SEVERAL ACCIDENTS ABOUT ERHRS OF CEFR

D. ZHANG
China Institute of Atomic Energy,
Beijing, China

Abstract

An analysis about several unusual accidents about Emergency Residual Heat Removal System (ERHRS) of China Experiment Fast Reactor (CEFR) is present. CEFR is a pool-type sodium-cooled fast reactor. The ERHRS of this reactor is designed in passive principle, which enhance the interior reliability of CEFR. It is consist of two sets of independent channels. Each channel is comprised of decay heat exchanger (DHX), intermediate circuit, sodium-air heat exchanger (AHX) and related auxiliary system. Both DHX are located in the hot pool of the main vessel directly, which is used to cool the hot sodium. The whole set of ERHRS is completely passive except the ventilation valves of AHX. But, as a very important set of engineered safety features which is the final way to remove the heat from the reactor core, it is necessary to pay attention to all of possibilities that may reduce this ability. Several accidents are analyzed include the ventilation valves couldn't be opened, only one set of ERHRS could work and so on. The calculation results show that the ERHRS can keep the reactor in a safety status. Even though it is, experiments are necessary in the view of engineering yet.

1. Introduction

ERHRS of CEFR is consisted of two independent sets of channels and each channel can remove 0.525MW heat from the reactor core. The whole system is a passive system except the ventilation valves of sodium-air heat exchanger. Each channel of the ERHRS is mainly include

- An sodium-sodium decay heat exchanger (DHX),
- An sodium-air heat exchanger (AHX),
- Intermediate circuit and chimney,
- Auxiliary systems include impurity inspecting system, heating system, temperature detecting system, sodium fire prevention system, etc.

The design of ERHRS must be ensure that the temperature of main vessel and metal structure in the vessel couldn't exceed 560 centigrade degree in order to keep their strength. At the same time, these means have been adopt to enhance the stability and reliability.

- The ventilation valve of AHX consist of three inlet air doors and one outlet air door that could be driven either by electric motor or by manual,
- Emergency power supply,
- Two valves locate in the line to auxiliary system,
- All intermediate circuit pipe is covered with guard tube,
- Physical separation is designed for two channels.

Figure-1 gives us the profile of ERHRS. In the following cases, it is possible for main heat transfer system losing its function:

- Loss of off-site power supply;
- Loss of main feed water;
- Earthquake.

