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REVISION HISTORY

Issue	Description	Date
00	First issue.	28-04-2008
01	PCSR June 2009 update including : - Clarification of text - Inclusion of references	27-06-2009
02	Consolidated Step 4 PCSR update: - Minor editorial changes - Clarification of text - New section added (§6.2.1.5.2.4) regarding P & T analysis results	31-03-2011
03	Consolidated PCSR update: - References listed under each numbered section or sub-section heading numbered [Ref-1], [Ref-2], [Ref-3], etc - Minor editorial changes	26-06-2012

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The numbering from the EPR Basic Design Report has been kept for consistency with original references to this Report.

APPENDIX 6 – MER CALCULATIONS - BDR RESULTS

This appendix reproduces sections of the Basic Design Report (1999 Edition) (BDR 99) [Ref-1] providing Mass and Energy Release (MER) analysis results which have not been re-analysed as part of the PCSR studies.

This appendix also contains BDR 99 results for pressure and temperature loads calculated with the PAREO code for a pressuriser surge line break and for a 2A-LOCA.

For convenience, BDR 99 section numbering is used in this Appendix as follows:

- 6.2.1.5.2.   Description of incidents and accidents used as the containment design basis

- 6.2.1.5.2.1   Large Break LOCA

- 6.2.1.5.2.2   2A-LOCA

- 6.2.1.5.2.3   Steam line break

- 6.2.1.5.2.4   P & T analysis results

6.2.1.5.2. Description of incidents and accidents used as the containment design basis

The behaviour of the containment wall is assessed in the event of Large Break - Loss of Coolant Accident (LB-LOCA), 2A-LOCA, Steam Line Break (SLB) and severe accidents.

6.2.1.5.2.1 Large break LOCA

6.2.1.5.2.1.1 Introduction

This section summarises the calculations undertaken to determine the mass and energy release (MER) into the containment as a consequence of the complete rupture of the pressuriser surge line. This event is representative of a LB-LOCA/PCC-4 LOCA scenario.

6.2.1.5.2.1.2 Calculation Model

The calculation uses the CATHARE [Ref-1] SB-LOCA and IB-LOCA methodology (the evolution of the accident is also described in the CATHARE documentation). The containment code COCO [Ref-2] is coupled with CATHARE to improve the accuracy of the calculated MER. The COCO response (containment backpressure and MHSI/LHSI temperature) is used as a boundary condition for CATHARE and hence both the RCP [RCS] response and the containment response are calculated simultaneously.

Note: For the calculation of the containment pressure and temperature, the COCO code was replaced by the CONPATE4 code [Ref-3].

6.2.1.5.2.1.3 Initial and Boundary Conditions

CATHARE modelling of primary/secondary circuit:

The MER is calculated using conservative assumptions, the most important of which are:

- Decay heat corresponding to ORIGEN/S [Ref-1] + uncertainties (point kinetic calculation)

- Initial reactor power 102% (= 4998 MW$_{th}$)

- Loss of off-site power with RT signal

- Loss of one diesel due to single failure

- Loss of one diesel due to preventive maintenance

- No manual actions are assumed

- I&C-functions correspond to the PCC-4 calculation.

COCO modelling of containment:

Conservative assumptions in the COCO input for the maximum containment pressure and maximum IRWST temperature have been used (see 6.2.1.5.2.1 - Table 1/2 and 2/2). Specifically, conservatively low values for containment volume, IRWST volume, and heat transfer coefficients between atmosphere/water are used.

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6.2.1.5.2.1.4 Analysis Results

Mass and energy release results are given in 6.2.1.5.2.1 - Figures 1/2 and 2/2.

6.2.1.5.2.2. 2A-LOCA

6.2.1.5.2.2.1 Introduction

This section summarises the calculations undertaken to determine the MER into the containment as a consequence of a double-ended (2A) guillotine break of a main coolant system cold leg. This event is a representative scenario for the assessment of short-term containment loads.

6.2.1.5.2.2.2 Calculation Model

The analysis was performed using the CATHARE 2V1.3L computer code. Containment pressure is provided by the computer code COCO, which runs interactively with CATHARE. This allows the RCP [RCS] response and the containment response to be calculated simultaneously.

6.2.1.5.2.2.3 Initial and Boundary Conditions

Best-estimate assumptions are used; the most important of which are:

- Initial rated reactor power 100%

- Decay heat corresponding to ORIGEN/S

- All trains of safety injection system available

- Off-site power available

- Containment-volume and heat transfer areas in containment (COCO-input) used corresponding to their nominal values.

COCO modelling of the containment

In general, best-estimate initial and boundary conditions are used, i.e. containment volume and heat transfer areas in containment are nominal values. Assumptions which maximise containment pressure are made for those parameters which do not have a clear best-estimate value - e.g. heat transfer coefficient between atmosphere and IRWST - (see 6.2.1.5.2.1 - Table 1/2). The LHSI heat exchangers have also been simulated using the data listed in 6.2.1.5.2.1 - Table 2/2.

6.2.1.5.2.2.4 Analysis Results

A description of the thermal-hydraulic behaviour of the RCP [RCS] together with the main phenomena which characterise a 2A cold leg break are provided in section 1.5 of Sub-chapter 6.2.

6.2.1.5.2.3   Steam line break

6.2.1.5.2.3.1 General

The most onerous case with respect to the containment loads, among all PCC events affecting the secondary system, corresponds to the double-ended guillotine break of a Main Steam Line inside the containment building.

A general description of the accident is provided in Sub-chapter 14.5.

The Mass and Energy Release (MER) associated with this type of break depends on initial and boundary conditions and also the single failure postulated in the safety systems.

The following sensitivity studies have been performed to identify the most onerous case:

- Sensitivity to the fuel management (UO_2, MOX)

- Sensitivity to the initial power level (from 0% to 102% of full power)

- Sensitivity to one of the following single failures:

    o   Failure to drop of the highest worth RCCA, which is assumed to be stuck in its fully withdrawn position

    o   Failure to close of a Main Feed Water Isolation valve on the affected SG

    o   Failure to close of the Main Steam Isolation Valve (VIV [MSIV]) on the affected SG.

6.2.1.5.2.3.2 Calculation model

The computer code THEMIS [Ref-1] is used to calculate the MER through the break from the affected SG, and from the three non-affected SGs through the Main Steam Header (MSH) until the VIV [MSIV] closes. In the event of failure to close the VIV [MSIV] on the affected SG, blowdown of the MSH is also assumed to take place.

The analysis methodology is described in Sub-chapter 14.5, except that the core neutronics is directly calculated by THEMIS with a point kinetics model, using a methodology and assumptions that are conservative in terms of calculating MER.

6.2.1.5.2.3.3 Calculation assumptions [Ref-1]

a) General assumptions

The following assumptions lead to a conservative calculation of the MER during a SLB:

- Maximisation of the initial energy in the primary side:

    Uncertainties are applied as follows:

    o   + 2% on core power

    o   + 2.5 bar on pressuriser pressure

       o   + 2.5°C on average primary temperature.

Heat stored in the primary metallic structures and power from the primary pumps is taken into account.

- Maximisation of the heat transferred from the primary side to the secondary side :

    o   the SG tubes are clean and 0% of them are plugged

    o   the mechanical primary flow rate is considered

    o   the RCP [RCS] pumps are running

    o   the neutronics data is conservative with respect to the core return to power

    o   the maximum decay heat curve is used (see Sub-chapter 14.0).

