FRAMATOME-CONF--5

FR 810 1099

TOPICAL MEETING ANS/ENS ON

THERMAL REACTOR SAFETY

~~7-8~~ - 11 AVRIL 1980

- KNOXVILLE - USA -

POST ACCIDENTAL SMALL BREAKS ANALYSIS.

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7-11/04/80

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ABSTRACT

EDF ordered to Framatome by 1977 to complete post accidental long term studies on "First Contrat-Programme" reactors, in order to demonstrate the safety criteria long term compliance, to get information on NSSS behaviour and to improve the post accidental procedures. Convenient analytical models were needed and EDF and Framatome respectively developped the AXEL and FRARELAP codes. The main result of these studies is that for the smallest breaks, it is possible to manually undertake cooling and pressure reducing actions by dumping the steam generators secondary side in order to meet the RHR operating specifications and perform long term cooling through this system. A specific small breaks procedure was written on this basis. The EDF and Framatome codes are continuously improved ; the results of a French set of separate effects experiments will be incorporated as well as integral system verification.

INTRODUCTION

Starting in 1975, a French program for building 28 PWR nuclear power plants (900 MW, 3 loop plants) has been carried out by EDF.

Within the frame of this program, in addition to satisfy French Safety Authorities requirements, studies have been requested by EDF to Framatome, in order to estimate a long term behaviour of the plant in addition of the studies already done in the Safety Analysis Reports demonstrating the Appendix K requirements compliance.

The post accidental studies which started in 1977 have been carried on, and since 1979, they have taken into consideration the Three Mile Island Unit 2 accident lessons. They investigate any accident for which the cause remains unresolved after the automatic safety systems actuation. Small and intermediate breaks are involved in such accidents.

The objectives of these studies can be summarized as follows :

- to verify that the safety criteria are always satisfied until a safe and quasi steady state has been reached with minimum operator intervention ;
- to give informations about the main plant parameters in order to improve the diagnosis abilities and the understanding of the plant behaviour during the accident, more specifically the different cooling modes and the changing from one mode to another ;

- to allow improvements and justifications for the operational procedures, especially manual actions on steam generators, actuating hot leg injection, actuating RHR.

The studies presented in this paper mainly result from Framatome computations in 1978, and from a few cross-checking computations on some specific problems performed by EDF.

EDF DEVELOPMENTS

EDF uses two types of computer codes :

- SIBEL : a simplified code where primary and secondary sides are both simulated by one or two control volumes,
- AXEL : a code where primary and secondary sides are both simulated using one dimensional model (3 main equations).

The computations performed with these codes agree with the conclusions of Framatome studies ; they especially permit to specify the possibilities of cooling and depressurizing the primary by dumping the secondary side of the steam generators in case of small breaks.

FRAMATOME DEVELOPMENT OF A COMPREHENSIVE ANALYTICAL MODEL

The different aspects of the long term cooling to be evaluated are the pressure transient, the recirculation procedures and time, the behaviour of the steam generators during the long term, the inventories of steam and water within the reactor pressure vessel, the possibilities of boron concentration built up in the core, the containment heat removal.

Since the small break spectrum covers equivalent break sizes of less than 2,5 cm (1 inch) up to about 25 cm (10 inches), break area ratio of more than one hundred, it is expected that the long term transients and behaviours may vary within large scales.

First of all, it was necessary for Framatome to develop an acceptable tool for small break thermal hydraulic transient analyses (FRARELAP).

Early in 1977, it was decided to evaluate the possibilities of the RELAP 4 MOD3 code. It appeared that this computer code could be the acceptable tool if some modifications are done. We performed these modifications during the two and a half past years.

The purpose of these modifications is threefold :

- better analytical models for small break transients,
- user's conveniences,
- computer code running time reduction.

