Development of Heat-Transfer and Thermal-Analysis Code for Radioactive-Material Packages(CRISCAT)

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INTRODUCTION

There are various structures of packagings for radioactive-materials according to the quantity and nature of the radioactive-material transported. When the thermal analysis is carried out, structures of the packagings and the thermal behavior of the radioactive material become problems. Until now, to solve these problems, various special techniques have been considered. To make heat-transfer and thermal analysis of the packagings for radioactive-materials easy, new analysis code is developed in which various techniques are reflected.

Heat-transfer and thermal-analysis of the packagings for radioactive-material

When the heat-transfer and thermal-analyses of the packaging for radioactive-material are carried out, due to the complicated structures of the packagings and thermal behavior of the radioactive-material, these analyses require a great deal of labor. The points taken into account to make calculation simple or precise are shown below and the analytical methods in CRIEPI are shown, too.

· Multi-layer structure of the packaging such as cask

The packaging containing high level radioactive material has a multi-layer structure in view of shielding. Between the layer structures, there exists a narrow gap, which is thermal resistance when heat is radially transferred. The gap is produced during the process in the manufacturing of the packaging and so it is impossible to measure the thickness of the gap. In the thermal analysis, the thickness estimated by the experimental data is used.

· Combustion of the neutron shielding material
High molecule material such as resin is used for the neutron shielding material of the packaging. If the fire accident occurs and the packaging is engulfed in the fire, combustion of the neutron shielding material occurs and more heat of combustion is added to the packagings. Due to this effect, it seems that temperature of the packaging may increase. Up to the present evaluation, this effect has not been taken into account. But, judging from the experimental result obtained by the fire test using the partial model of the packaging(see Fig 1.), it is necessary to take this effect into account to obtain the precise result. In the proposed method, the heat input caused by the combustion of neutron shielding is modified by using the heat flux obtained on comparing the fire test data using the partial model and differential thermal characteristic of neutron shielding material. As an example, the correction value of the heat flux is shown in Fig 2. And comparison of the results obtained by the former analysis method with the results obtained by the new method (taking the combustion effect into account) is shown in Fig 3. In Fig 3, it is found that the calculated result using the new method agree well with the experimental result.

· structure of the fuel assembly
Spent fuel assembly contained in the packaging is composed of so many fuel pins. When the analysis for the packaging containing the spent fuel assemblies is carried out and all the fuel pins are taken into account, the analysis requires a great deal of labor and needs much calculation time. Until now, for the fuel assembly, the analysis using the simplified model is carried out. In the simplified model, heat transfer through the fuel pins are replaced by the equivalent conductivity taking convection, radiation and conduction into account(see Fig 4). Examples of the equivalent conductivity are shown in Fig 5.

· thermal behavior of UF6
When UF6 is heated, its thermal behavior is very complicated. There are several uncertainties on heat transfer in the packaging. In view of the safety of the packaging, it is important to take phase change and volume expansion effect into account. To evaluate the thermal behavior of UF6, some experimental and analytical programs are now being put into practice.

Heat-transfer and thermal-analysis code (CRISCAT:CRIEPI System for Cask Thermal Analysis)

Outline of the code

To make thermal-analysis of the packaging for radioactive material easy, new analysis code was developed.
Basic functions of the code are shown below.

- Three Dimensional Finite Element Method Code
- Steady and Unsteady thermal Analysis
- Heat Conduction and Radiation
- Static-elastic Analysis

The particular features of this analysis code are as follows.

- Probabilistic finite element method

This code has a function of probabilistic finite element method for the radiation boundary. When the packaging is engulfed in the fire, heat is transmitted from fire to the packaging by thermal radiation. The quantity of heat transmitted by radiation depends on the emissivity of the outer surface of the packaging. Emissivity changes in response to ambient temperature and fire condition, so emissivity is important analytical parameter. Using the probabilistic finite element method, the temperature fluctuation can be obtained by one calculation using the changes in the emissivity. This method is useful in saving calculation time for analysis of the complicated packaging.

