ISP-20

International Standard Problem No 20

STEAM GENERATOR TUBE RUPTURE

Nuclear Power Plant Doel 2, Belgium

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INTERNATIONAL STANDARD PROBLEM-20
STEAM GENERATOR TUBE RUPTURE
NUCLEAR POWER PLANT DOEL 2 - BELGIUM

FINAL REPORT

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Annexe 2 : Overlay-plots of the parameters to be calculated.
1. INTRODUCTION

At the fourth meeting of the Principal Working Group n°2 (PWG2) on transients and breaks, held in Paris on 9-11th October 1985, an International Standard Problem (ISP) for the Doel 2 steam generator tube rupture (SGTR) incident, was proposed and endorsed by a large number of delegates.

At the seventh meeting of the task group on the status and assessment of codes for transients and ECCS, (16th - 18th December 1985), it was decided to select this Doel 2 SGTR incident as the basis for the next ISP-20.

It was considered that the available plant data and recordings obtained on-line during this incident, provides a valuable data base for an ISP especially in view of the fact that real plant data are scarcely available and provide an unique opportunity to test the code models and constitutive equations on full scaled facilities, thereby eliminating the scaling uncertainties in extrapolating data from test facilities to real plants.

There are however serious drawbacks which to a certain extent do not fullfill the objectives for an ISP (ref.1). This is principally related to the quantity and quality of the available data from real plants which are by nature inferior to well instrumented test facility data. Furthermore, one should be aware of the uncertainties in the plant initial and boundary conditions when trying to match the calculated data to the plant data.

At the seventh task force meeting, it was decided that an existing RELAP 5 input model with the complementary information given at the first workshop would be the basis for this ISP-20.

The accident-scenario, best estimate boundary conditions and reconstructed plant data were provided to all participants (i.e. ISP-20 is an open problem).

During the first comparison group meeting the number and the nature of the parameters to be calculated was determined (annexe 1).
In agreement with the above approach, the host country (Belgium) provided the following information (ref.2):

- An overall description of the Doel 2 plant, the systems which influence the transient, the plant diagnostics and uncertainty bands

- A detailed anatomy of the plant transient on the basis of the available plant recordings and the available chronology of events from the on-line plant computer

- In order to avoid the reconstruction of a numerical model of the plant, the initial- and the boundary conditions on the basis of plant drawings and recordings, it was decided to take the existing RELAP-5 MOD-2 data deck, constructed by Belgium, as the reference deck.

- Two workshops have been held in preparation of this ISP (ref.3-4).

Section 2 gives a brief description of the Doel 2 plant and plant systems which conditionned the transient, such as the high pressure safety injection system, the charging and letdown system and the auxiliary feedwater system.

Section 3 gives an analysis of the plant transient on the basis of the recorded data an computer diagnostics.

Section 4 specifies the general information available to all participants and presents a brief description of the various thermalhydraulic system codes used by the participants.

The numerical results from the different participants are discussed in section 5 for each phase of the transient, and section 6 presents the code run time statistics.

Finally, section 7 formulates some conclusions from this exercise and presents a number of recommendations for the selection of future ISP's based on real plant transients.
2. DOEL 2 – PLANT AND SYSTEM DESCRIPTION.

Doel 2 is a Westinghouse, 2 loop pressurized water reactor (PWR) rated at 392 MWe (NET) and commissioned in 1975, for which TRACTEBEL was the architect/engineer. This plant is part of the twin concept with Doel 1, as they share some common engineered safety systems such as the high pressure safety injection system (HPSI).

2.1. Reactor coolant system.

A flow schematic of the reactor coolant system (RCS) is presented in fig. 2.1. The reactor vessel (2R1) is equipped with 2 reactor coolant loops (A and B) comprising each 1 steam generator (2E1A, 2E1B) and 1 main coolant pump (2P1A, 2P1B).

Doel 2 is equipped with a 8ft core consisting of 121 fuel assemblies with 179 fuel rods per assembly (outside cladding diameter is 10.79 mm). The nominal core power is 1187 MWh.

The primary coolant pumps, with a rated power of 2.44 MW each maintain a loop flowrate of 3628 kg/s at nominal power with a net pump head of 4.275 bar.

A 24 m³ pressuriser (2R2) is connected by a 10" surgeline to the "B" loop hot leg.