Provided are the main aspects of the RELAP 4 MOD3 improvements for small break analyses :

- bubble rise velocities function of both pressure and void fraction based on separate effect experiments,
- heat transfer coefficients between the coolant and heat slabs, core or metal hea depending on the mixture level,
- possibility of the core node to have a mixture level and a superheated steam dome ; steam superheats along the uncovered core,
- gravity heads based on steam water interface as reference,
- heat transfer coefficients in the steam generators based on covered and uncovered parts, as for heat slabs, with in addition test of the heat flux direction : steam generators secondary cooling or heating the primary side,
- non horizontal flow paths, T nodes, safety or relief valve, pump modeled in a flow path, trips to stop a function, additionnal outputs...

POST ACCIDENTAL STUDIES RESULT

The main results of the long term post accidental studies performed with FRAREIAP are described in the following.

The small breaks spectrum can be split into three different types :

a) intermediate breaks of sizes larger than 10 cm (4 inches),

b) intermediate breaks of sizes less or equal to 10 cm (4 inches),

c) small breaks of sizes less or in the range of 2,5 cm (1 inch).

a) For the first ones, the break size is rather large, the system depressurizes rather quickly even without any operator action to dump the secondary side of the steam generators (figure 1).
The steam generators primary side tubes experience quick draining ; natural circulation fastly interrupts and never gets reestablished.
Residual heat is removed through the break only when breakflow turns from saturated liquid to saturated steam, after clearing the loop seal in case of a cold leg break.
Steam generators are no longer needed for the remaining of the transient. At the cold leg recirculation time, the low head safety injection pumps may or no: inject directly into the reactor coolant system. Thus, the recirculation throu; the high head safety injection system is needed.
Steam is continuously escaping out of the core and boron concentration built u; may occur. Switchover from cold leg recirculation to hot leg recirculation is needed at about 18 hours.
At such long term, the low head safety injection provides enough flow into the reactor vessel. .
Since for such break sizes, the steam generators are of no aid in cooling the system, the whole core residual heat is released to the containment through the break.
The containment pressure and temperature are reduced by the containment spray system ; the heat exchangers on the spray system are used to cool the containment sumps.

b) For the smallest intermediate break sizes, about 5 cm (two inches) equivalent diameter, similar phenomena occur.
For about 250 seconds, natural circulation keeps removing the residual heat through the steam generators with a primary flowrate of 10 % of nominal flowrate, system pressure being controlled by pressurizer and next upper plenum.
As break size is still large enough, safety injection flow does not match the liquid break flow and the system empties.
The previous natural circulation modes stop when the mixture level in the pressure vessel falls below the upper elevation of the hot legs. From this time, the upflow part of the steam generators U-tubes start draining, and next the down flow part. The driving head reduction decreases the loop flow.
The mixture level in the core keeps going down and in case of a cold leg break core uncovery may occur until the downcomer driving head matches, the pump suction resistance head. No credit for countercurrent flow in hot leg is taken
At about 1200 seconds, the loop seal clears and breakflow turns from saturated liquid to saturated steam ; residual heat is mainly removed through the break. As safety injection flow matches the saturated steam break flow, no further core uncovery may occur but steam production in the core is still going on.

Without dumping the steam generators secondary side, the primary pressure remains above the low head safety injection pumps shut off head for about 48 hours (figure 2). Cold leg recirculation using the high head pumps is required. Again the sumps have to be cooled through the heat exchangers on the containment spray system. The primary system is almost in a steady state condition with full downcomer and core covered (figure 3) ; the safety injection flow matches the boil-off flow ; residual heat is removed through the break to the containment. Hot leg recirculation on the long term using the high head pumps prevents from core boiling.

With dumping the secondary side, the condensing heat transfer coefficients allow a faster depressurization of the primary system (figures 4 and 5). At the switchover time from cold leg recirculation to hot leg recirculation, i.e. about 18 hours, pressure may have decreased enough so that low head safety injection pumps inject into the primary. Safety injection flow then matches the liquid break flow, the primary system refills and may go from core boiling to natural circulation.

c) The small breaks, about 2,5 cm (1 inch) equivalent diameter, behave differently. Early in the transient the safety injection flow is able at high pressure, secondary valve setpoint or more, to match the break flow. Residual heat cannot be removed through the break because of its small size and the steam generators cooling is needed for an extended period of time.