- Maximisation of the mass and energy release from the secondary side :

    o   + 10% uncertainty is applied to the initial SG water inventory, which includes uncertainties on the SG level control and on the SG water temperature

      The resulting initial SG water inventory is:

      - 102 te at full power,

      - 132 te at zero power.

    o   the ARE [MFWS] temperature is maximised i.e. nominal + 5°C

    o   the flashing effect [1] in the main feedwater line is taken into account

    o   a constant back pressure of 1 bar is assumed for the containment atmosphere

    o   perfect moisture separation is assumed at the steam generator outlet, leading to a break flow quality of 1 (pure steam flow at the break maximises the total energy released)

   o   blowdown of the MSH is assumed to continue until VIV [MSIV] closure.

b) Specific assumptions

The relevant I&C protection signals are described in Sub-chapter 14.0.

The following protection actions are taken into account in a conservative manner by assuming maximum times to occurrence:

---

[1]) After Main Feed Water isolation, a volume of water stays in the ARE [MFWS] pipes at initial ARE [MFWS] temperature and SG pressure. As SG pressure decreases under the saturation pressure of the ARE [MFWS], this water flashes to steam in the ARE [MFWS] pipes and flows into the affected SG.

- Reactor trip (for SLB at power):

  o performed by RCCAs dropping into core, F1A qualified

  o on F1A signal "SG pressure drop > MAX1", with 0.9 seconds signal delay, 0.3 seconds RCCA gripper release and 5 seconds RCCA drop time.

- MSH isolation:

  o performed by closing the four VIV [MSIV], F1A qualified

  o on F1A signal "SG pressure drop > MAX1", with 0.9 seconds signal delay and 5 seconds VIV [MSIV] closing time.

- ARE [MFWS] isolation:

  o performed by closing the three ARE [MFWS] isolation valves on each SG, all F1A qualified :

    - the high load isolation valve (MFIV-HL) closes the high load line

    - the low load isolation valve (MFIV-LL) closes the low load line

    - the main isolation valve (MFIV) closes the main FW line.

  o the MFIV-HL is closed on F1A signal "SG pressure drop > MAX1", with 0.9 seconds signal delay and 10 seconds valve closing time,
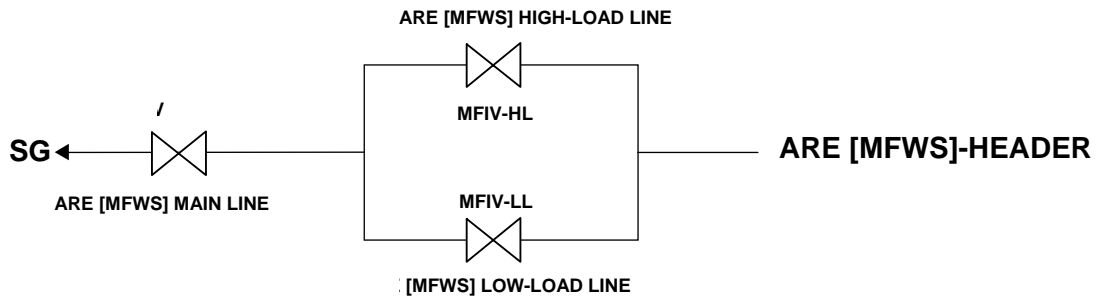
  o the MFIV-LL and the MFIV are closed on F1A signal "SG pressure drop > MAX2", with 0.9 seconds signal delay and 10 seconds valve closing time.

The ARE [MFWS], AAD [SSS], ASG [EFWS] flow rates entering the affected SG prior to their isolation are bounding values:

- ARE [MFWS] flow rate[1]

  o for an initial power state higher than 20% NP (Nominal Power), the ARE [MFWS] flow rate entering the affected SG is:

    - 1100 kg/s (~160% of nominal ARE [MFWS] flow) before MSH isolation

---

[1] After more precise definition of the Conventional Island, these values will be redefined.

- 1670 kg/s (~240% of nominal ARE [MFWS] flow) after MSH isolation, and before ARE [MFWS] high-load line isolation

- 900 kg/s (~130% of nominal ARE [MFWS] flow) after MSH isolation, and ARE [MFWS] high-load line isolation

- 0 kg/s after ARE [MFWS] main line and low-load line are isolated.

o for an initial power state lower than 20% NP, the high-load line is closed in normal operation, and the ARE [MFWS] flow rate entering the affected SG is:

- 900 kg/s before ARE [MFWS] main line and low-load line isolations.

- 0 kg/s after ARE [MFWS] main line and low-load line are isolated.

- AAD [SSS] flow rate: The start-up system is not considered in this study because the ARE [MFWS] system remains in operation until total ARE [MFWS] isolation. The ARE [MFWS] flow rate bounds the AAD [SSS] flow rate.

- ASG [EFWS] flow rate: The Emergency Feed Water ASG [EFWS] flow rate into the affected SG is assumed to be constant at 200 m^3/h, with a maximum temperature of 50°C, from the start of the accident. This is terminated by the operator 0.5 hours after reactor trip. Conservatively, the assumed value of 200 m^3/h does not take any credit for active limitation of the ASG [EFWS] flow. This is judged to be an excessively conservative assumption since this failure is additional to the already assumed single failure.

c) Single failure

Sensitivity to one of the following single failures is performed, in order to identify the most onerous:

- Single failure preventing closure of the MFIV-HL valve of the affected SG:

  As a consequence, isolation of the ARE [MFWS] High-load line fails. The ARE [MFWS] flow entering the affected SG remains at 1670 kg/s (rather than reducing to 900 kg/s) until isolation of the ARE [MFWS] main line and ARE [MFWS] low-load line.

- Single failure of the highest worth RCCA:

  The reactivity is calculated assuming all RCCA are inserted into the core except the highest worth RCCA, which is assumed to be stuck in its fully withdrawn position.

- Single failure preventing closure of the VIV [MSIV] of the affected SG:

  The VIV [MSIV] of the affected SG remains open. Consequently, the steam contained in the MSH flows into the containment. The MSH includes the main steam lines up to the main steam bypass and the turbine inlet pipes up to the turbine stop valves. The total MSH volume is assumed to be 300 m^3.

d) Preventive maintenance

Preventive maintenance has no impact on the MER analysis in SLB, since the protective actions are limited to reactor trip and actuation of valves (isolation functions). These actions are not affected by preventive maintenance.

e) Break assumption

The break area on the SG side corresponds to the flow area of the SG flow-limiter located at the SG outlet, i.e. 1300 cm².

The break area on the main steam header side corresponds to the flow area of the fully open VIV [MSIV] i.e. 3900 cm².

6.2.1.5.2.3.4 Analysis Results [Ref-1]

Sensitivity studies have shown that the most onerous configuration corresponds to the following conditions:

- 0% of initial power (2% considered to bound decay heat level at hot shutdown)

- Failure to close the VIV [MSIV] on the affected SG.

The sequence of events, corresponding to the most onerous case, is as follows:

SG pressure drop signal > MAX1 at	2.0 seconds
Rod dropping starts at	3.2 seconds
SG pressure drop signal > MAX2 at	5.2 seconds
Main Steam Header isolation at	7.9 seconds
Main Feed Water isolation at	16.1 seconds
RIS [SIS] actuation on low pressuriser pressure at	69 seconds
Affected SG dry-out at	323 seconds
Emergency Feedwater isolation at	1803 seconds
Mass of steam released inside the containment	191.0 te at 323 seconds
Mass of steam released inside the containment	273.5 te at 1803 seconds

The Mass and Energy Release data corresponding to the most onerous case is presented in 6.2.1.5.2.3 - Figure 1/4 and Figure 2/4.

6.2.1.5.2.3 - Figures 3/4 and 4/4 present the MER data for the same case but with an initial power of 100% (102% including uncertainty).

6.2.1.5.2.4. P & T analysis results

Pressure and temperature in the containment are presented in 6.2.1.5.2.4 – Figure 1 and 2/4 for the surge line break and in 6.2.1.5.2.4 – Figure 3 and 4/4 for the 2A-LOCA, with:

- Pgaz : total containment pressure

- Pvap : partial pressure of steam

- Tliq : temperature of IRWST

- Tgaz : atmosphere temperature

- TsatPvap : saturation temperature of the partial pressure of steam.