Two pressuriser spray lines connect the pressuriser spray nozzle with both cold legs, yielding a maximum total spray flow of 1500 l/min under nominal conditions when spray valves are fully open (2PR001, 2PR002 and 2PR006).

The pressuriser is equipped with pressuriser heaters (proportional + back-up) with a total maximum power of 850 kW. The heaters are switched off automatically when the pressuriser level drops below 20%.
2.2. High pressure safety injection (SI).

The Doel 1-2 plants are equipped with a common HPSI system consisting of 4 motor driven pumps, which through a system of valves and interconnected piping can feed cold water from the refueling water storage tanks into both cold legs of the RCS and also directly into the downcomer of the reactor vessel.

Fig.2.2 shows a flow schematic of the HPSI system.

The HPSI pumps are actuated on generation of a SI signal. For this event, the SI signal was generated at low-low pressuriser pressure (117 bar) and pumps start feeding cold water when reactor pressure drops below the high head cut-off pressure of the HPSI pumps (108 bar).

2.3. Doel 2 charging and letdown system.

The water inventory and primary water chemistry in the reactor coolant system is maintained by the charging and letdown system.

For the charging system, 3 positive displacement pumps take suction from the volumetric control tank and feed cold borated water via a regenerative heat exchanger into the cold leg of loop B.

The flowrate is normally controlled by the programmed water level in the pressuriser which controls the speed of the pumps. Normally only 1 pump is in operation. The flowrate per pump varies between 8.7 m³/hr for lowest speed of 140 RPM to 14.7 m³/hr at 234 RPM.

The charging system also provides the seal injection water for both main coolant pumps. Part of the seal water goes into the RCS and part returns to the charging system.

The letdown flow is controlled mainly by three orifices in a letdown line connected to the intermediate leg between S.G. and primary pump of loop B. The orifices are sized to discharge respectively 10, 10 and 20 t/hr. The backpressure is controlled by an automatic pressure control valve.

The letdown is closed when the pressuriser water level decreases below 20%.

Upon generation of a SI signal, phase A containment isolation is initiated which cuts off the compressed - air supply in the reactor building. The containment isolation valve in the letdown line remains closed as long as the SI signal is not RESET.
2.4. Steam generators - Main steam lines - Auxiliary feedwater system.

A schematic drawing of the Doel 2 main steam and auxiliary feedwater system is given in fig. 2.3.

The Doel 2 steam generators are U-type Westinghouse series 44 models, with a nominal heat transfer area of 4130 m² consisting of 3260 tubes (outside diameter is 22.2 mm) with average length of 18.16m.

The power-operated atmospheric steam dump valves are hydraulic operated valves each with a steam capacity of 5% of the total plant steam flow (or 33.3 kg/s at 72 bar).

These valves, with limited capacity, (one per S.G.) are used for pressure control of the S.G. They have a setpoint below the setpoint of the safety valves to avoid lifting the safety valves (6 per SG) and to provide a means of plant cooldown when the condenser is unavailable.

The main steam isolation valves (MSIV) are HOPKINSON valves. During the Doel 2 event, both MSIV were closed during the heat-up phase and accident. However, during the heat-up the MSIV bypass valves are open to allow conditioning of the mean steam lines downstream the isolation valves.

Also the main feedwater pumps were not operational at the moment the break occurred. The auxiliary feedwater system supplies cold feedwater to the S.G. when the main feedwater system is unavailable. The system consists of 2 motor-driven auxiliary feedwater pumps (MFA and MPB) and one steam turbine-driven auxiliary pump (TP) (fig.2.3). These pumps take suction from the auxiliary feedwater storage tank and supplition water storage tank.

2.5. Plant diagnostic and uncertainty bands.

2.5.1. Measured plant parameters.

Following plant parameters were recorded:

- Temperatures
  - hot leg loop A : sensor TR/2RC5 (see fig.2.1)
  - hot leg loop B : sensor TR/2RC25
  - cold leg loop A : sensor TR/2RC09
  - cold leg loop B : sensor TR/2RC29

The precision of the temperature sensors is estimated at about 1.5%.
. Primary pressure

RCS pressure : sensor PRA/2RC11 in hot leg A
pressuriser pressure : sensor PICA/2PR61 in pressuriser

The precision of the pressure sensors is estimated at ± 2 bar at the nominal system pressure resulting in an uncertainty of 1.3%.