The steam generators auxiliary feedwater system keeps the secondary water level at the 0 % power level and compensates for the steam flow released to the condenser or to the atmosphere.

The primary system remains essentially in liquid, and does not depressurize if no operator action is taken (figure 6) ; natural circulation controlled by upper pleoum pressure keeps removing the residual heat to the steam generators for about 24 hours if no operator action (figures 7 and 8).

For these break sizes, primary pressure above secondary pressure, the operator may dump the secondary side at a rate of 28°C/hour. Heat transfer from the primary to the secondary allows to depressurize and cool the primary system. After about 3 hours cooling, the primary parameters are as follows :

- pressure about 3 MPa (figure 9),
- temperature less than 180°C (figure 10),
- injection flow matches the subcooled break flow,
- the system is solid, with visible level in the pressurizer (figure 11).

Therefore, since these conditions are equivalent or very close to the RHR system operating specifications, the long term cooling may continue using this system. As a benefit, this procedure may allow not to actuate the containment spray system.

POST ACCIDENTAL PROCEDURES

The previous demonstration made it possible to write a suitable post accidental procedure for small breaks.

This procedure tells the operator to use the normal systems - i.e. the RHR - for long term cooling after appropriate actions.

The symptoms allowing the operator to undertake cooling and pressure reducing actions by dumping the steam generators secondary side, in order to meet the convenient conditions of pressure and temperature in the primary for turning on the RHR, are the following ones :

- slow decrease of pressurizer level and pressure,
- primary pressure equilibrium above steam generators secondary pressure, if no fast cooling action,
- efficient cooling of primary through steam generators secondary side (condenser or atmosphere),
- slow increase of containment pressure,
- identical pressure in each steam generator secondary side,
- core outlet thermocouples showing saturation or subcooled conditions.

However, if any reason such as equipment unavailability makes this procedure fail, the operator uses the large or intermediate breaks post accidental procedure, that is cold leg recirculation, switchover to hot leg recirculation at about 18 hours after the accident and sump water cooling through containment spray exchangers.

FUTURE DEVELOPMENTS AND ORIENTATIONS

Independently of the previous long term studies performed during 1978 and 1979, new studies were ordered following TMI accident, dealing with pressurizer vapor space breaks, effects of primary pumps running, break isolation, non condensible gases effects, safety injection termination, breaks occuring during cold shutdown with RRA in service.

For these purposes, the FRARELAP and EDF/AXEL computer codes are continuously improved. Results of separate effects experiments have been or will be incorporated as well as integral tests verifications based on LOFT or LOBI.

Separate effects experiments are conducted in cooperation between Westinghouse, CEA, Framatome and EDF. They are briefly listed in the following table (see under).

Specifically, PWS 2.21 (Westinghouse proprietary tests on the G2 loop facility) results were used as a basis of improvement of bubble rise model in FRARELAP code.

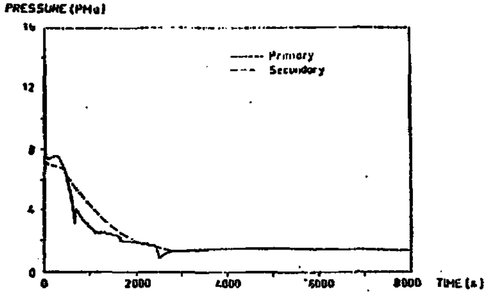
PWS 2.3 is an experiment of horizontal pipe flow regime in large diameter and simulates both the U-tube loop seal and the hot leg (results expected in mid 1980).

PATRICIA is a separate effects experiment for studying the heat transfer coefficients and hydrodynamic behaviour of the steam generator in degraded situation (first results expected in 1981).

On this specific point, EDF/AXEL code allowed to define the boundary conditions required to develop this experiment (temperature, void fraction, flow...).

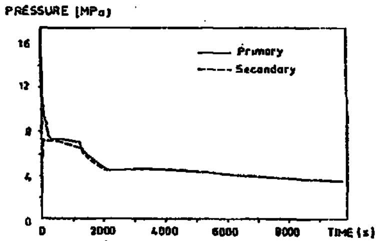
At last, a joint team composed by CEA, EDF and Framatome is developing a new generation code using a 6 equations model for both small and large breaks analyses.