- Database for package materials

This analysis code can be linked with simple database for package materials for easy data input. The properties dependent upon temperature are in the database and it is possible to add data to the database easily. Equivalent conductivities of fuel assembly are also in it.

- Miscellaneous

To solve the above-mentioned problems, this analysis code has functions taking latent heat and thermal gap into account. Furthermore, to take combustion of the shielding material into account, heat flux can be given at the boundary.

Results of test analyses

To prove the validity of this analysis code, several calculations were carried out. Among them, two analytical results are shown. In Fig 6, results of one dimensional heat conduction analysis is shown. It is proved the analytical solution well agree with theoretical solution. Fig 7 shows that results of two dimensional analysis for simple cask body model and Fig 8 shows the results by probabilistic finite element method. In Fig 8, all the temperatures obtained by probabilistic finite element method well agree with the temperature obtained by finite element method.

Conclusion

The points to which special attention should be paid are listed when the thermal analysis of the packaging for radioactive material is performed. In those points, it is proved that the effect of the combustion of the shielding material is important. Making a simple thermal experiment, the evaluation method are proposed.

To make the thermal-analysis easy and precise, thermal analysis code was developed. In its code, several special techniques are reflected. Using this code, probabilistic finite element method was carried out and it is proved that its analysis is useful for thermal-analysis.