6.2.1.5.2.1 - TABLE 1/2 [REF-1]

Assumptions for Containment Code COCO

Description	Value
Heat transfer between containment atmosphere and IRWST-water	
HT-area between atmosphere and IRWST	6 m²
HTC between atmosphere and IRWST	5 W/m²K
Containment free volume	78000 m³
IRWST water volume	1300 m³
Initial conditions	
containment pressure	110 kPa
containment atmosphere temperature	42°C
IRWST water temperature	42°C
wall temperature	30 / 42°C
Heat transfer area of containment walls and internal structures	
• containment wall	9572 m²
• wall 1	5071 m²
• wall 2	10730 m²
• slab 1	3528 m²
• slab 3	5540 m²
• pool wall inside	950 m²
• pool wall outside	950 m²
• all steel structures	27010 m²

6.2.1.5.2.1 - TABLE 2/2

Main Data for LHSI Heat Exchanger Model (COCO Input)

Description	Value
Mass flow rates (single system) Essential Service Water System (SEC)[ESWS] -pump Component Cooling Water System (RRI) [CCWS] -pump LHSI heat exchanger (secondary side) Heat exchanger for common users	775 kg/s 457.5 kg/s 358.75 kg/s 98.75 kg/s
LHSI heat exchanger data heat transfer area (A) heat transfer coefficient (k) resulting kA-value	433.33 m² 3000 W/m²K 1.3 MW/K
RRI [CCWS] heat exchanger data heat transfer area (A) heat transfer coefficient (k) resulting kA-value	833.3 m² 3000 W/m²K 2.5 MW/K
Total heat-input to heat exchanger	12 MW
River temperature	30°C

6.2.1.5.2.1 - FIGURE 1/2 [REF-1]

Large Break LOCA
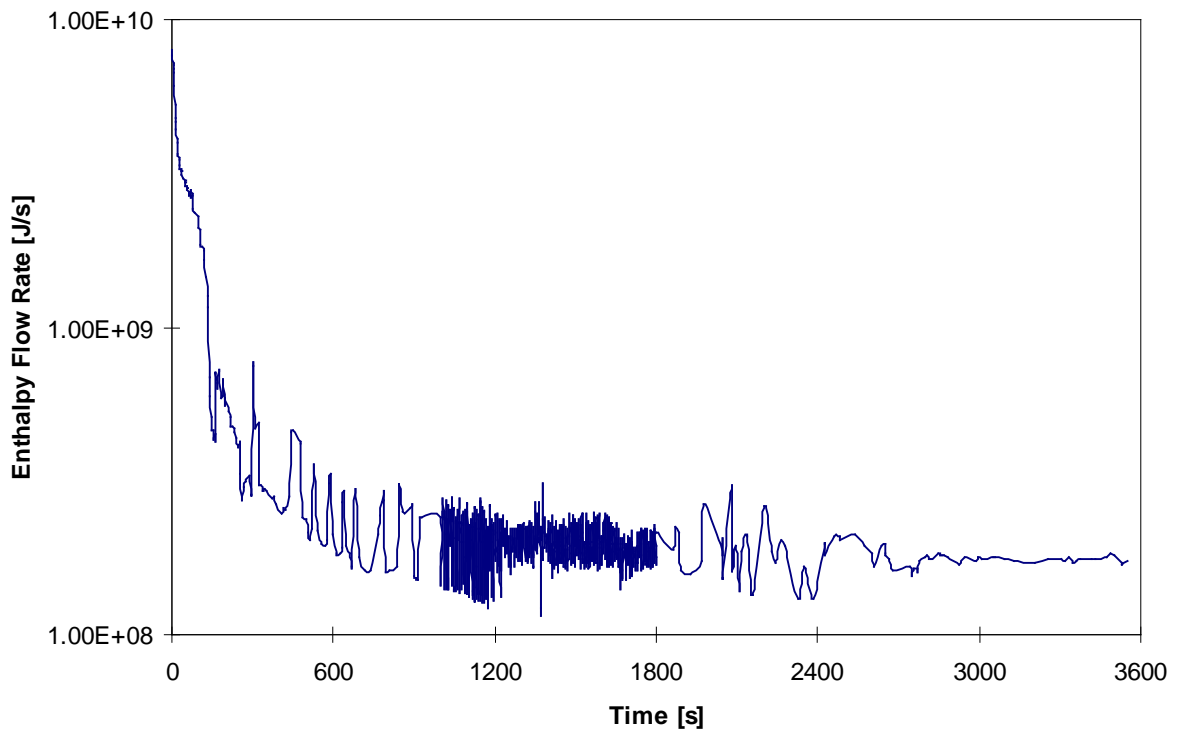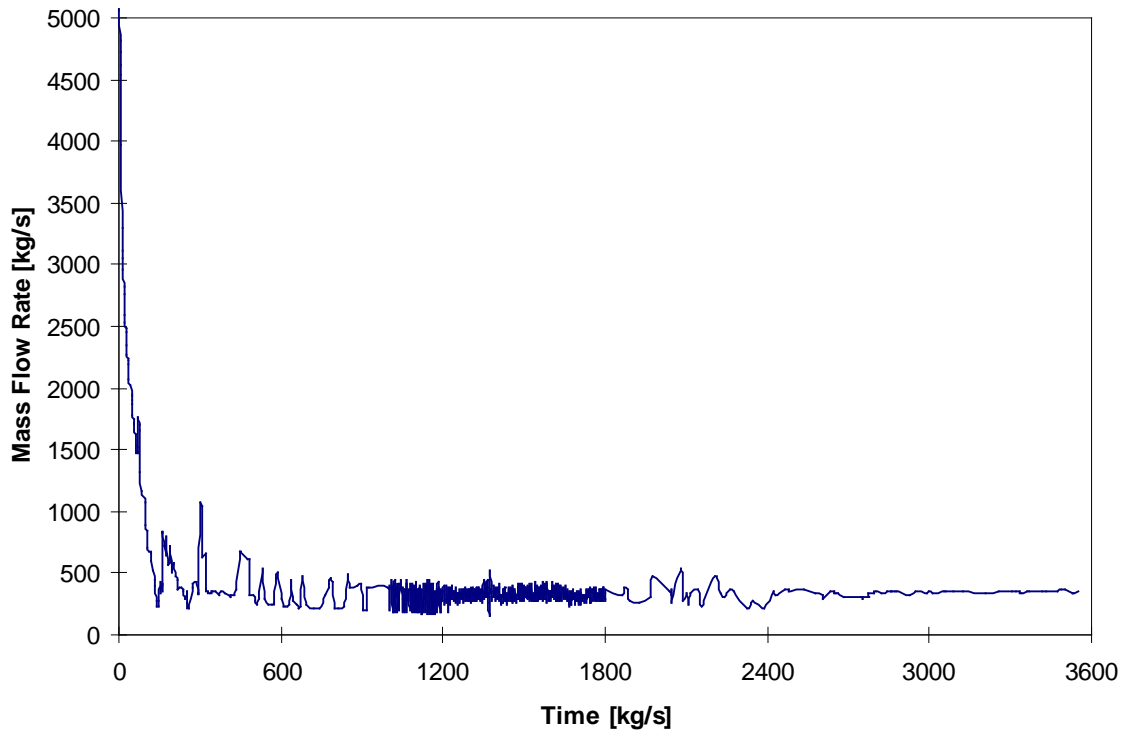
6.2.1.5.2.1 - FIGURE 2/2 [REF-1]