. Pressuriser level : sensor LRCA/2PR11.
The uncertainty band for the level gauge is estimated at 5%.

. Steam generator pressure
  intact : sensor MS4A
  affected SG : sensor MS4B
  These sensors are located just upstream of the main steam isolation valves.
The tolerance on the S.G. pressure gauges is estimated at 3%.

. Steam generator water level (narrow range)
  intact SG : sensor FW9A
  affected SG : sensor FW9B
  The tolerance on the S.G. level gauges is estimated at 16%.

2.5.2. Recorder uncertainties.

For the parameter values, a global recorder uncertainty of 3% should be added to the instrument uncertainty.

From comparing the time values in the computer listing to recorded times, one can estimate an uncertainty of 2 minutes for the timing.

Furthermore, by comparing some recorded data, a large horizontal time shift (about 20 minutes) is evident due to improper adjustment of timing. Hence, some engineering judgment is required to synchronise the recorder data which can be done on the basis of some important events (time of break) and on the basis of the timing listed in the plant computer listing.
FIG 2.2 - FLOW DIAGRAM OF HIGH PRESSURE SAFETY INJECTION SYSTEM

COLD LEG A

2RC073  2SI011

COLD LEG B

2RC072  2SI009

2SI 127

2SI 128  2SI 125

2SI006

2SI004  2SI002

2SI004

2SI001  2SI003

OP8A

OP8B

OP8C

OP8D

REACTOR VESSEL

2RC016

2RC017  2SI126
FIG 2.3: FLOW DIAGRAM OF THE AUXILIARY FEEDWATER SYSTEM
3. **Anatomy of the Plant Transient.**

A report on the incident was issued on October 25th, 1979 (ref.5).

From the raw plant recordings and from the original plant computer records, the best estimate sequence of events and operator interventions, was reconstructed, and is used as the basis for the event simulation.

3.1. **Plant status prior to the SGTR (fig.3.1 prior to point A).**

At the moment the event occurred on June 25th 1979, the primary system was in the heat up phase after a 24 hour stop for repair work on the main steam isolation valves.

The pressure had reached the rated value of 155 bar, with a RCS temperature of about 255°C (about 20°C below hot standby conditions).

The water level in the pressuriser was kept constant at 25% by the automatic control of the charging flow. For the letdown, two orifices of about 10 t/hr were used.

The reactor was subcritical with all control rods down. Both primary pumps were running and the pressuriser heaters were ON. On the secondary side, the main steam isolation valves were closed. The main feedwater pumps were not operational and water level in both S.G.'s was manually controlled around 29% narrow range level by means of the SG blowdown. The auxiliary feedwater pumps were not running.

The total heating power was about 11 MWth (2.5 MWth per primary coolant pump and 6 MWth decay heat), with an additional pressuriser heaters power of 850 kW.

3.2. **Initiating event : (fig.3.1. between points A and D).**

At 19h20 (= to) a quick level decrease in the pressuriser and a pressure decrease (±2.5 bar/min) in the RCS was observed followed by a demand for increased charging capacity, and closure of the letdown line when the pressuriser level dropped below 20%.

While the pressuriser level recording went off scale low (point B) a quick level increase in the B loop steam generator was observed (point C).
When the radiation monitoring channels of the SG blowdown recorded a maximum activity level, the operator diagnosed within a couple of minutes the cause of the event to be a major leak in the B steam generator tube bundle.

Post examination of the faulted steam generator U tube bundle revealed a failure of 1 tube with a longitudinal crack of about 7 cm long located in the U bend and most probably caused by stress corrosion cracking. The initial break flowrate was about 15 kg/s (300 gpm).

3.3. Mitigation phase (fig. 3.1 between points D and L).

The faulted S.G. was completely isolated on the steam side, but the isolation of the steam discharge to the turbo-pump was omitted.

The atmospheric steam dump valve setpoint of the affected S.G. was set at maximum pressure to avoid steam release from this S.G.

A third charging pump was started in an attempt to compensate the leak rate.

By steam discharge to the atmosphere from the intact S.G. (point D), the operator started to cool down the plant, causing a decrease in temperature and a faster depressurization rate at to +15 min, in the RCS.

At to +18 min, the operator tripped the primary pump of the affected loop to reduce the RCS heat input.