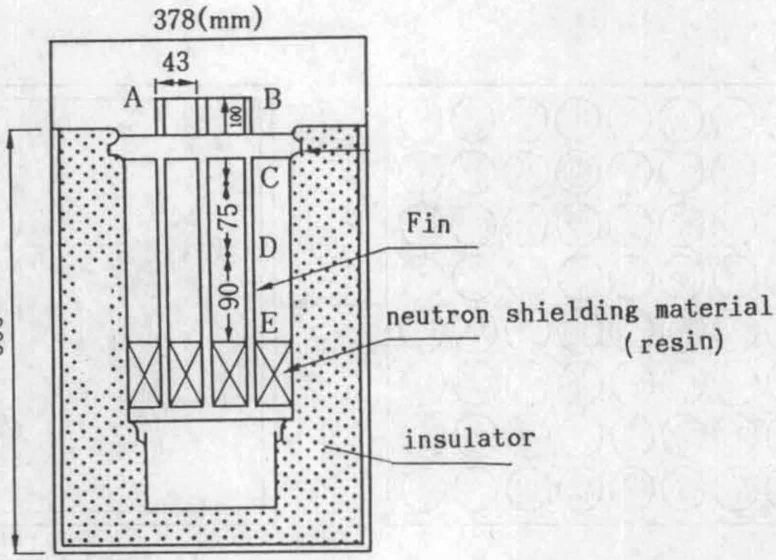

Fig 1. Partial model test body

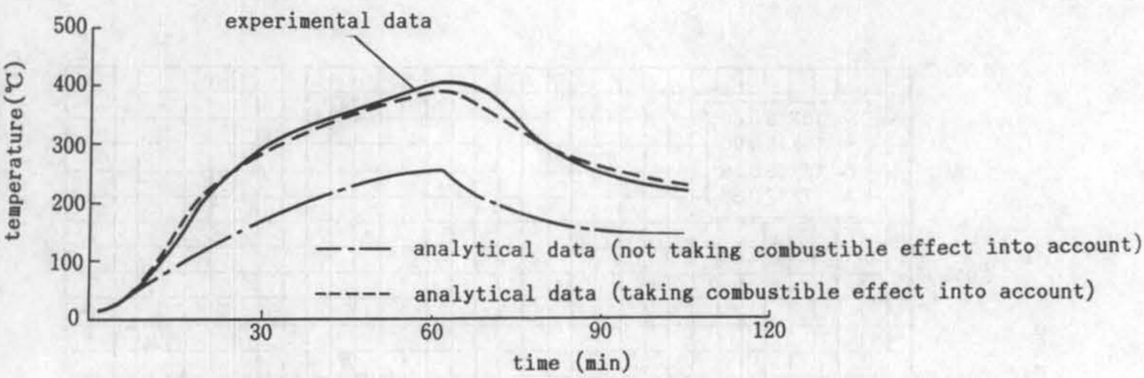

Fig 2. Comparison between thermal test result and analytical result

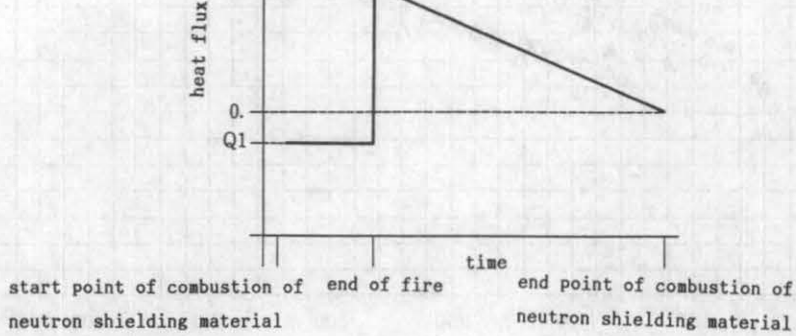

Fig 3. Conceptual drawing of heat flux