Large Break LOCA

Mass Release to Confinement
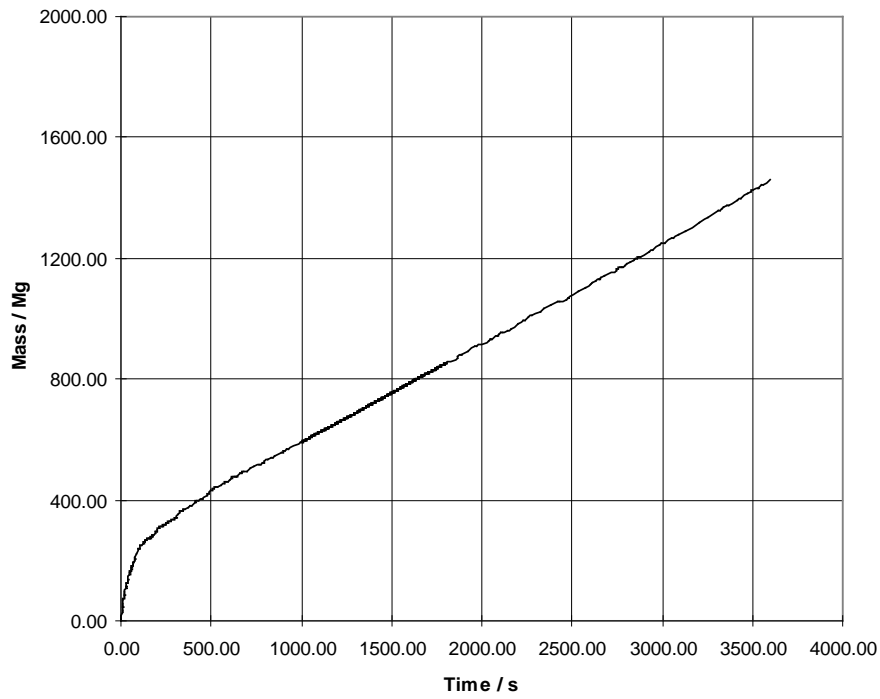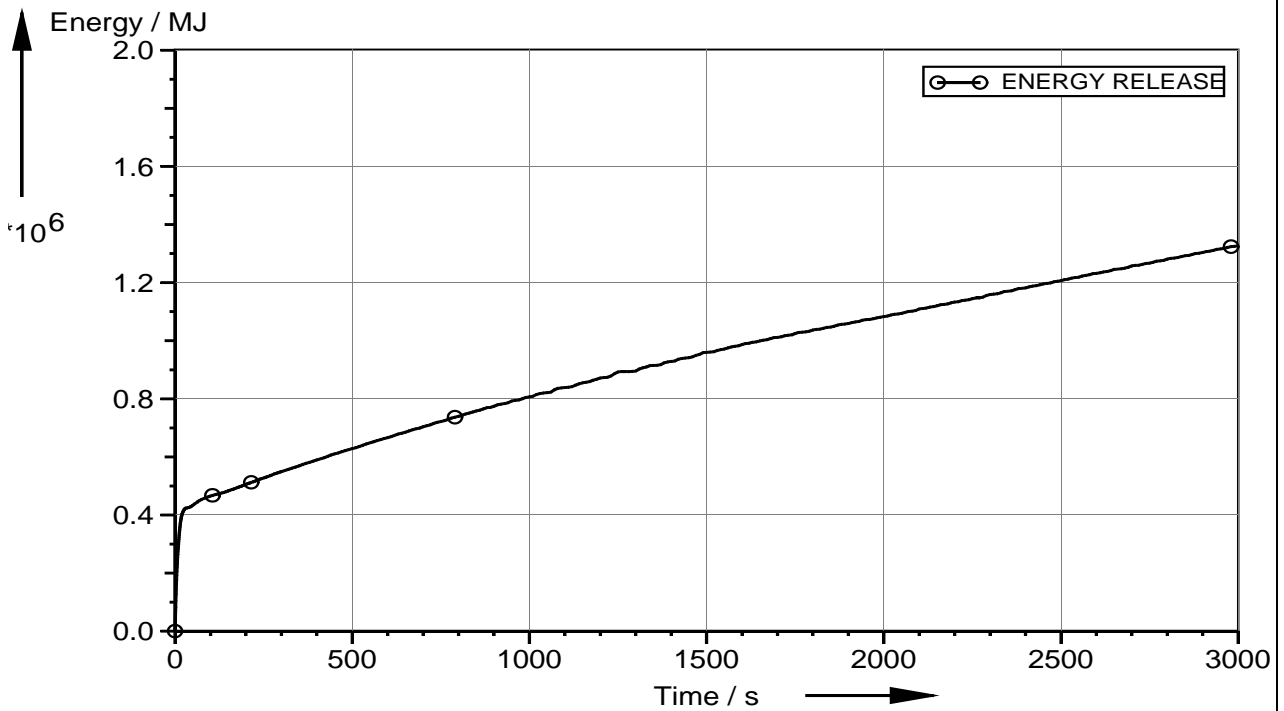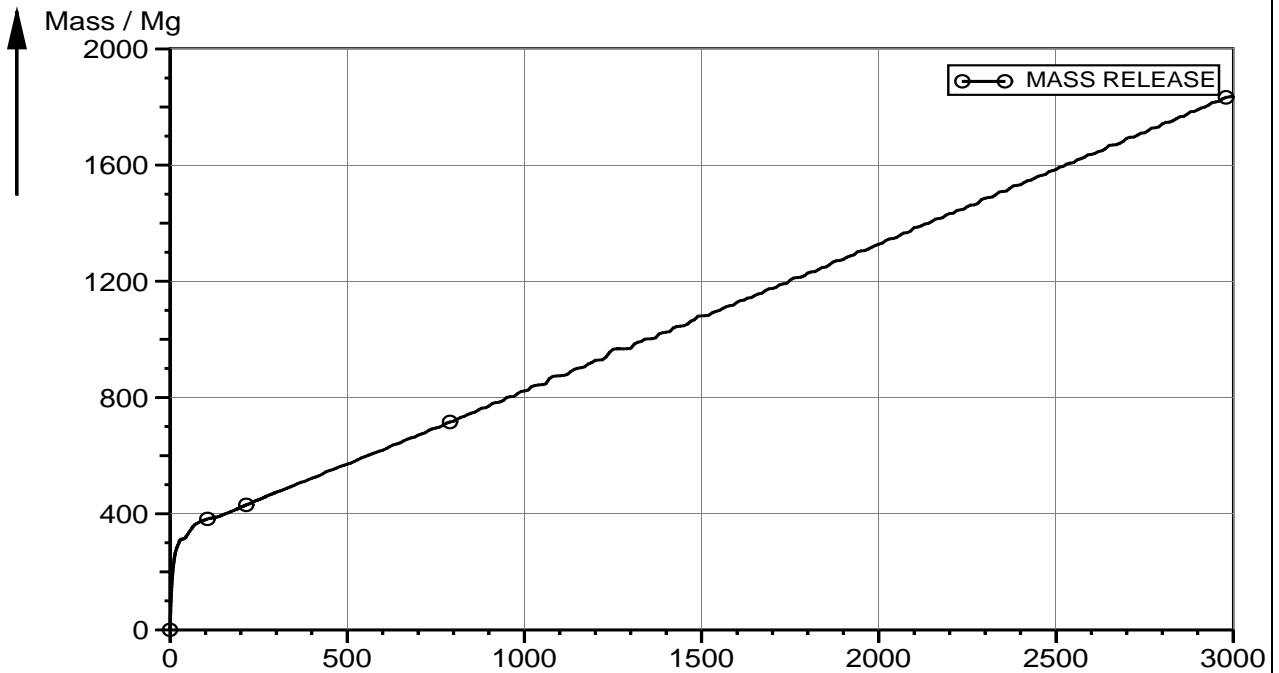