At to +20 min, the safety injection signal was generated on very low RCS pressure (117 bar) (point E) which caused the emergency diesels to start, initiated the containment isolation phase A, and caused ventilation isolation of the reactor building.

When reaching a pressure of 107 bar in the RCS (point F) all four HPSI pump injection started and stabilized the RCS pressure.

Steam discharge from the intact S.G. caused a water level drop below the low setpoint of 0.96 m on the narrow band level gauge (point G) and opened both steam discharge lines to the turbine driven auxiliary feedwater pump. This resulted in a quick pressure decrease of both S.G.'s (point H) followed by a rapid increase in the SG-A water level. The steam discharge from the affected S.G. through the turbine driven auxiliary feedwater pump was stopped about 8 min. later (point I) during which time about 1 ton of steam was released.
In an attempt to reduce the leak rate by equilibrating the RCS pressure to the affected SG, the operator started the primary pump B and used the full pressuriser spray capacity (point J) which caused a rapid drop of the RCS pressure. Vapour condensation in the pressuriser, combined with the full HPSI capacity caused a rapid increase in the water inventory such that the pressuriser water level went off scale high (point K) at which time the operator stopped the pressuriser spray. This caused the pressure to increase from 75 bar to the cut-off head of the HPSI pumps and stabilized at 107 bar (point L).

3.4. Safety injection cancelling phase (fig.3.1 between L and R).

A further primary pressure decrease was mandatory to

- reduce the break mass flow rate and avoid flooding of the SG-B main steam lines;

- avoid the opening of the safety valves of the faulted S.G.;

- start as soon as possible the shutdown cooling system (28 bar).

Therefore the operator first tried to cancel the S.I. signal in order to be able to trip the HPSI pumps. A circuit fault however did regenerate the S.I. signal on low RCS pressure after reset, each time requiring about 5 min. before resetting. After about 20 min, the concerned bistables were flicked over manually which cancelled definitively the SI signal.

Three HPSI pumps were tripped (point M) and soon after (point N) the remaining pump was stopped after checking the subcooling margin. The RCS pressure dropped to about 65 bar (point O) for which pressure the charging system compensated the leak rate.

An attempt to open the letdown line failed as the isolation phase A also eliminated the compressed air supply in the reactor building.

It took the operator about 20 min to restore the air supply and to open the pneumatic isolation valves of the letdown line (point P).

After stopping a charging pump (point Q) the pressure decreased to the point where the residual heat removal system could be coupled to the reactor coolant system (point R).
FIG 3.1

EVOLUTION OF SOME IMPORTANT SYSTEM PARAMETERS DURING TRANSIENT

a) HOT LEG TEMPERATURE

b) REACTOR COOLANT PRESSURE

RCA / RC11

RTR / RCG5

RPR / R11

PR / HS44

PR / HS4B

c) PRESSURIZER WATER LEVEL

LR / PW9A

LR / PW9B

d) STEAM GENERATOR PRESSURES

e) STEAM GENERATOR WATER LEVELS
4. ISP-20 : SPECIFICATIONS, PARTICIPATING ORGANISATIONS AND CODES.

4.1. General specifications.

All participants received a ISP-20 specifications document containing a detailed description of the Doel 2 plant (primary, steam generators and auxiliary systems), an anatomy of the plant transient (including the incident report and raw plant recorded data), and a description of the nodalisation of the various components (Ref. 2).

All participants received a RELAP-5 input datadeck (hard copy and floppy disk) which contained:

- The geometry, junction data and heat slabs for the primary system and steam generators, based on best estimate data for the Doel 2 plant.

- Operating characteristics of the engineered safeguard systems, such as the high pressure injection system, the charging and letdown system, the auxiliary feedwater system and the steam discharge valve characteristics of the steam generator. The HPSI and auxiliary feedwater pump characteristics and associated logic where fully described in the specification document.

- The initial plant conditions as inferred from the available recorded data corresponding to the time just prior to the break (point A in fig. 3.1) as discussed in chapter 3.1.

- The boundary conditions in terms of the general plant logical signals (SI, charging, heaters, etc..) and the incident specific conditions which were reconstructed from the information available from several sources such as
  - the on-line plant computer listings
  - the plant recorded data
  - discussions with the plant operating staff
- The reconstructed plant recorded data (cf. figure 3.1) in numerical form.