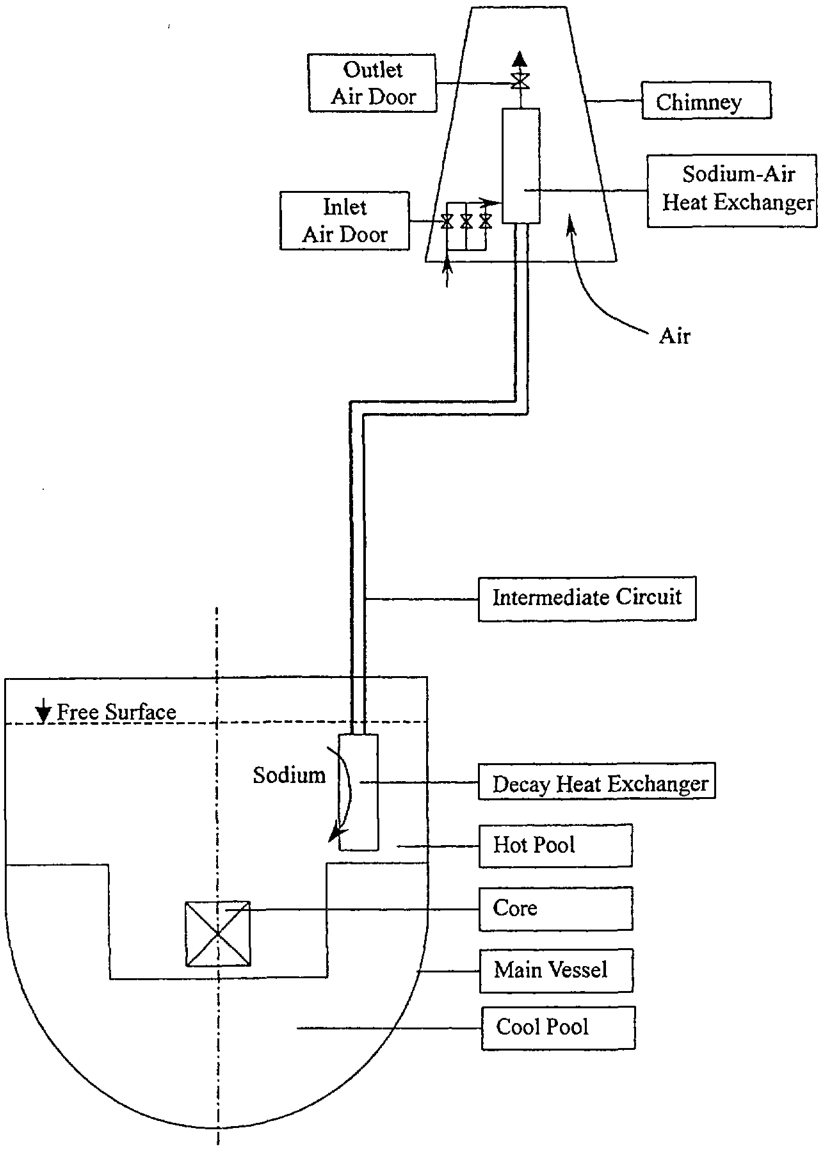

FIG. 1 Principle Diagram of ERHRS

When the main heat transfer system can not work normally, the ERHRS will automatically put into operation in ten minutes to remove reactor residual heat to ultimate heat sink (atmosphere).

2. Several Typical Accidents

For ERHRS of CEFR, there are some conditions that may cause the system loss partial or whole ability to removal residual heat. These occurrences are, 1) the natural convection is broken because pipe losing its integrality or losing partial or all coolant; 2) the pipes is blocked because of sodium's frozen; 3) the ventilation valves couldn't be opened. For the first case, the design has considered earthquake and all of the pipes are equipped with guard-tube that makes this type accident meet a very low probability. For the second case, there are few sodium-temperature detecting points and electric-heaters that prevent those accidents occurring, and, it is possible to adjust the ventilation-valve to decrease heat losing which could reduce the probability at the same time. For the last case, the failure probability is lager than the forth two cases because the ventilation valves need power to drive though it is divided into several sections and every section is consist of multi-vanes. Although it is, this condition must be analyzed in the base of safety considering and safety-guide requiring. We are either interesting in the condition that only one loop could work and other unusual occurrences except those mentioned above.

2.1 Both ventilation valves could not be opened

CEFR is pool-type reactor and the main vessel is divided into two parts. The upper part is called hot pool because it contains hot sodium whose temperature is 516 centigrade degree. The lower part is called cool pool because it contains cool sodium whose temperature is 360 centigrade degree. This accident is a BDBA (Beyond Design Basis Accident) in the Primary Safe Analysis Report of CEFR. Here are initial conditions,

- The reactor operated under full power (65MW),
- ERHRS is standing by.

In order to calculate within a long period, this accident must be analyzed in detail in the first hundreds second. 3D method is used for taking into consideration the complex rapid flow changing. Figure 4 shows us the sodium temperature field and flow scheme in the main vessel at 1 second, 81 second and 618 second respectively. These figures show that the cool sodium from could cool reactor core and partial residual heat is stored in the sodium.

The curves of sodium temperature in the core and mass flow of primary loop are given in Figure-2 and Figure-3 respectively. At the beginning of this accident, the coolant-temperature falls first because of the primary pumps' coast-down more slowly than the reactor power's decreasing. After that, the coolant temperature increase in the reason of flow lower than residual-heat and natural convection begins to establish. Figure 3 shows that the coolant flow changes very slowly after 100