Energy Release to Confinement
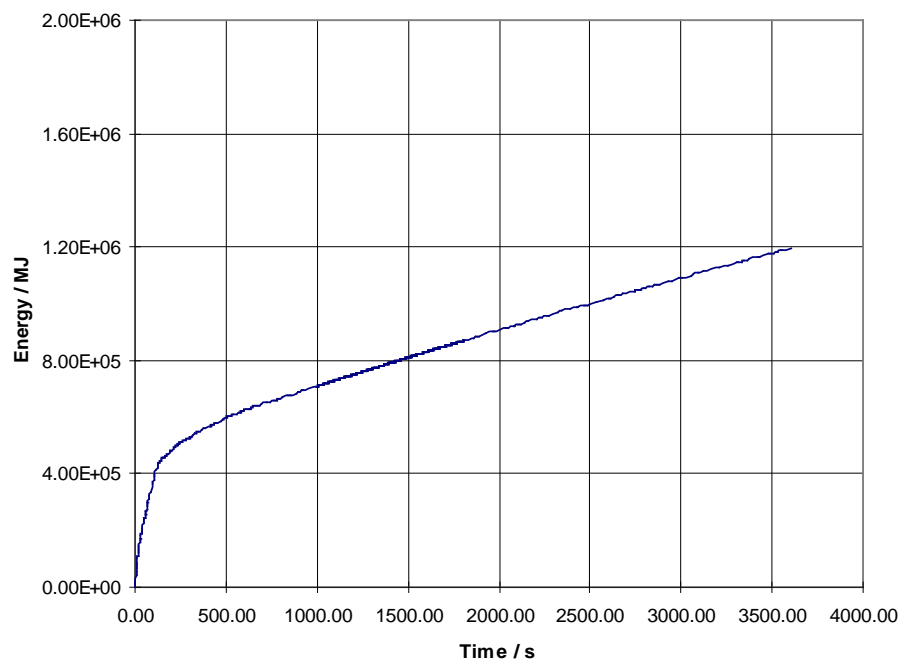
6.2.1.5.2.2 - FIGURE 1/2 [REF-1]

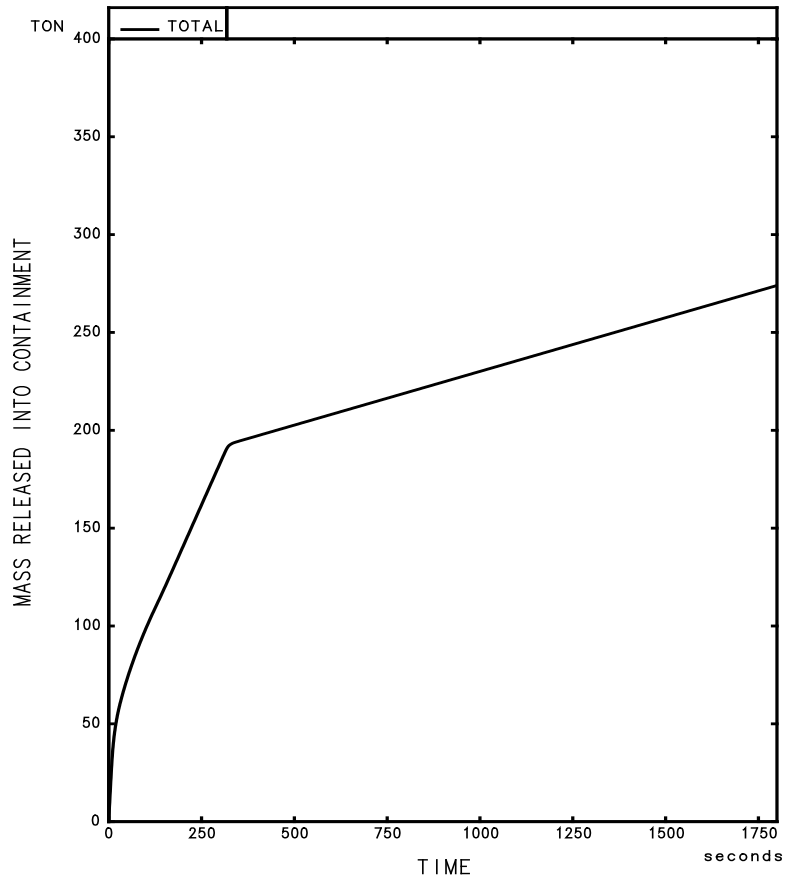### 2A LOCA
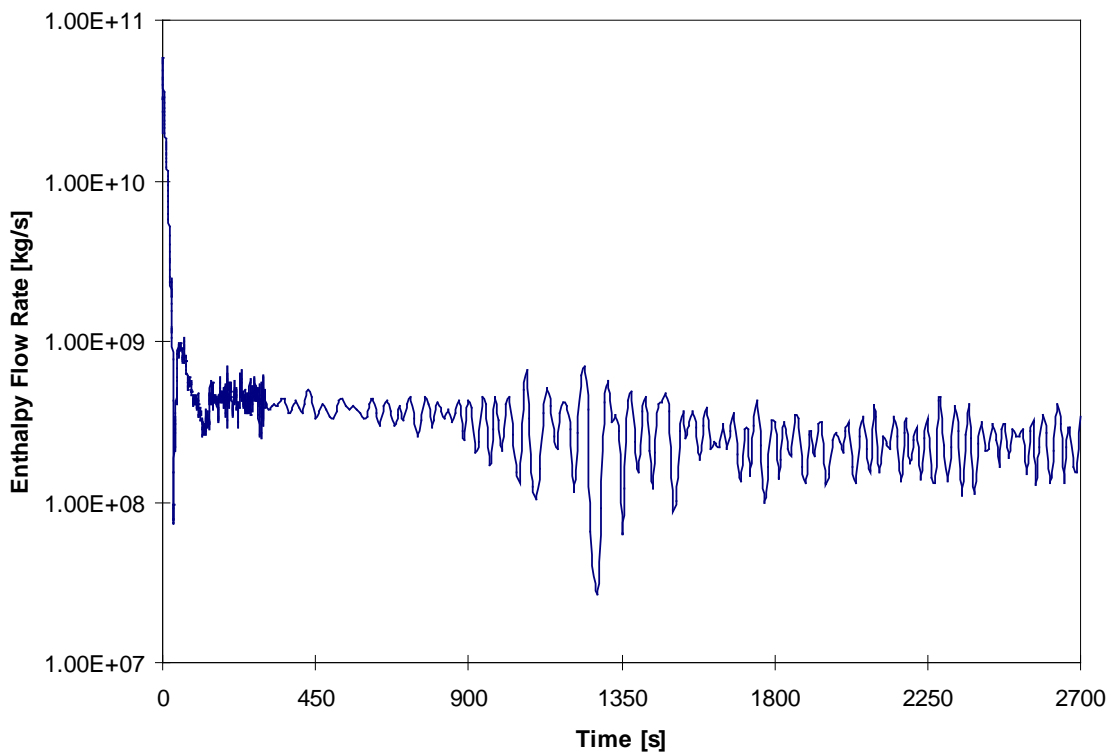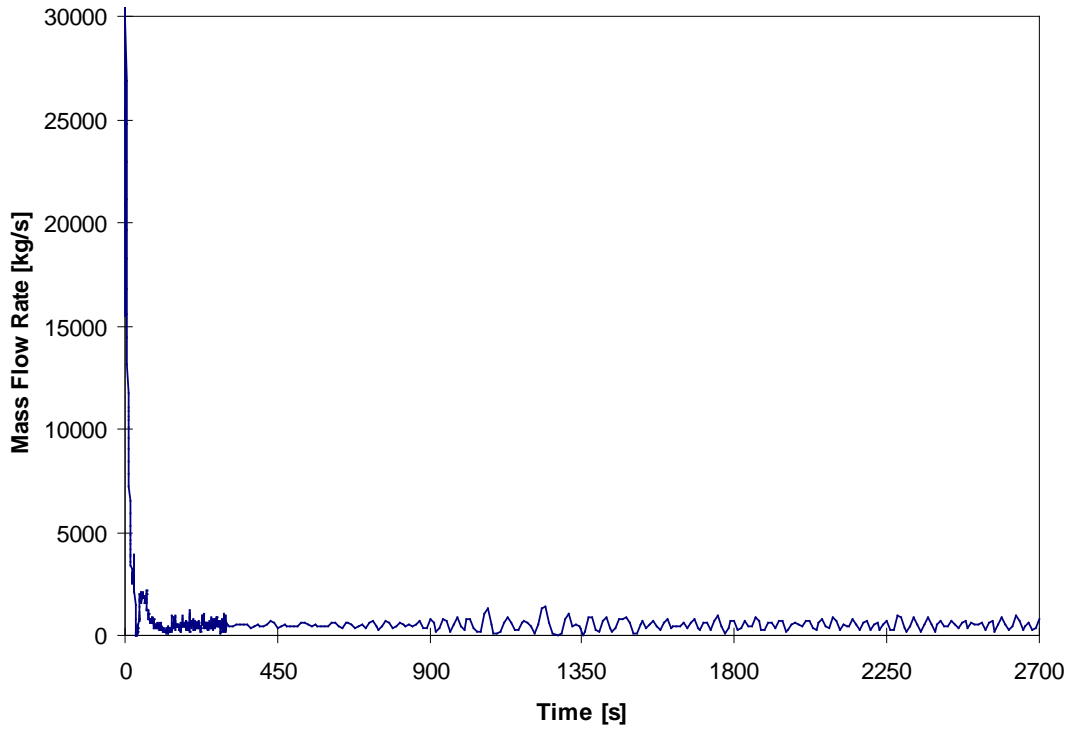
6.2.1.5.2.2 - FIGURE 2/2 [REF-1]