SMALL BREAKS		Mass & Momentum Transfer			Wall Heat Transfer			Components					
SEPARATE EFFECTS EXPERIMENTS IN FRANCE	First results	Low vertical velocity	Low horizontal velocity	Entrainment - deentrainment	Non condensible gas effects	Core	Condensation in S-G tubes	Upper plenum	Hot leg	Steam generator inlet & outlet plenum	Steam generator 'U' tubes	Cross over leg	Pipe connecting junctions
ECTHOR (PWS 2.3)	79,83	X	X					X	X	X		X	
PATRICIA 1	81	X			X		X				X		
SUPER MOBY DICK	81	X	X										X
DADINE	81	X											
REBECCA	81	X			X								
SEROPS	80			X				X					
SERPAT	79					X							
ERSEC	80					X							
SIROCCO	80					X							
PERICLES	84					X							



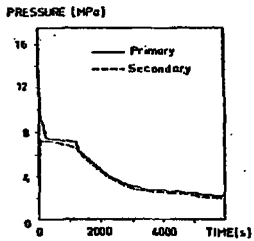
10cm (4inches) cold leg break

Figure 1



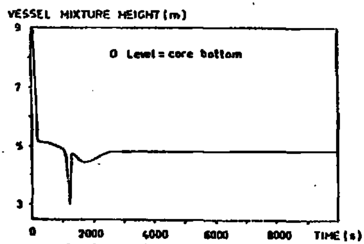
5cm(2inches) cold leg break
no operator action

Figure 2



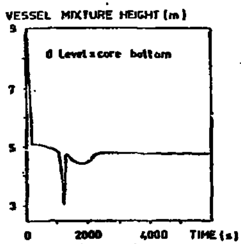
5cm(2inches) cold leg break
operator action

Figure 4



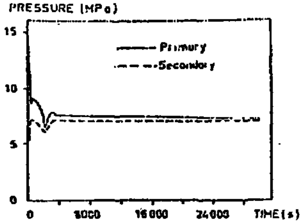
5cm(2inches) cold leg break
no operator action

Figure 3



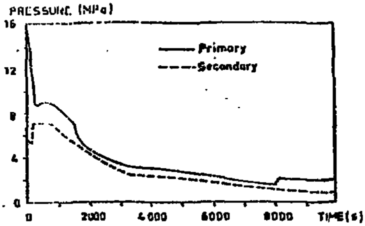
5cm (2inches) cold leg break
operator action

Figure 5



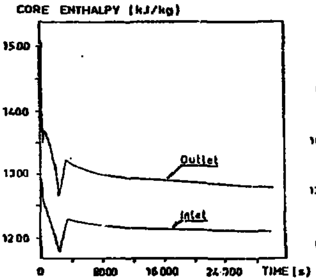
2,5cm(1inch) cold leg break
no operator action

Figure : 6



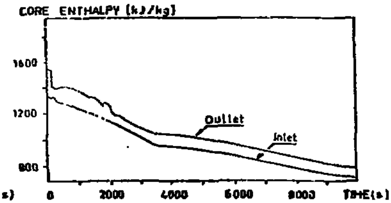
2,5cm(1inch) cold leg break
operator action

Figure : 9



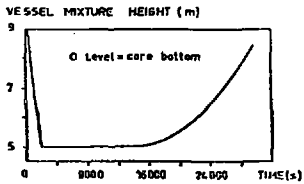
2,5cm(1inch) cold leg break
no operator action

Figure : 7



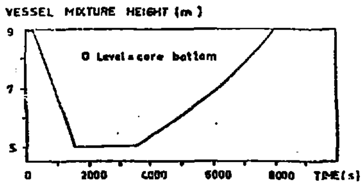
2,5cm(1inch) cold leg break
operator action

Figure : 10



2,5cm(1inch) cold leg break
no operator action

Figure : 8



2,5cm(1inch) cold leg break
operator action

Figure : 11