All participants were asked to simulate that part of the transient, starting at the onset of the primary depressurisation (point A in figure 3.1) and ending at the time when the primary pressure stagnates at the HPSI pressure after closing the pressuriser spray valves (point L in figure 3.1). This time interval amounts to roughly 2700 s.

Furthermore, the participants were asked to generate a plot tape, in a fixed format, containing the time history of 55 plant parameters (cf. annex 1), and to write a short report with their major observations.

Two workshops have been held (References 3, 4) to discuss the content of the data package and to give the participants a better insight in the systems and the behaviour of the plant during the incident.
4.2. Participating organisations and codes used.

GRS-KOLN, who volunteered to perform the plotting of the data (annexe 2), received eight contributions from the five following countries: Belgium, Finland, France, Italy, Yugoslavia and from JRC (ISPRA). The participating organisations, the codes used and the computer configurations are indicated in table 4.1.

As can be seen from table 4.1 most calculations were performed by different versions of RELAP V. Further codes which were used are CATHARE, the French LWR system code and SMABRE, a code developed at the Technical Research Centre of Finland for small break LOCA calculations and used as a simulator model.

The RELAP-V mod.2 code is a two-fluid nonequilibrium, nonhomogeneous hydrodynamic model for transient simulation of the two-phase system behaviour. The six field equations are solved by a fast, partial implicit numerical scheme. The basic component models, from which general systems can be simulated are: volumes, junctions, branches, time dependent volumes and junctions, pipes, pumps, valves, heat structures, turbines, separators, accumulators, reactor point kinetics and control system components. In addition, special process models are included for effects such as form loss, flow at abrupt area changes, branching, choked flow, boron tracking and non condensible gas.

The CATHARE code is the French Advanced Safety Code developed by a joint team: French Atomic Energy Commission CEA, Electricité de France and FRAMATOME. The objective is to perform best estimate calculations of PWR transients and LOCA's, both small and large breaks. A simulator is being developed using the CATHARE models and numerics as a software. The basic model is the 1D-2 fluid (six equation) model; the modelling of capacities is one specific feature of the code. Another specific feature is the fully implicit numerical solution associated to an actual steady state calculation for initialization.

It must be noticed that this version of CATHARE used a three equations drift-flux model for simulating the steam generators secondary side, instead of the six equation model for the primary side. Further modifications were introduced in the code such as materials properties, pump characteristics and modelling.

SMABRE is a code used in Finland for the safety analyses of the Finnish reactors and has been installed as a two-phase model into the Loviisa training simulator. The code is based on the global compressibility approach in the primary coolant system. The code can be described as a 4.5 equation model, using a drift flux correlation for phase separation and integrated pressures for steam density and saturation temperature.
The steam and liquid temperatures are calculated using a non equilibrium model. The basic numerical method uses a finite difference scheme with the donor cell approach for the formulation of the corrective terms. The numerical solution method is partially implicit. The main features of the codes with respect to the physical modelling and the numerical techniques are summarized in table 4.2.

4.3. Input model description, Nodalisation.

The general nodalisation philosophy of the reference RELAP V input deck was a compromise between precision and economy. For the primary system, a minimum transport time of 0.15 sec was selected, at nominal conditions, leading to a four volume representation of the core. In the U-tube bundle, the number of axial nodes is based on a rule of thumb of about 2° delta T per volume, in order to obtain an acceptable heat transfer and temperature drop between primary and secondary. This resulted in ten axial nodes in the upgoing leg, and five axial nodes in the descending leg of the U-tube bundle. This also sets the volume length in the riser of the SG. All important structures were modelled as heat slabs in order to properly account for the heat exchange between structures and fluid during important temperature changes in the system. During the second workshop it was indicated that the presence of the MSIV bypass valves resulted in an interconnection of both SG during the initial phase of the transient. This interconnection required the simulation of the main steam lines downstream the isolation valves and the main steam header.

4.3.1. RELAP V nodalisation.

All RELAP V users used more or less the same nodalisation scheme as the one which was used in the reference RELAP V input deck. A typical example of a RELAP V nodalisation for this ISP is shown in fig.4.1. Each participant however introduced some modification in the nodalisation scheme for the base case calculation.