2A LOCA

MASS AND ENERGY RELEASE TO THE CONFINEMENT
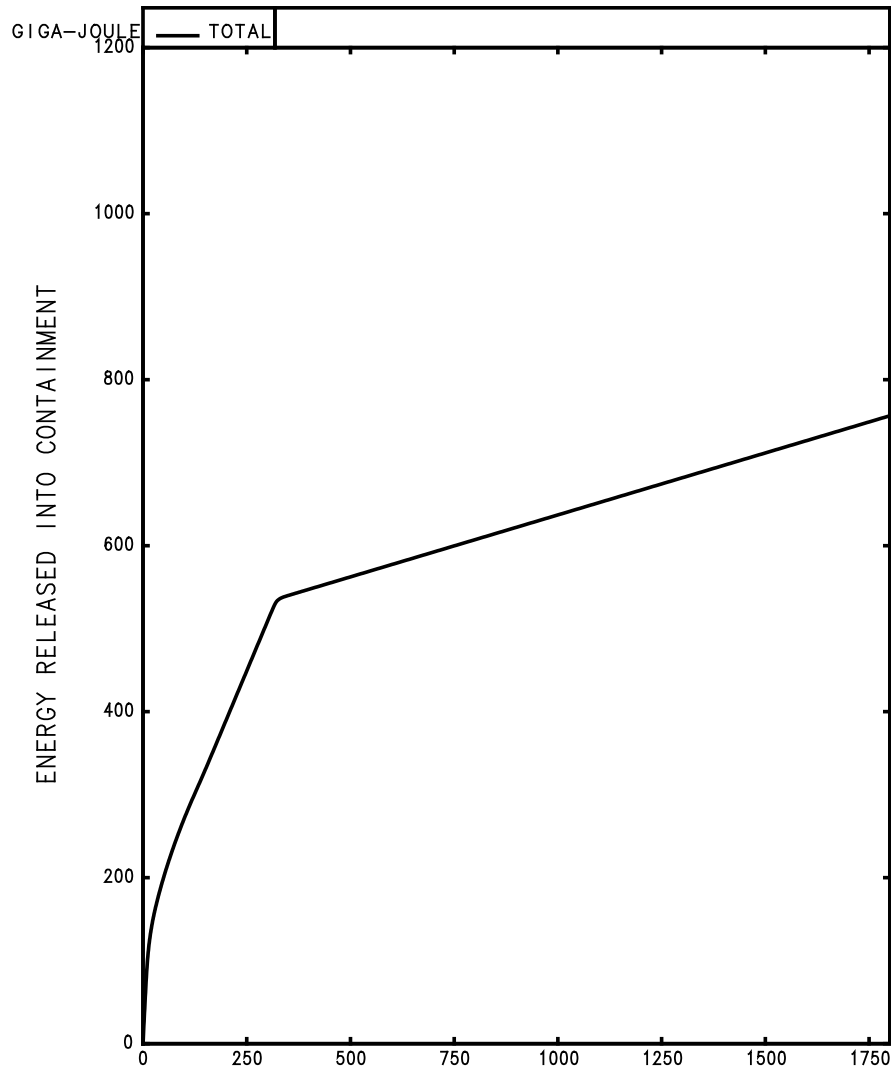
6.2.1.5.2.3 - FIGURE 1/4 [REF-1]

Steam Line Break

MER in SLB (from 2% NP)
UO2 out-in, all rods inserted, single failure on 1 VIV [MSIV] to close
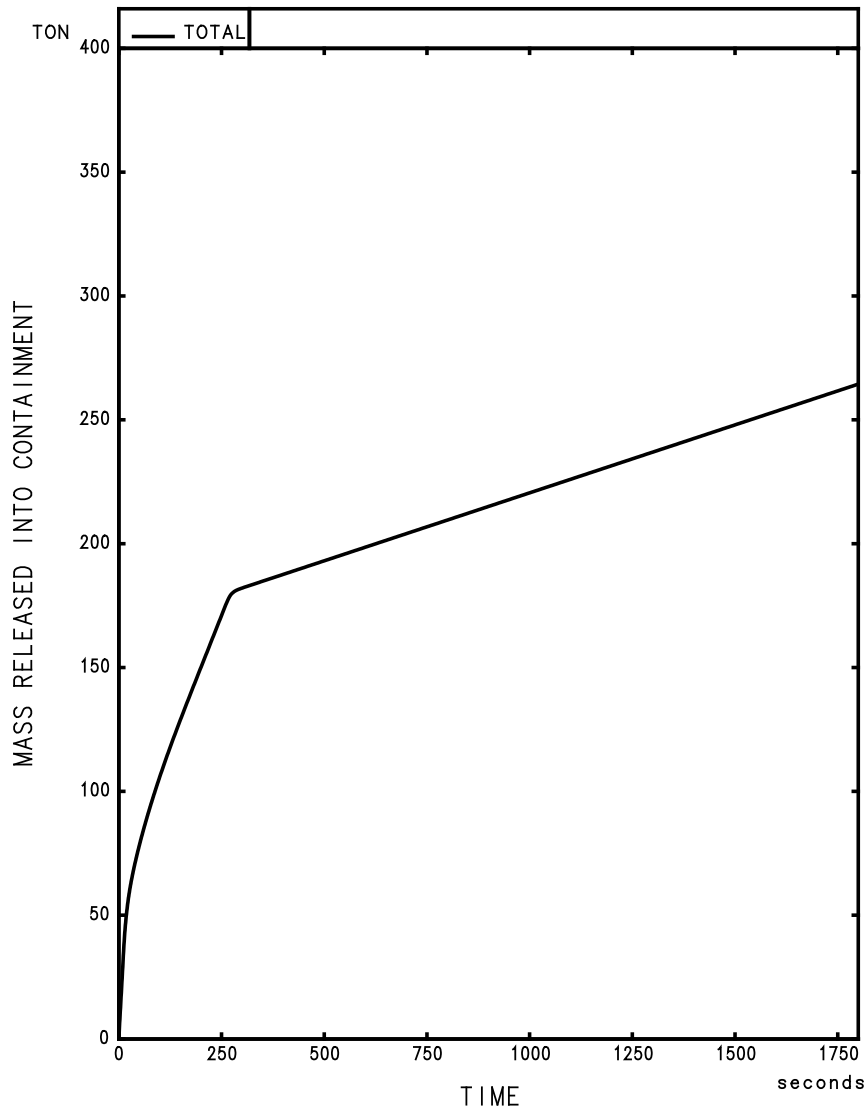INTEGRATED BREAK MASS FLOW