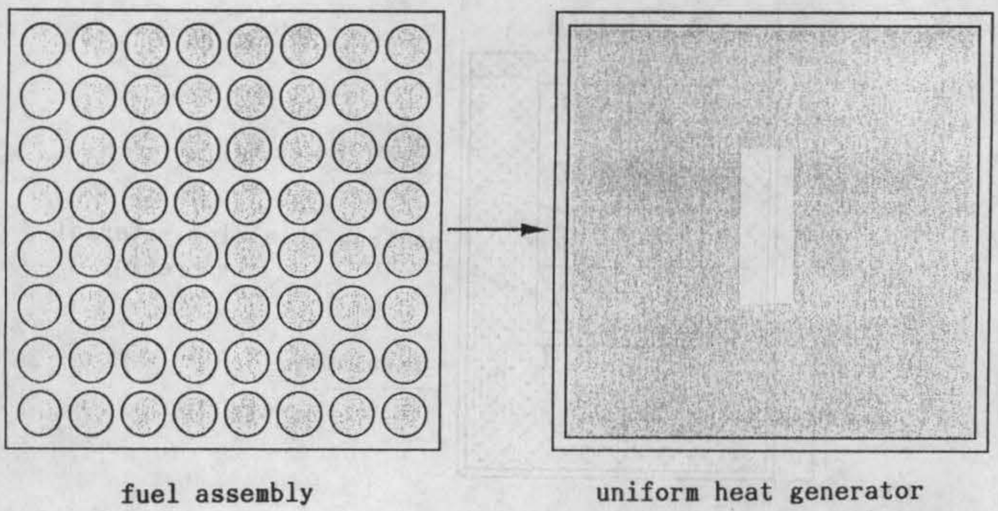

Fig 4. Modeling of the fuel assembly

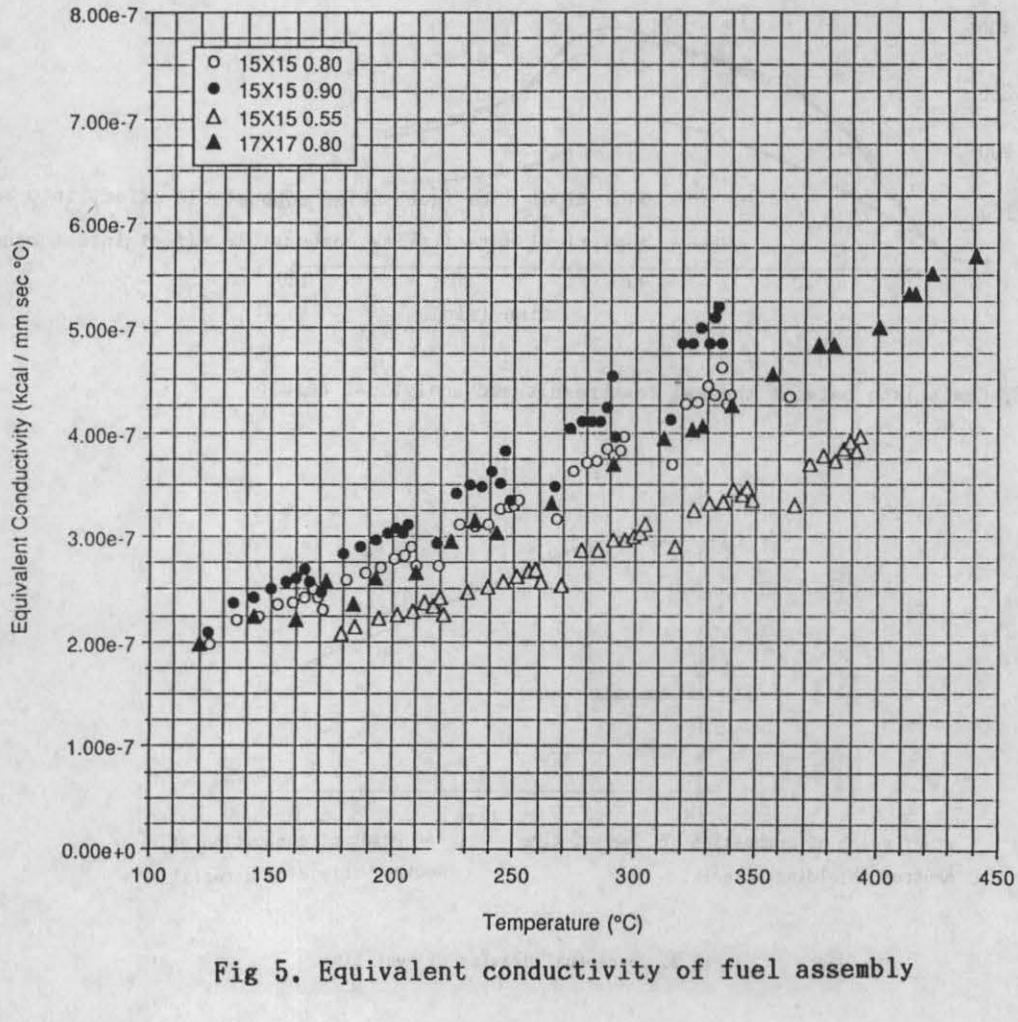

Fig 5. Equivalent conductivity of fuel assembly

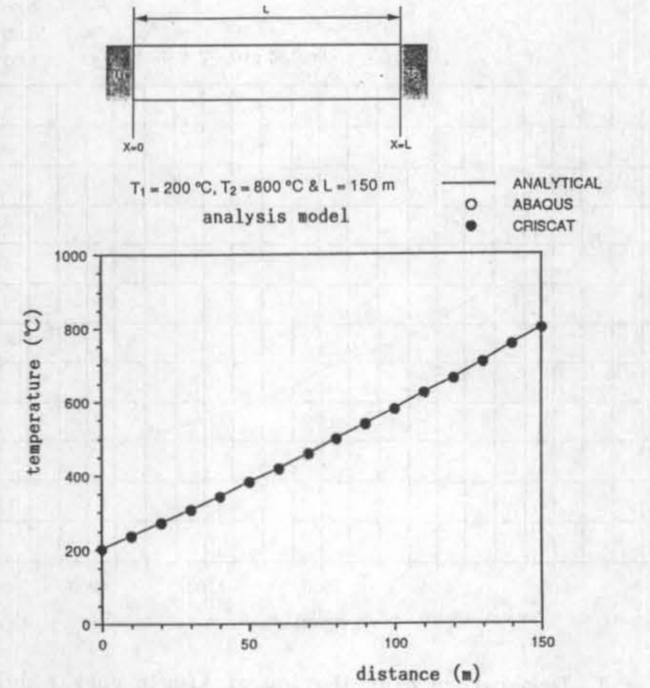

Fig 6. Temperature distribution of one dimensional steel rod

