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Analysis of energy released from core disruptive accident of sodium cooled fast reactor using CDA-ER and VENUS-II codes

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1. Introduction

In this work, the energy released from the core disruptive accident (CDA) of sodium cooled fast reactor was analyzed using a CDA-ER [1] and VENUS-II code [2] for various reactivity insertion rates up to 100$/s, which has been widely considered to be the upper limit of the ramp rates due to a fuel compaction [3]. The CDA-ER is a one-dimensional code that calculates energy and pressure behavior during CDA of fast reactor using Bethe-Tait method modified by Nicholson [4], and was developed at KAERI. The VENUS-II code is a two-dimensional coupled neutronics-hydrodynamics program that calculates the dynamic behavior of an LMFR during a prompt critical excursion, and was developed at Argonne National Laboratory.

The fast reactor has a unique feature in that rearranged core materials can produce a large increase in reactivity and recriticality. If such a rearrangement of core materials should occur rapidly, there would be a high rate of reactivity increase producing power excursions. The released energy from such an energetic recriticality might challenge the reactor vessel integrity.

An analysis of the hypothetical excursions that result in the disassembly of the reactor plays an important role in a liquid metal fast reactor (LMFR) safety analysis. The analysis of such excursions generally consists of three phases (initial or pre-disassembly phase, disassembly phase, energy-work conversion phase).

The first step is referred to as the “accident initiation” or “pre-disassembly” phase. In this phase, the accident is traced from some initiating event, such as a coolant pump failure or control rod ejection, up to a prompt critical condition where high temperatures and pressures rapidly develop in the core. Such complex processes as fuel pin failure, sodium voiding, and fuel slumping are treated in this phase. Several computer programs are available for this type of calculation, including SAS4A, MELT-II and FREADM.

If prompt critical conditions are reached as a result of the pre-disassembly calculation, a switch is then made to a second phase, or disassembly, calculation. In this phase, the excursion is followed until the power burst has been terminated by the disassembly of the core. The hydrodynamic effects that describe the motion of the reactor materials play a dominant role. Doppler feedback is also normally accounted for. Computer programs such as MARS and VENUS are used for disassembly calculations.

The final objective of most accident analyses is to determine what effect the excursion will ultimately have on the reactor vessel and containment. In the third phase, one attempts to follow the accident from the termination of the power burst up to some determination of these effects. This third area of analysis is referred to as energy-work conversion or energy-partition since one attempts to calculate what portion of the nuclear energy deposited during the excursion can ultimately be converted into work done on the containment. A number of models have been developed for this type of analysis, including the REXCO and SOCOOL-II computer programs.

VENUS-II deals with the second phase (disassembly analysis). Most of the models used in the code have been based on the original work of Bethe and Tait. The disassembly motion is calculated using a set of two-dimensional hydrodynamics equations in the VENUS code. The density changes can be explicitly calculated, which in turn allows the use of a more accurate density dependent equation of state. The main functional parts of the computational model can be summarized as follows:

1. Power and energy (point kinetics)
2. Temperature (energy balance)
3. Internal pressure (equation of state)
4. Material displacement (hydrodynamics)
5. Reactivity feedback (Doppler and displacement)

VENUS-II has the following assumptions.

1. The reactor materials behave like a homogeneous mixture with the property of an isotropic and nonviscous fluid

2. The reactivity change caused by a material displacement can be calculated with first-order perturbation theory. Further, the reactivity worth of spatial gradients remain constant and distort with the grid.

3. The heat transfer from the fuel can be ignored. Although several heat transfer mechanisms can become significant, one of the greatest potential influence would appear to be a rapid molten-fuel-coolant interaction (MFCI).

4. The nonfuel core constituents are considered to be compressible, but inert, materials.

5. The fuel vapor pressure and compression of the reactor materials are the only sources of internal pressure. Thus, such potential pressure sources such as fission gas and sodium vapor pressure are ignored.

6. The time history of the power level can be described using point kinetics, and the spatial power-density distribution remains constant.