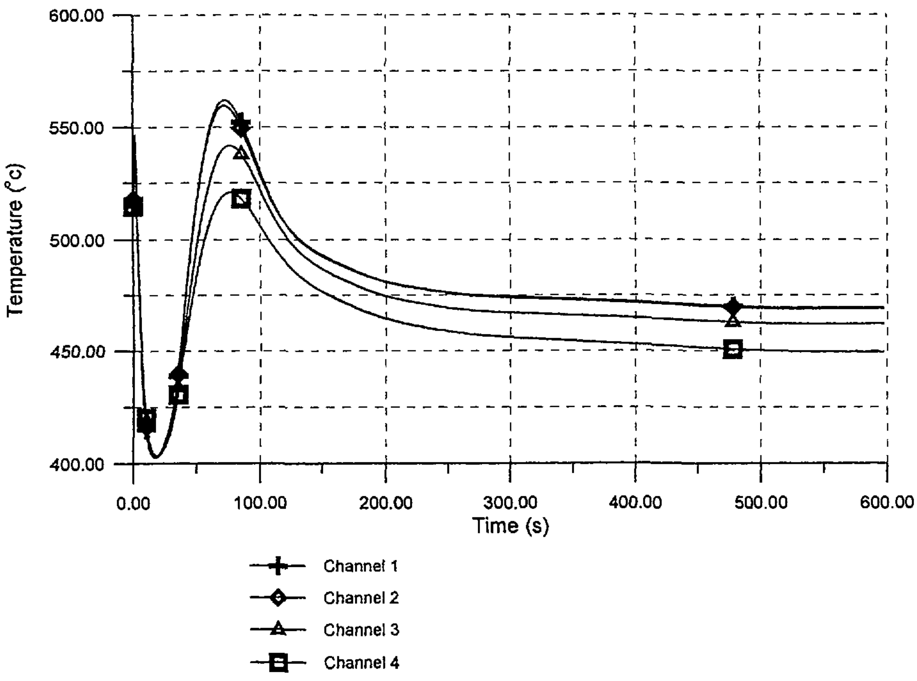

FIG. 2 Core Outlet Temperature

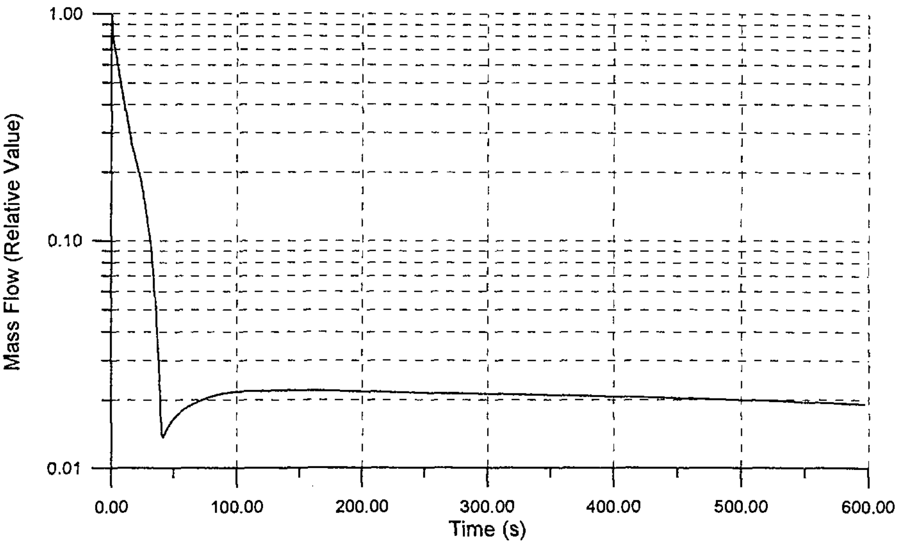

FIG. 3 Primary Sodium Flow

second, which means the natural convection has established basically. During this period, we should pay attention to the clad temperature because the maximum value will appear in this period. Fortunately, the maximum temperature is 563 centigrade degree, which is lower than the permitting line (850 centigrade degree).

1D method is adept to analyze the quasi-steady state. Figures 5 to 8 have given the calculation results on a long period. It can be seen that the sodium temperature outlet from the reactor core reach to 547 centigrade degree at 19.13 hour. On the other hand, the sodium temperature, bounded with main vessel, continue decrease for the reason of heat loss through steel vessel wall. And the temperature of wall approximately equal to this temperature. It can be summarized that the reactor structure temperature is lower than the permit value of 560 centigrade degree. The heat removed by ERHRS changes slightly after the accident occurring. Otherwise, it is better to pay attention to the heat losing through secondary loop, which makes a great contribution to the mass flow rate of primary loop. In another way, it can decrease the maximum temperature at the exit of core.

2.2 One loop failure absolutely

It's necessary to analyze this accident in the view of studying the reliability of ERHRS except the accident mentioned above. Figure 9 to 12 give us the calculation results. It can be seen that the sodium temperature in the hot pool is lower than the first accident. The reason is that AHX power jumps from 10% to 100% very soon after the ventilation valves being opened. Another more severe case is calculated too which the air door could not be opened at the same time. The results are good either if the vanes could be destroyed after 40 minutes.