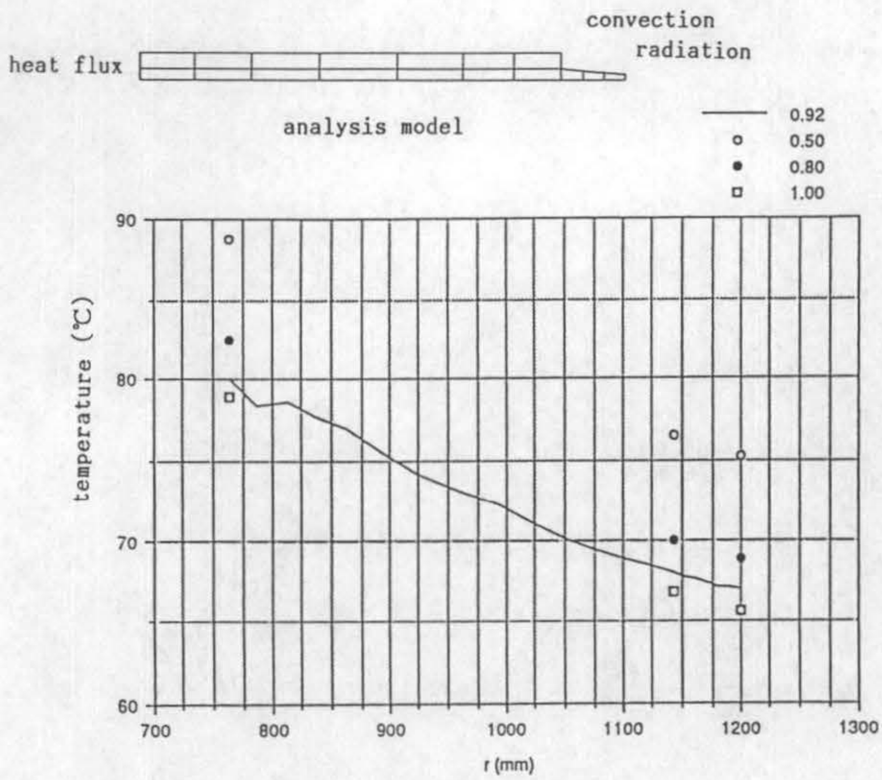

Fig 7. Temperature distribution of simple cask model
(finite element method)

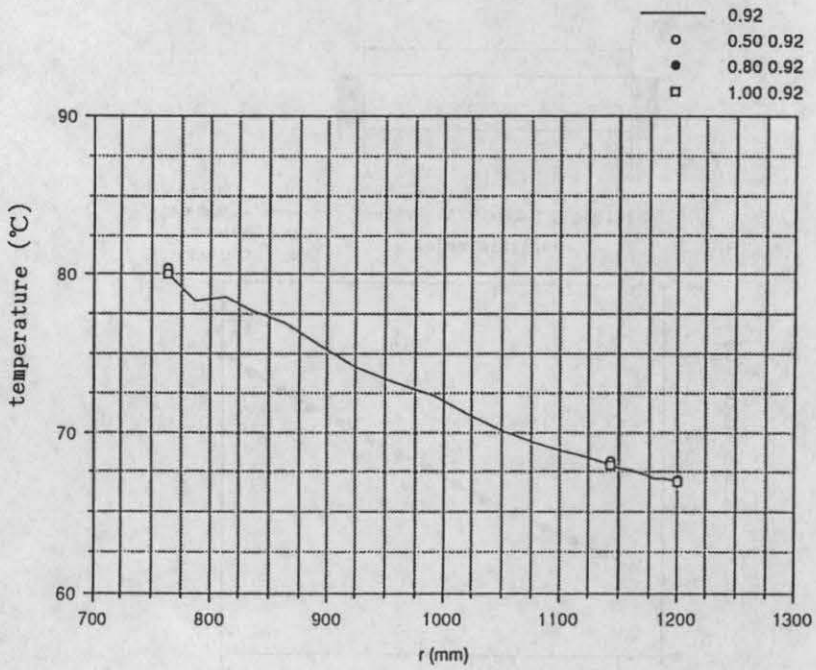

Fig 8. Temperature distribution of simple cask model
(Probabilistic finite element method)