6.2.1.5.2.3 - FIGURE 2/4 [REF-1]

Steam Line Break

MER in SLB (from 2% NP)
UO2 out-in, all rods inserted, single failure on 1 VIV [MSIV] to close
INTEGRATED BREAK ENERGY FLOW

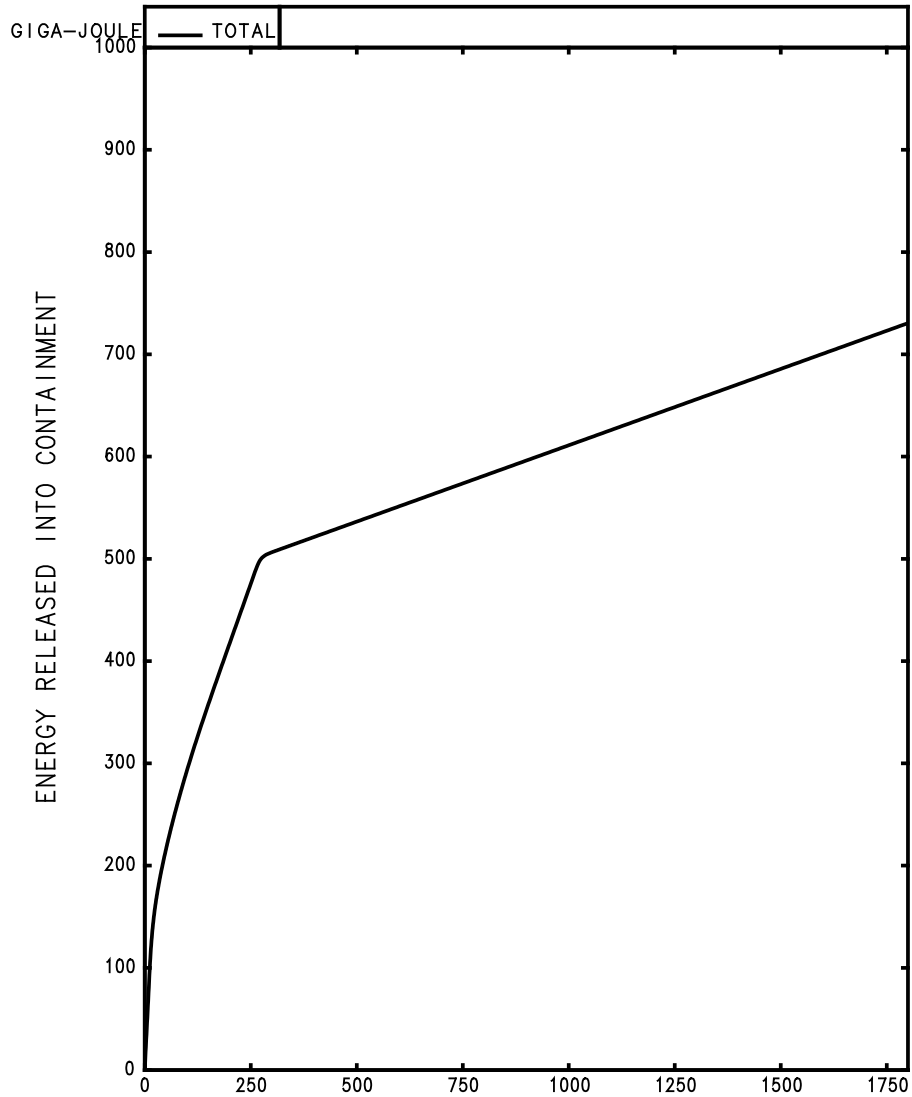## 6.2.1.5.2.3 - FIGURE 3/4 [REF-1]

Steam Line Break

MER in SLB (from 102% NP)
UO2 out-in, all rods inserted, single failure on 1 VIV [MSIV] to close
INTEGRATED BREAK MASS FLOW

6.2.1.5.2.3 - FIGURE 4/4 [REF-1]

Steam Line Break

MER in SLB (from 102% NP)
UO2 out-in, all rods inserted, single failure on 1 VIV [MSIV] to close
INTEGRATED BREAK ENERGY FLOW

6.2.1.5.2.4 - FIGURE 1 AND 2/4 [REF-1]
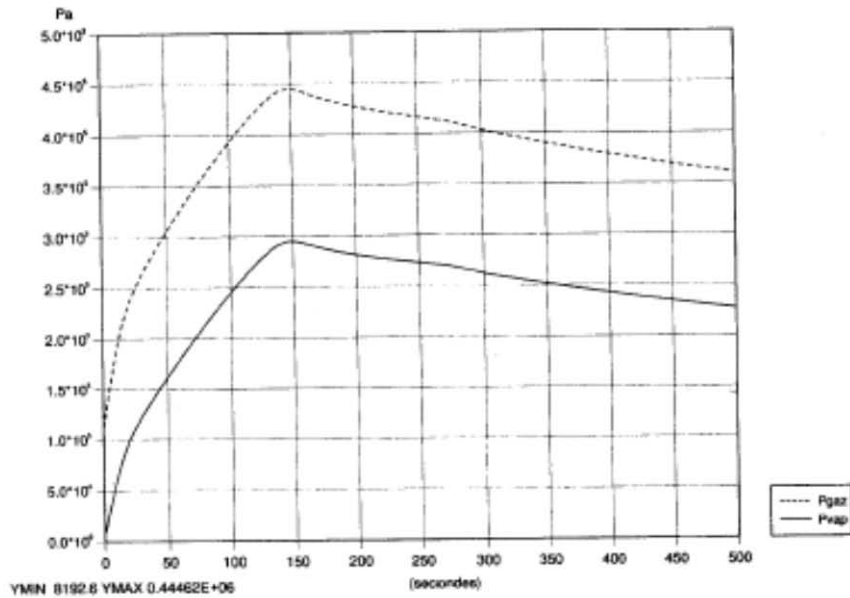
P&T Analysis Results

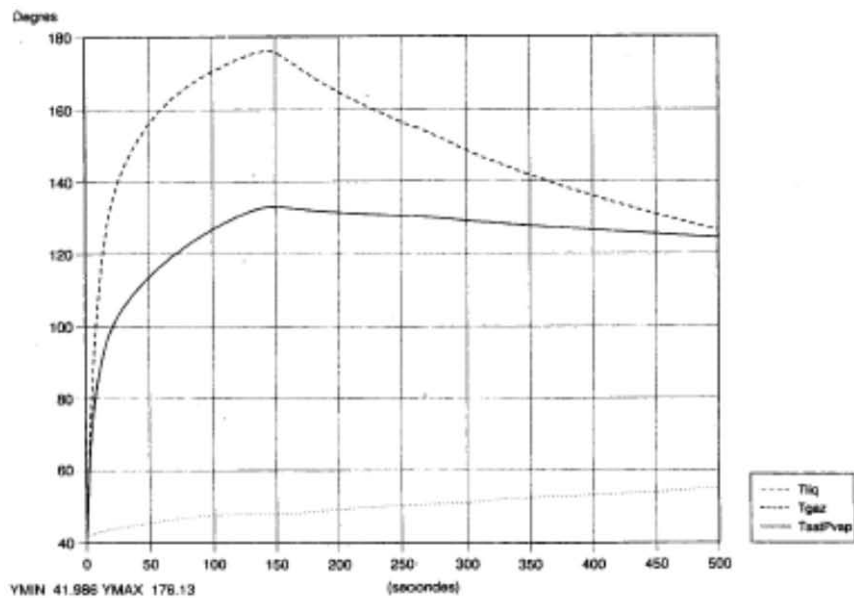Fig. 1 : Surge Line Break - Containment total and vapor Pressure