- **ENEA**: changed four multiple-input/multiple-output SNGLVOL PIPE components of the original nodalisation with BRANCH components
- **DCMN**: introduced the same modifications as ENEA and also changed the SGTR break which originally was a CROSS FLOW JUNCTION to a VALVE junction having the same area and the same localized pressure loss coefficient.
- **JRC**: modelled the break as a normal junction with a smooth area change. Non equilibrium conditions for all volumes including pressuriser and surge line
- **TRCR**: changed the time dependent junction 865 (turbopump) into a valve junction. The heat transfer area of steam generator U-tubes has been changed to 4130 m². The turbo pump model has been replaced by a more simpler one.
- **TRACT**: has changed the steam dome in both steam generators from a single volume into a five volume pipe component
Table 4.3 gives an overview of the number of volumes, junctions and heat slabs for the different RELAP-users.

4.3.2. CATHARE nodalisation.

The nodalisation used in CATHARE is represented in fig.4.2. The primary circuit is nodalised using 9 pipes (71 nodes), 5 CATHARE volumes (which are lower plenum, upper plenum, reactor vessel inlet nozzle, reactor vessel upper head and pressuriser) and one tee (surgeline connection to the hot leg).

A total of 76 heat slabs were used in the primary system only. The ECCS, charging and letdown systems and the break are represented with source or sink terms. Each steam generator secondary side (fig. 4.3) is nodalised with 13 axial meshes and one cavity with two regions (steam and water).

No heat slabs were simulated in the secondary side.

4.3.3. SMABRE nodalisation.

The nodalisation in SMABRE, represented in fig.4.4, uses 150 volumes, 156 junctions and 173 heat slabs.

4.4. Initial and Boundary Conditions.

Besides the modifications in the nodalisation schema some of the participants also changed boundary conditions specified in the transmitted RELAP 5 input deck.

DCMN : - a steady state calculation lasting 100 sec. was performed. This assures a self-consistent initial pressure and temperature distribution. The steady state was achieved equalizing letdown and charging flowrate in such a way to maintain the energy balance in the RCS.

IJS : - The entire letdown flow was reduced to 2.78 kg/s and the initial temperature of pressuriser heaters was increased by 10°C at constant heater power.

JRC : - time shift for start of 3rd charging pump from 900 sec to 1400 sec
- time shift for start opening of steam relief valve SG A from 900 s to 1400 s; reduction of effective valve cross section from 2.7x10⁻³ m² to 0.7x10⁻³ m².
- time period for vapour flow from SG B to turbo pump extended to 2100 sec and vapour flow rate reduced by 30%.
- up to 1400 sec a small bypass was allowed for steam lines connecting SG A and SG B, bypass flow area equivalent to 3 inch bypass valves.
TRACT: - the isolation of the main steam isolation bypass valves was set at 900 s, with a closing time of 3 s
- the HPSI flow characteristics were modified according to data from fig.2.2 from the data package
- third charging pump start-up was delayed to 1100 sec with a 60 sec ramp
- temperature of charging water increased to 45°C
- the steam requirements of the steam driven auxiliary feedwater pump were reduced by 15%
- cooldown rate by means of the intact SG was reduced by setting the maximum valve opening at 25% of the nominal full valve capacity, starting at t = 900 sec with a 300 sec ramp.

TRCR: - speed of main coolant pumps has been reduced.
- the letdown has been reduced

TRCS: - no isolation of the two SG's.

CEA, ENEA: Have made no modifications at the specified boundary conditions for their "base case".
TABLE 4.1

List of participants, codes and computers for ISP-20.

