transient gradient in the heat transfer of the spent fuel dry storage.

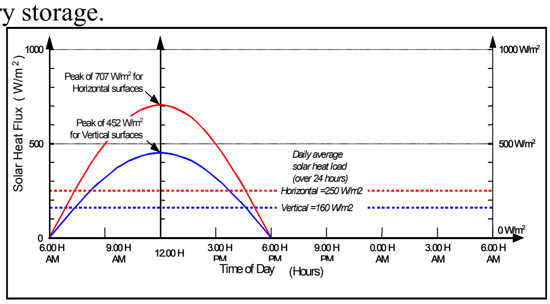

Figure2. Variations of solar loads in the heat transfer analysis

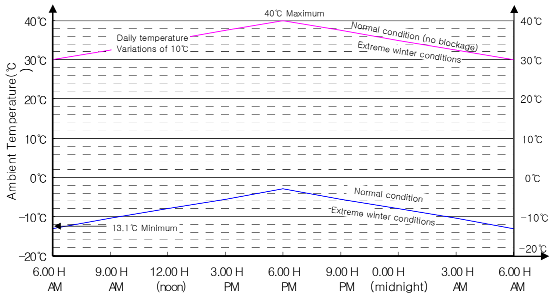

Figure3. Ambient temperature variations over one day

5. Conservatisms retained in the analysis

In the previous analysis, it was considered that all fuel baskets were initially stored at the same time in the module. Actually, it may take fourteen months to completely load all baskets into the module. Also, actual decay heat would be expected to be lower than reference decay heat. Therefore, analysis results could be more conservative than actual results.

6. Analysis Methodology

6.1 Analysis code

The thermal-hydraulic CATHENA which simulates one-dimensional fluid flow and two-dimensional heat transfer in solids was used to predict concrete temperature.

6.2 Model

The CATHENA model for the MACSTOR/KN-400, comprising sixteen cylinders is modeled as shown in Figure 4. The concrete wall, top slab and the storage cylinders are modeled. Thermal radiation between the storage cylinder and concrete wall and roof is modeled. The main mode of heat removal is free convection by air from the storage cylinders. The coefficients, such as concrete conductivity and loss factor, need to be verified from the measured temperature of the MACSTOR/KN-400.

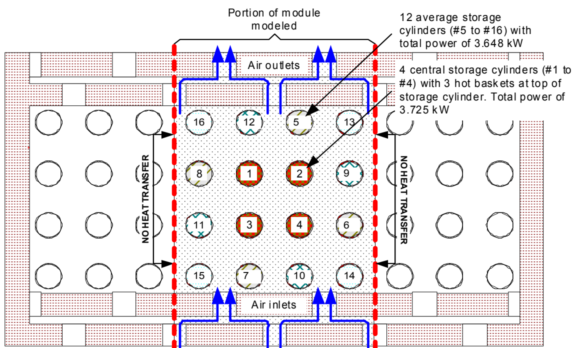

Figure4. CATHENA Thermal-hydraulic Model

7. Verification Methodology

7.1 Installation of thermocouples

Figure 5 shows the location of thermocouples on the concrete module. A total of six thermocouples will be set up to measure critical maximum concrete temperatures, and inlet and outlet air temperatures. The temperature will be measured hourly and results will be stored in the data acquisition system. Maximum temperature may be predicted at A, A2, which is situated at the center of the top slab. The inlet and outlet air temperature will also be very important in terms of estimation of loss factor in the surface of the air route.

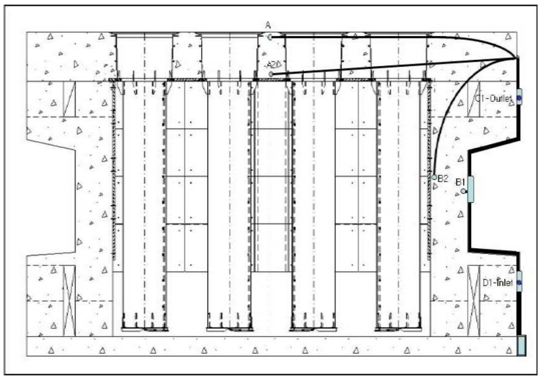

Figure5. The location of installed thermocouples

7.2 Methodology

Maximum concrete temperature needs to be below the allowable value as specified by the ACI-349. In order to meet the standard requirements, the measured temperatures will be compared with the analyzed temperature. Empirical equations that can collaborate with actual temperature will be derived based on the measured temperature. Loss factor and concrete conductivity can also be assessed. Acquired maximum temperature would be lower than the one determined in the analysis due to the conservatisms of the analysis. By measuring the concrete temperature, and the inlet and outlet air temperatures, the conservatisms retained in the analysis would be estimated quantitatively. Daily temperature variations and solar loads would affect temperature distributions and gradients as well. It is important to know how much these natural conditions will affect concrete temperatures and temperature gradients for future monitoring and aging management of the storage module.

8. Conclusions

In order to secure the structural safety of the concrete module, the analysis results need to be confirmed as to whether they will meet the thermal requirements of the ACI-349. By installing thermocouples on the wall of the storage module, these factors like maximum concrete temperature, temperature gradients, concrete conductivity and loss factor can be estimated. The conservatisms in the assessment will be removed so that a capacity expansion of the storage module can be possible. These verification results can also be applied in the aging management of the MACSTOR/KN-400 in the future.

REFERENCES

[1] ACI-349-97, "Code Requirements for Nuclear Safety Related Concrete", American Concrete Institution, 1997.