2.3 Ventilation valves opened abnormally

The nominal power of CEFR is 65.MW and the sodium mass flow rate through the reactor core is 300kg/s. If the ERHRS is put into using unexpected, heat losing through ERHRS is only 1.62

percent of full power. The difference of sodium temperature at the entrance of IHX (Intermediate Heat Exchanger) is less than 3 centigrade degrees. On the other hand, it will spend 3 minutes at least to decrease 1 centigrade degree of the hot pool sodium temperature. Time is enough to terminate this accident with various means.

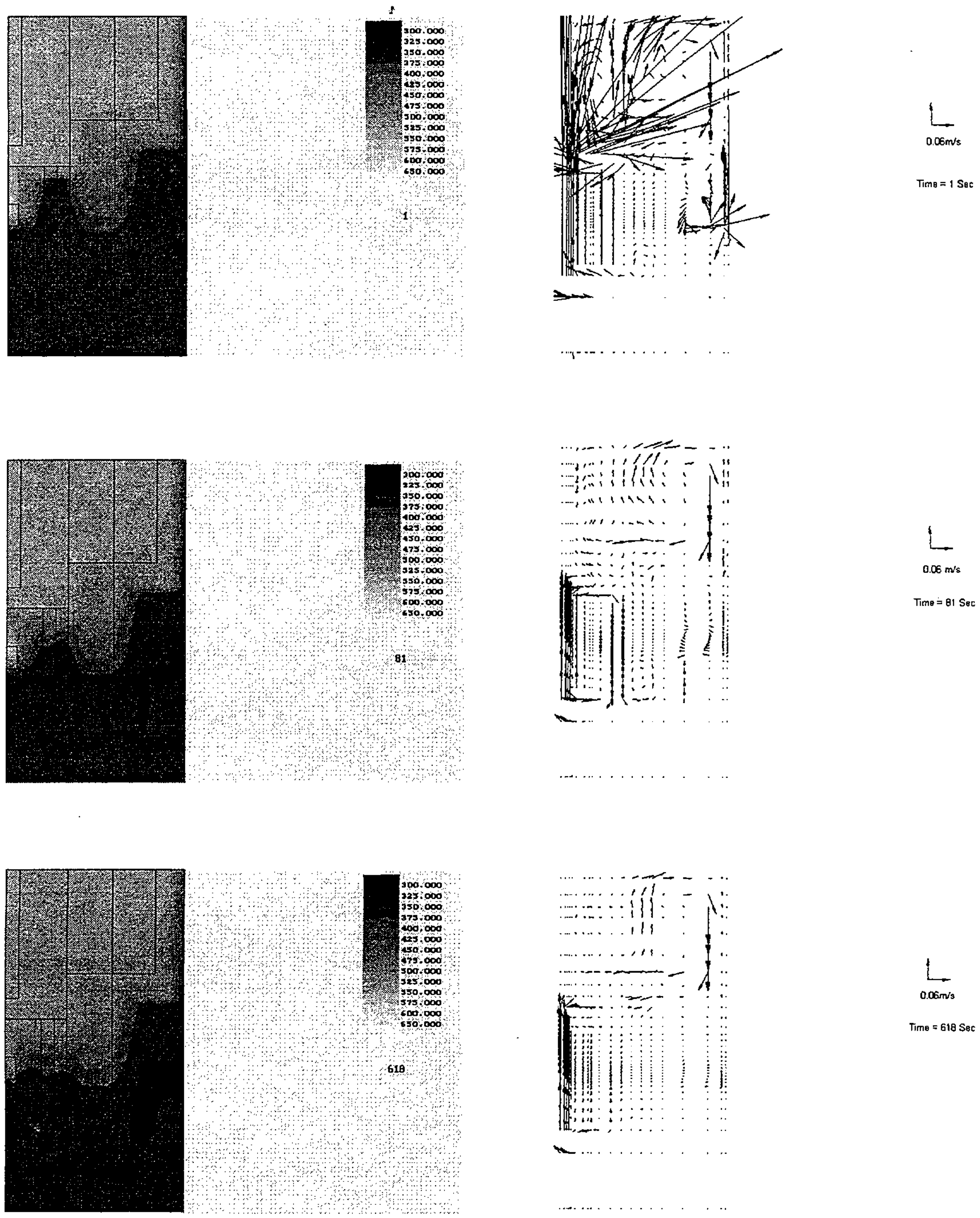

FIG. 4 Temperature and Flow Field of Primary Sodium in Reactor Vessel

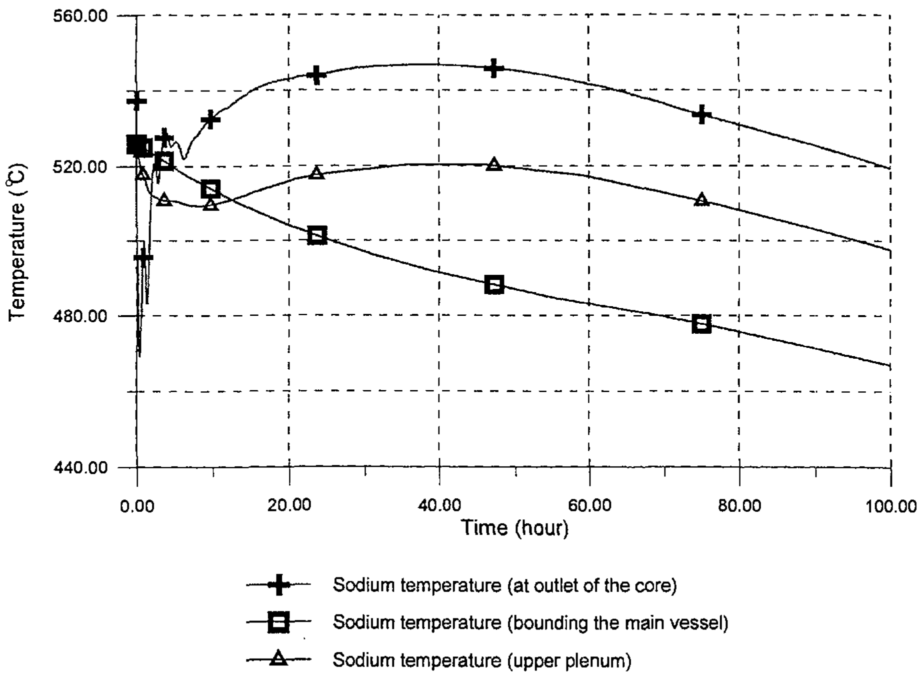

FIG. 5 Sodium Temperature in Hot-Pool

