Predicting thermal-hydraulic behaviour of nuclear reactors

In the last decades, several codes have been developed to predict the thermal-hydraulic behaviour of nuclear reactors – like ATHLET, CATHARE, RELAP, RETRAN. However, these codes were developed to power reactors perform. To extend the application for the analyses of research reactor some modifications or addition of some procedures have been done. This section presents some considerations for using of RELAP/SCDAP and MELCOR for accident analysis of KHRR reactor.

1. 1. RELAP/SCDAP

1. 1. 1. Thermal Hydraulic

RELAP5 computer program can be applied to a wide range of reactor designs and transient/accident conditions. Except for certain reactivity-initiated events, the code is applicable to LOCAs; loss of flow accidents (LOFAs); loss of heat removal events and anticipated transients without scram (ATWS).

Modelling of a subcooled boiling flow is important because an accurate knowledge of the void fraction distribution in reactor cores is required to properly perform various safety analyses. Most available boiling models were developed for and tested at the high-pressure conditions of a power reactor. Many reactor safety analysis codes such as RELAP5, which use such models, cannot satisfactorily predict void fraction distributions in low pressure subcooled boiling flows. This has limited the use of the RELAP5 code for low-pressure research reactor applications. It seems that the case of fast reactivity transient will be affected due to the importance of the models for the precise description of the complex phenomenon of subcooled boiling and two phase flow taking place during the transient. With respect to the reliability of the RELAP5 code for the analysis of research reactor transients additional investigations related to the above topics are needed.

1. 1. 2. Core Melt Progression

Although developed for light water reactors (LWR), the code is a flexible tool for computerized simulation as its approach allows to models as much as needed of a particular thermal-hydraulic system, with use both for anticipated transients of nuclear power plants or of research reactors, and also for small scale test facilities.

It is generally known that design peculiarities of HWR type reactors, especially the moderator separated from the coolant do not allow a straightforward application of the advanced core degradation models existing in computer codes such as SCDAP/RELAP5, MELCOR, ICARE/CATHARE or ATHLET. But the analysis of design basis accidents and the modelling of experiments in specially designed facilities can be successfully performed. Moreover, the early phase of the accident, including heatup due to voiding and oxidation, as well as, to a certain extent, other particular phenomena associated with the loss of geometrical integrity in course of a LOCA type accident coincident with ECCS, can be successfully modeled.

Several code extensions (for Atucha specific features) were added in RELAP/SCDAPsim3. 6. These modifications included: modeling of coolant channel to coolant channel radiation heat transfer, oxidation of the outer wall of the coolant channels, molten pool behavior and relocation of a core with separated coolant channels, and heat transfer in a lower head that includes a filling body (massive steel structure occupy most of the hemispherical volume and causing relocated debris to have a wide and thin-in-height shape). As an extra argument in favor of the utilization of the code for KHRR, the existence of the heavy water library in the release packages of RELAP/SCDAPSIM versions can be mentioned.

1. 2. MELCOR

1. 2. 1. Material Properties

Thermophysical properties for some solid materials should be added to the Material Properties (MP) package database. They are melting point, latent heat of fusion, density, specific heat, thermal conductivity and enthalpy for Zr-1. 5%Nb, type 304 stainless steel. Values for these material properties can be obtained from an open literature or, because of lack of data for the alloys at high temperatures, can be estimated by Nause and Leonard.

In addition to properties of solid materials, the MP package in MELCOR contains tabulated values for thermal conductivity and Viscosity of light water (H_2O) and steam. Because of the presence of heavy water (D_2O) in the KHRR reactor, an assessment was made concerning the differences between these properties and those appropriate for D_2O. Nause and Leonard concluded that the differences between heavy and light water thermal conductivity, heavy and light steam viscosity, and heavy and light steam thermal conductivity are negligible for the purpose and intended applications of MELCOR. For these properties, MELCOR will use the light water data in the MELCOR database to model heavy and light water in the KHRR reactor system .

The only thermophysical property of D_2O observed to differ from that of H_2O by more than ten percent is viscosity. Viscosity of D_2O is observed to differ from that of H_2O by as such as 30 percent over fluid, the temperature range of interest for the KHRR reactor. It is not known if differences in this single property are large enough to result in considerably different predictions of KHRR reactor coolant system hydrodynamic behavior. Sensitivity analyses will be performed in the future to examine this remaining uncertainty

The MP package in MELCOR includes tabulated values for the viscosity of hydrogen gas and the Noncondensible Gas (NCG) Equation of State package contains values for hydrogen heat capacity. Again, because of the possible coexistence of hydrogen and deuterium gas in the KHRR reactor systems, a comparison of the viscosity and heat capacity between the two gases was made. The difference between hydrogen and deuterium gas viscosity and heat capacity is concluded to be sufficiently large to warrant adding D_2 to the noncondensible gas flow field in MELCOR (D_2 gas viscosity is approximately 40 percent greater than H_2, and H_2 heat capacity is approximately 50 percent greater than D_2.). As a result, both properties have been included in their appropriate MELCOR database locations

The H_2O package in MELCOR represents the equation of state for light water. Because heavy water is the primary coolant and moderator in the KHRR reactor system, a comparison of the thermodynamic properties of light and heavy water and steam was made. It was found that the saturation pressure versus temperature data for light and heavy water differ by less than six percent. The difference in enthalpy between light and heavy water for the saturated and subcooled liquid states is below five percent at all temperatures and pressures of concern. The differences between light and heavy steam enthalpy are below eight percent over all temperatures and pressures of concern. These differences in properties between light and heavy water and steam are tolerable for the purpose and intended applications of MELCOR. Any change in properties related to the equation of state for light water in MELCOR would require that the changes be made in a manner that preserves the Maxwell relations. Therefore, simple adjustments to the current H_2O properties are not practical. Either the properties contained in the H_2O package must be replaced, or the current properties must be used. It has been concluded that using light water transport properties to represent the coolant, moderator Emergency Cooling System (ECS), and confinement spray fluids in the KHRR reactor system is a reasonable and pragmatic approximation to those for the true mixed H_2O/D_2O system .

1. 2. 2. Core Melt Progression

Unique features of KHRR do not allow a straightforward application of MELCOR for analysis of core melt progression in KHRR reactor, same as RELAP/SCDAP.

Coolant channels in KHRR reactor are located inside the moderator tank in a hexagonal pitch, so it is expected that the behavior of the core during meltdown will be somewhat different from that of regular LWRs. As the coolant channels are not in close contact with each other, molten material from different channels most likely will not agglomerate to form a crust strong enough to support an in-core molten pool. So the most expected behavior is that molten material is directly relocate to the bottom of the core.