Fig. 2 : Surge Line Break - Atmosphere and IRWST temperatures

6.2.1.5.2.4 - FIGURE 3 AND 4/4 [REF-1]
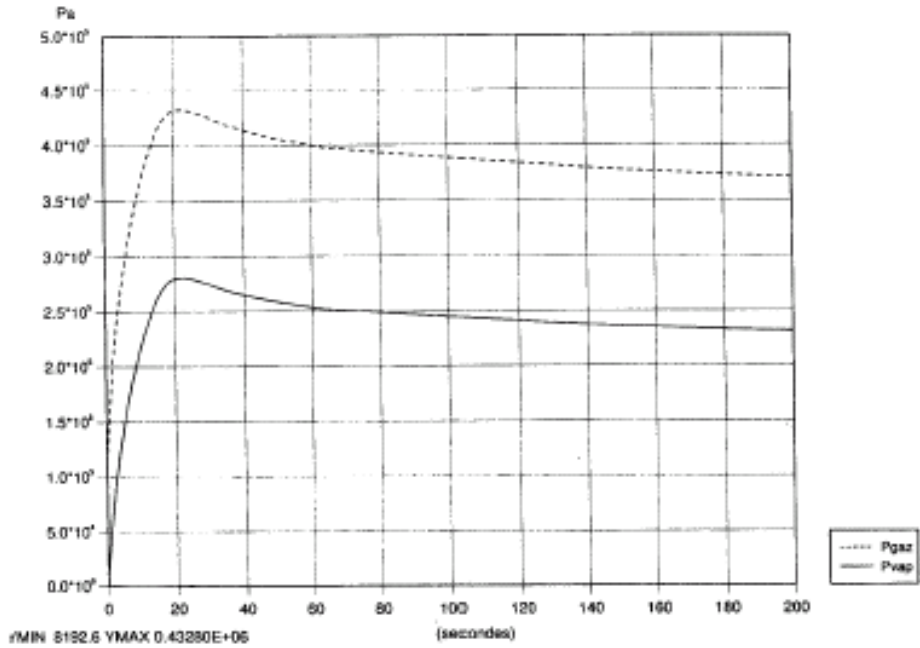
P&T Analysis Results

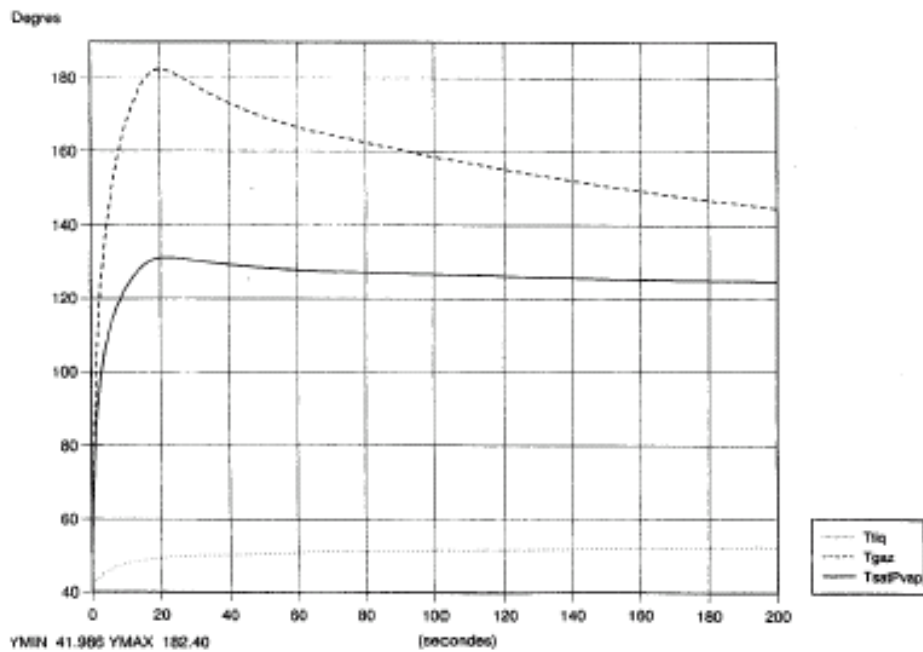Fig. 3 : 2A LOCA - Containment total and vapor Pressure

Fig. 4 : 2A LOCA - Atmosphere and IRWST temperature

APPENDIX 6 – REFERENCES

External references are identified within this sub-chapter by the text [Ref-1], [Ref-2], etc at the appropriate point within the sub-chapter. These references are listed here under the heading of the section or sub-section in which they are quoted.

[Ref-1] Basic Design Report. Report jointly prepared by EdF, German utilities, Framatome, Siemens AG, Nuclear power international. February 1999. (E).

6.2.1.5.2. Description of incidents and accidents used as the containment design basis

6.2.1.5.2.1. *Large break LOCA*

6.2.1.5.2.1.2. Calculation Model

[Ref-1] A Barbier. CATHARE 2 – Code synthetic qualification assessment. EPD DC 490 Revision C. AREVA. September 2007. (E)

[Ref-2] Topical Report - COCO containment code - Model description and validation. NGPS1/2004/en/0507 Revision A. AREVA. October 2004. (E)

[Ref-3] B Marchal. CONPATE4 – Qualification Report. EPRX DM 77 Revision A. AREVA November 1993. (E)

6.2.1.5.2.1.3. Initial and Boundary Conditions

[Ref-1] S Ebalard. ORIGEN-S: Qualification manual. EPDS DC 150 Revision C. AREVA. November 2005. (E)

6.2.1.5.2.3 *Steam line break*

6.2.1.5.2.3.2 Calculation model

[Ref-1] F Goux. THEMIS code – Qualification report. EP/TA/DM.482 Revision B. AREVA. August 1995. (E)

6.2.1.5.2.3.3 Calculation assumptions

[Ref-1] N Nicaise. PSAR Section 6.2.1.3.1 to 4 – Large Break LOCA (PCC) 2A-LOCA, Steam Line Break (PCC), 2A-SLB. PSRR DC 5 Revision B. AREVA. December 2003. (E)

6.2.1.5.2.3.4 Analysis Results

[Ref-1] N Nicaise. PSAR Section 6.2.1.3.1 to 4 – Large Break LOCA (PCC) 2A-LOCA, Steam Line Break (PCC), 2A-SLB. PSRR DC 5 Revision B. AREVA. December 2003. (E)

6.2.1.5.2.1 - TABLES AND FIGURES

[Ref-1] N Nicaise. PSAR Section 6.2.1.3.1 to 4 – Large Break LOCA (PCC) 2A-LOCA, Steam Line Break (PCC), 2A-SLB. PSRR DC 5 Revision B. AREVA. December 2003. (E)

6.2.1.5.2.2 – FIGURES

[Ref-1] N Nicaise. PSAR Section 6.2.1.3.1 to 4 – Large Break LOCA (PCC) 2A-LOCA, Steam Line Break (PCC), 2A-SLB. PSRR DC 5 Revision B. AREVA. December 2003. (E)

6.2.1.5.2.3 – FIGURES

[Ref-1] N Nicaise. PSAR Section 6.2.1.3.1 to 4 – Large Break LOCA (PCC) 2A-LOCA, Steam Line Break (PCC), 2A-SLB. PSRR DC 5 Revision B. AREVA. December 2003. (E)

6.2.1.5.4 - FIGURES

[Ref-1] N Nicaise. PSAR Section 6.2.1.3.1 to 4 – Large Break LOCA (PCC) 2A-LOCA, Steam Line Break (PCC), 2A-SLB. PSRR DC 5 Revision B. AREVA. December 2003. (E)