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>ORGANISATION</th>
<th>DESCRIPTION</th>
<th>CODE</th>
<th>COMPUTER (performance:Mips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. BELGIUM</td>
<td>TRACTEBEL BRUSSELS</td>
<td>TRACT</td>
<td>RELAP V/MOD 2 C 36.05</td>
<td>CYBER 180/825 (1.2 Mips)</td>
</tr>
<tr>
<td>2. FINLAND</td>
<td>TECHNICAL RESEARCH</td>
<td>TRCR</td>
<td>RELAP V/MOD 2 C 36.04</td>
<td>CYBER 180/840 (4.5 Mips)</td>
</tr>
<tr>
<td></td>
<td>CENTRE OF FINLAND</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. FINLAND</td>
<td>TECHNICAL RESEARCH</td>
<td>TRCS</td>
<td>SMABRE</td>
<td>MICRO VAX II/VMS (0.9 Mips)</td>
</tr>
<tr>
<td></td>
<td>CENTRE OF FINLAND</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. FRANCE</td>
<td>COMMISSARIAT A L'ENERGIE ATOMEQUE</td>
<td>CEA</td>
<td>CATHARE 1.3 rev.4</td>
<td>CRAY XMP (103-105 Mips)</td>
</tr>
<tr>
<td>5. CEC - ITALY</td>
<td>JOINT RESEARCH CENTRE - ISPRA</td>
<td>JRC</td>
<td>RELAP V/MOD 2 IBM VERSION -ISPRA</td>
<td>AMDAHL 5850 (10 Mips)</td>
</tr>
<tr>
<td>6. ITALY</td>
<td>UNIVERSITY OF PISA</td>
<td>DCMN</td>
<td>RELAP V/MOD 2 C 36.04</td>
<td>IBM 3080 (8 Mips)</td>
</tr>
<tr>
<td>7. ITALY</td>
<td>ENEA</td>
<td>ENEA</td>
<td>RELAP V/MOD 2</td>
<td>IBM 3090 (15 Mips)</td>
</tr>
<tr>
<td>8. YOUGOSLAVIE</td>
<td>INSTITUT &quot;JOSEF STEFAN&quot; LJUBLJANA</td>
<td>IJS</td>
<td>RELAP V/MOD 1 C.25</td>
<td>IBM 4381 (4 Mips)</td>
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</tbody>
</table>
### Table 4.2

**Main Features of Codes Used for ISP-20.**

<table>
<thead>
<tr>
<th>Code</th>
<th>Basic Flow Models</th>
<th>Number of Field Equations</th>
<th>Basic Numerical Method</th>
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Fig. 4.2: CATHARE nodalisation
5 VOLUMES
9 TUYAUX (71 mailles)
1 TEE

spray A → spray B
break
prussu

genvapi

A

spray
hpsi

Iroidel

plensup
chaudecr
topressu

expans

couve

B

spray
hpsi

charging system

Iroidel

letdown

volinf

bypass

down
Fig. 4.4:
SMABRE nodalization for DOEL 2
Fig. 4.3: CATHARE nodalization of steam generator
5. RESULTS OF ISP-20.

Annexe 1 summarises the list of parameters to be calculated.

The enclosed set of figures (annexe 2) contains the overlay plots of the base case results for all participants and the plant data when available.

The discussion of the results will be split up according to the important phases of the transient.

1. Status prior to the SGTR
2. Plant depressurisation due to the break
3. Plant cooldown by means of the SG
4. Plant depressurisation by means of the pressuriser spray
5. Affected steam generator pressure evolution

5.1. Initialisation : status prior to the SGTR.

During the second ISP-20 workshop (ref.4) JRC (ISPRA) and CEA (France) observed some discrepancies during the heat-up period prior to the incident when using the reference RELAP V deck data, without triggering the break flow. The observation of too high pressurisation rate, unstable pressuriser level and too high temperature increase in the primary circuit may have been caused by too low thermal inertia in the secondary side, or uncertainty of the real decay heat power.

The original information package was updated by adding the heat-up of the main steam lines, via the MSIV bypass valves. Moreover, the overwhelming effect of the break is bound to mask slight inaccuracies of the initial steady state.

DCMN (Pisa) simulated a steady state calculation by equalising initial letdown and charging flow rate in such a way as to maintain a zero energy balance in the RCS.

Most participants obtain correct initial conditions for the thermal hydraulic parameters. Discrepancies are observed where postprocessing of the hydraulic parameters is required (e.g. collapsed water level fig. 8, 34, 35, 36) delta P water level (fig.32) ; water inventory in both steam generators (fig. 49, 50) and RCP pump speed (fig.23).

One should recall that a water level indication (in pressuriser or steam generators) is obtained by comparing the weight of a water column between two level taps with a reference water column located outside the pressure vessel. To simulate such level indication, code control variables or post-processors must be used.