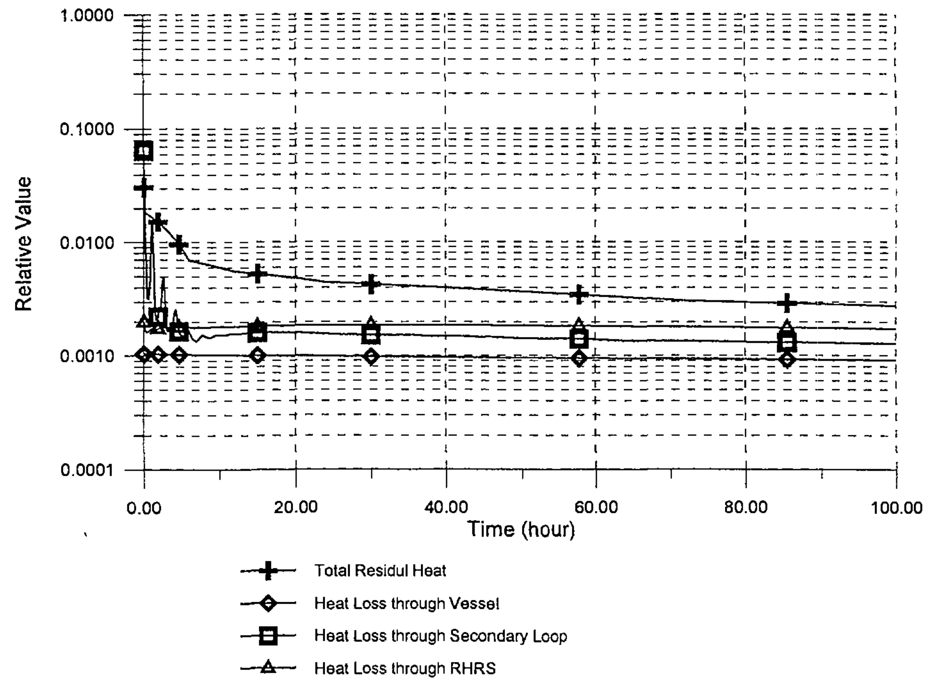

FIG. 6 Heat Removal Portions

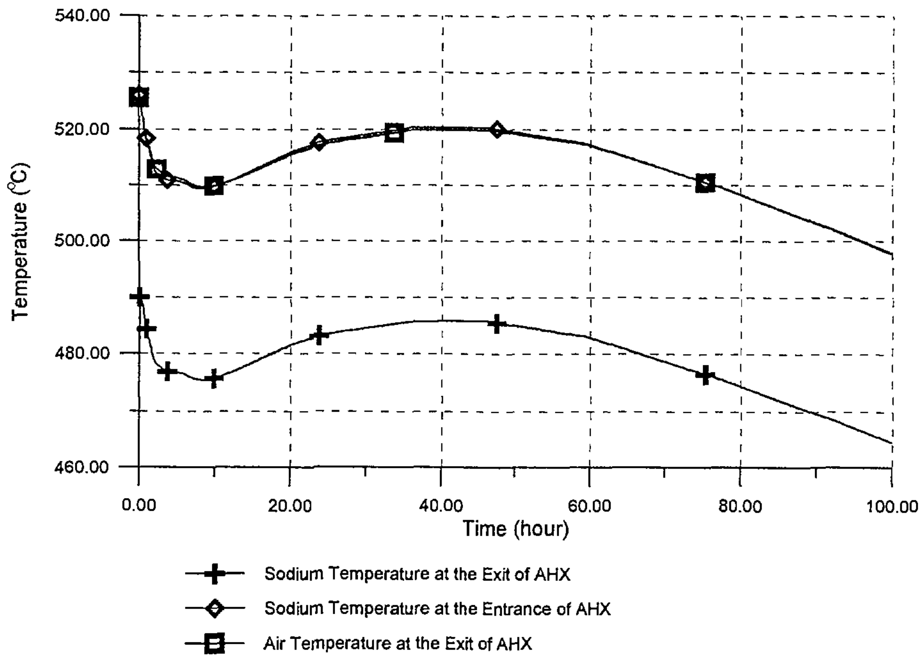

FIG. 7 Temperature Variation of AHX

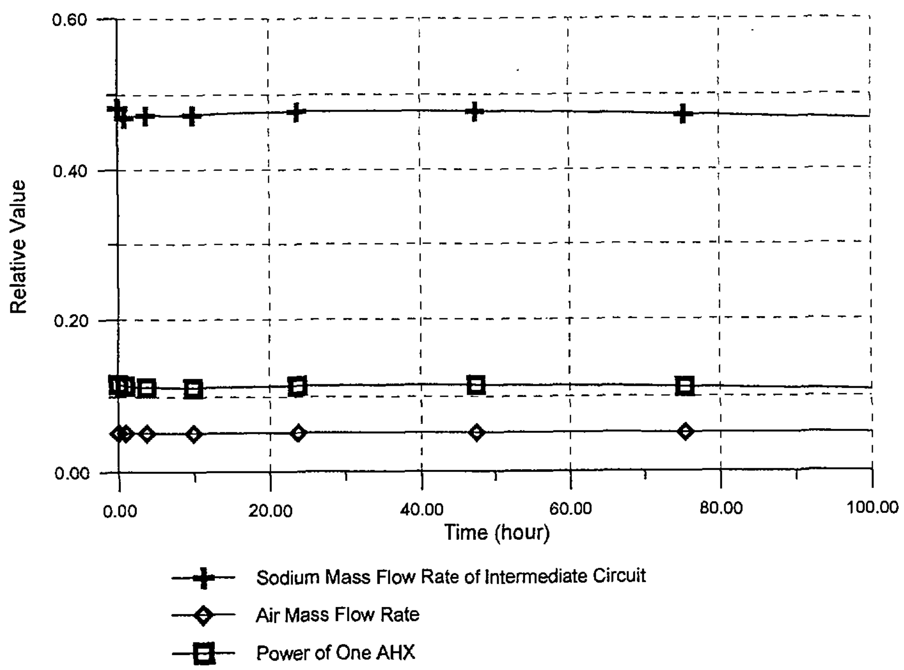

FIG. 8 Flow and Power Variation of AHX

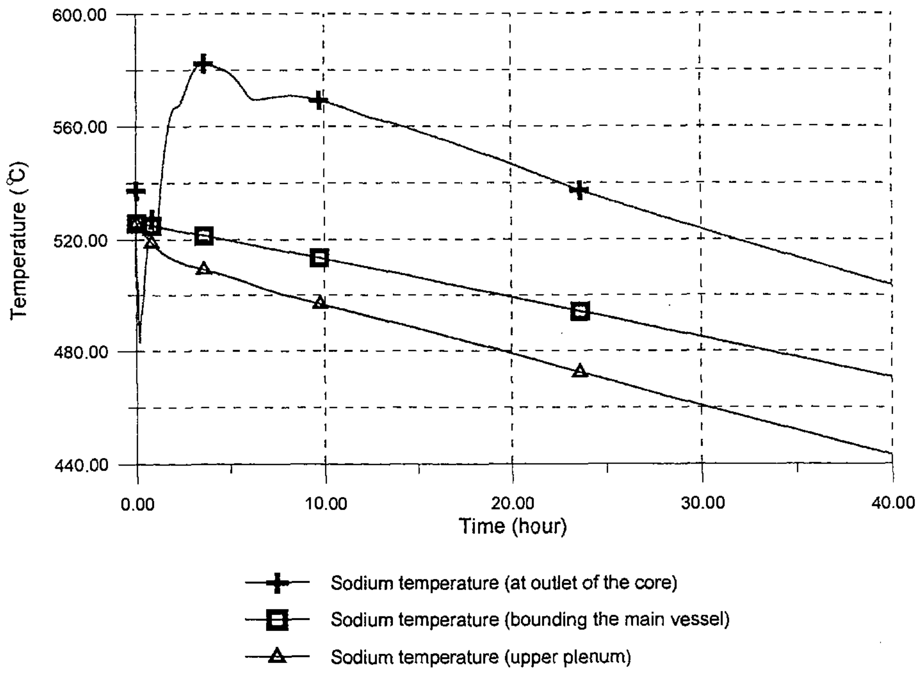

FIG. 9 Sodium Temperature in Reactor Vessel

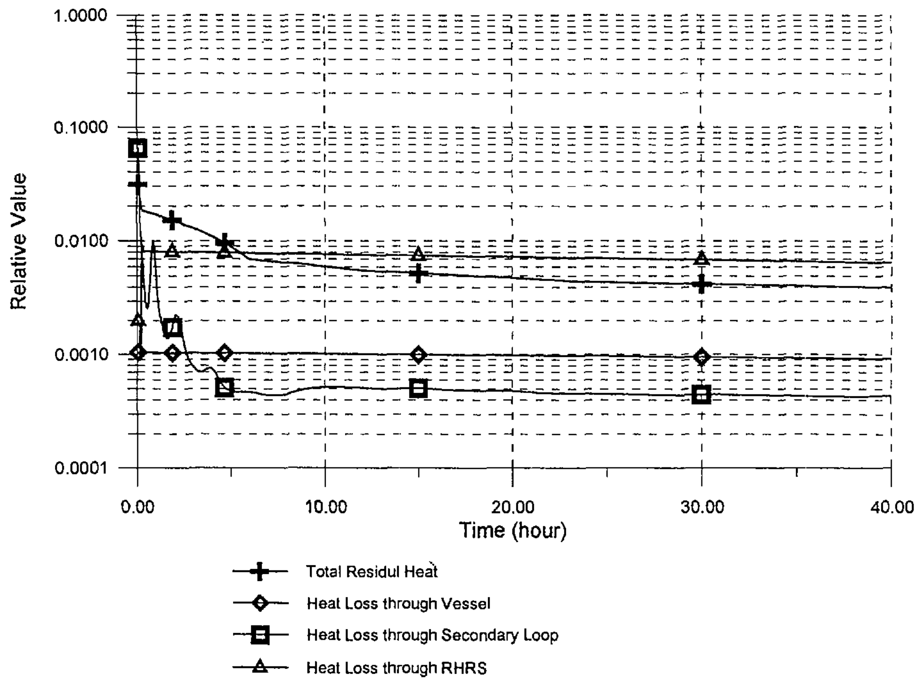