2. Analysis of core explosion during CDA

An evaluation of a CDA energy release was conducted using the CDA-ER and VENUS-II codes, respectively [1]. Calculations were performed for the super prompt power excursions of the KALIMER-150 core shown in Fig. 1, initiated by reactivity insertion. The whole core meltdown is assumed in the calculation.

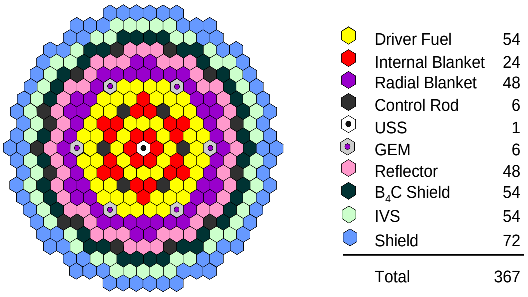

Fig. 1 KALIMER-150 core configuration

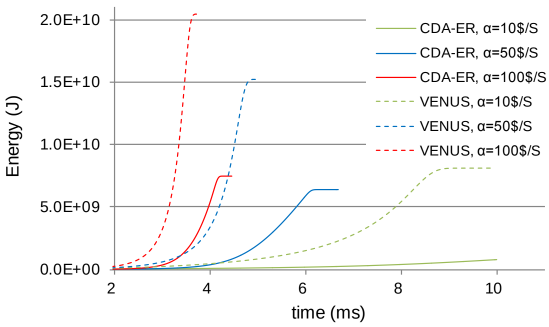

Fig. 2 Calculation results of energy release without Doppler effect

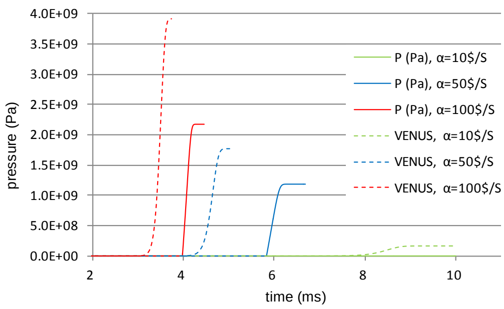

Fig. 3 Calculation results of core pressure variation with time without Doppler effect

Figures 2 and 3 show the calculated results of energy and pressure with various reactivity insertion rates without Doppler reactivity feedback effect. Tables 1 and 2 show the maximum energy and pressure results of Figs. 1 and 2, respectively.

All results of VENUS-II are shown to be higher than those of CDA-ER. This is thought to be due to the differences between two codes in the calculation algorithm, equation of state for core materials and computational dimensions in solving the hydrodynamics equations and treating the molten core, though each code is based on the same Bethe-Tait formulations and assumptions.

Table 1. Maximum released energy results with reactivity insertion rates

α ($/s)	CDA-ER (GJ)	VENUS-II (GJ)
10	0.79	8.12
50	6.40	15.23
100	7.48	20.46

Table 2. Maximum pressure results with reactivity insertion rates

α ($/s)	CDA-ER (GPa)	VENUS-II (GPa)
10	0.0	0.16
50	1.18	1.77
100	2.17	3.91

3. Conclusion and further work

In this work, the energy released from core disruptive accident (CDA) of sodium cooled fast reactor was investigated using CDA-ER [1] and VENUS-II code [2] for various reactivity insertion rates up to 100$/s, and their results were compared.

The calculation results of two codes showed similar trends of energy, power and pressure from CDA. But most results of VENUS-II were found to be larger than those of CDA-ER. The released energy results calculated from VENUS-II were about 2 ~ 3 times higher than those from CDA-ER. It is thought that the discrepancies between two codes' results were mainly owing to the differences of equation of state for molten core, and computation dimensions treated in the two codes.

Further work is necessary to improve analysis ability of VENES-II code by complementing the metal fuel properties, since it did not incorporate metal fuel analysis module. And more work is needed to prepare elaborated 2-dimensional core condition data used in the code as an input so that more accurate analysis can be performed.

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