FIG. 10 Heat Removal Portions

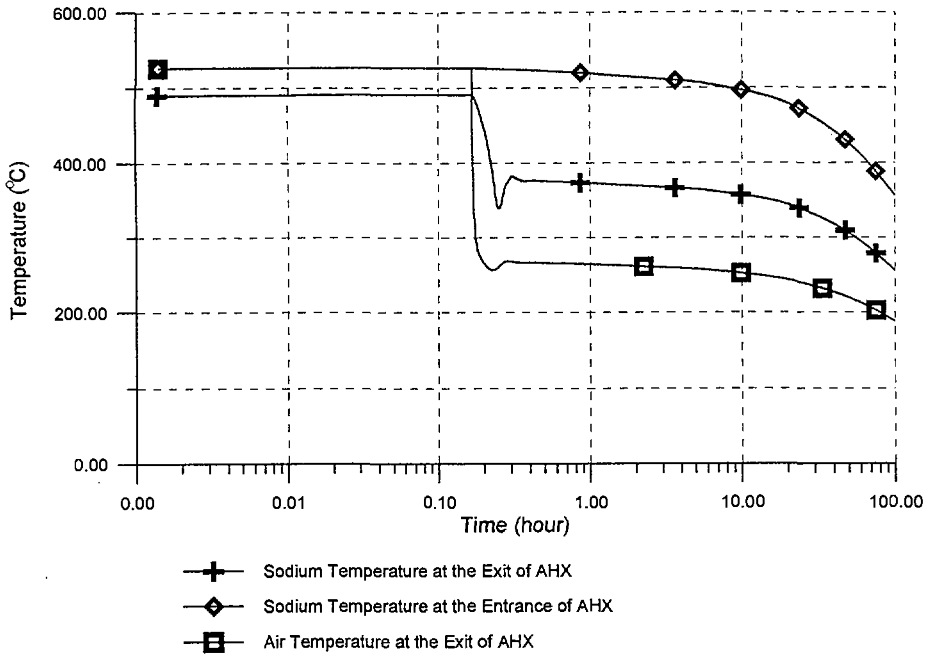

FIG. 11 Temperature Variation of AHX

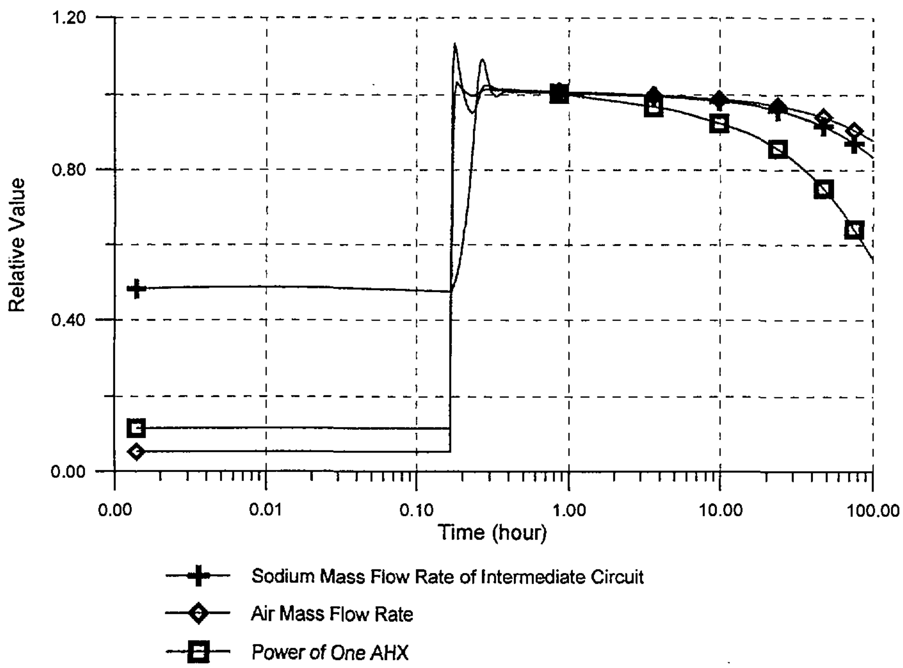

FIG. 12 Flow and Power Variation of AHX

3. Conclusion

As mentioned above, the ERHRS is designed to ensure safety and reliability, therefore, few measures are considered in design. They are:

(1) Inlet air door of AHX is divided into three sections,

(2) Ventilation valves could be driven by normal power supply, emergency power supply or manual operation,

(3) All intermediate circuit pipes are covered by guard tube,

(4) Physical separation is designed for two subsystems.

Calculations show that in all considered ERHRS accidents, including BDBA, primary sodium temperature is always within safety range.