For DCMN, the initial breakflow is about 80% larger due to the use of a valve junction for the break (fig.16).
Fig.25 : differences in loop flow rate (TRCR, TRCS)
Fig.28 : structural heat input excludes the primary-secondary heat transfer (CEA, TRCS)

5.2. RCS depressurisation (t=0 to 1200 sec).

Due to the subcooled state of the primary coolant, the RCS pressure and temperature are not coupled together.
While the temperature is controlled by the net primary energy balance, the primary pressure is mainly controlled by the pressuriser behaviour, and hence by the net coolant inventory. Fig. 06, 07 illustrate that all codes give an acceptable evolution of the primary pressure up to about 900 seconds.

While all participants calculated a slight increase in the RCS temperature during the initial 900 sec. (figs. 1 to 4) the plant recordings show a constant RCS temperature. This common discrepancy could be due to a misinterpretation of the plant data, to a too high decay heat level or too low heat losses.

At about 900 sec. a third charging pump was added which yields a total charging flow rate which is very close to the break flow rate (fig. 16,19). Hence the timing of the increased charging rate could influence the RCS depressurisation rate (fig. 5-6). Only JRC and TRACT have postponed the additional charging flow (fig.19).

Furthermore, upon emptying of the pressuriser (fig.08) condensation of saturated steam (fig. 09) on subcooled water in the hot leg (figs.01 to 04) produces a stronger depressurisation of the RCS (fig. 06) between 900 and 1200 sec. as can be observed in fig.14. This figure gives an indication of the non equilibrium vapour condensation rates of the best estimate thermal hydraulic codes in the surgeline T-connection where small vapour voids can be observed (fig.13).

Note the very large variation in vapour condensation rate between various codes and the relative small impact on the depressurisation, which may be due to a relative small condensation volume.

5.3. Plant cooldown by means of intact SG (after 900 sec.)

The cooldown rate is controlled by the steam release by means of the intact SG atmospheric relief valve. Most participants used the assumption made in the reference deck that the relief valve was fully opened within a period between 900 and 1200 sec. As was mentioned (ref.3), a very large uncertainty should be attributed to this operator intervention and two participants (JRC, TRACT) have presented different scenario's.
JRC has postponed the cooldown initiation to 1400 sec. and assumed a reduced discharge rate corresponding to an effective valve cross section of 7 cm² instead of the full open valve cross section of 27 cm².

TRACTEBEL opted for a valve opening of 25% of full opening selected on the basis of various runs to yield an average primary cooldown rate which is comparable to the measured cooldown rate.

This reduced cooldown produces an acceptable primary coolant temperature during the pressuriser spray period (fig.01).

CEA produced a primary cooldown rate close to the JRC and TRACT data (fig. 01,02,03,04) with the full capacity of the intact steam generator relief valve (fig.44), for which no explanation has yet been found.

All other participants, using a maximum relief capacity produced such an excessive primary cooldown that at the moment of pressuriser spray initiation the colder pressuriser spray would yield excessive pressuriser depressurisation (see 5.4).

The resulting pressure evolution in the intact SG (fig. 30-44) clearly illustrates the various boundary conditions of:
- full capacity steam release (all except JRC, TRACT)
- reduced steam release capacity (JRC, TRACT).

while the measured pressure lies in between.

Regarding the water level evolution in the intact steam generator (fig.32), a very large spread in the data is observed while no participant succeeded in calculating a level evolution close to the measured data, except for IJS.

The trend calculated by all codes, except TRCS, is very similar, and different from the trend in the measured value. This should point to a common uncertainty in the boundary conditions for the cooldown which is highly speculative. This illustrates one of the most important limitations of such a standard problem.

A dynamic water level swell is calculated by all users of the RELAP V mod.2 around 1200 sec. (the very high level swell by DCMN is caused by an erroneous high steam release at 900 sec. fig.44).

The calculated level swell exceeds the measured level swell in the intact steam generator for all RELAP-5 MOD.2 users. This discrepancy could result from an excessive interphasial shear in the SG riser.

5.4. Pressuriser spray period (t = 2108-2287 sec).

The calculated primary pressure depressurisation upon opening the pressuriser spray valves presents a large spread for all participants (fig.6).

The pressuriser spray efficiency is basically controlled by the following plant parameters:
- pressuriser spray flow : same value used by all participants, except by TRCS (fig.22).
- the subcooling of the primary system during the spray.
The extra large spray flow used by TRCS (fig. 22) leads logically to an excessive depressurisation (fig. 06).
Concerning the results of all RELAP-V users, the calculated depressurisation is larger than the measured one which could be explained by the excessive subcooling of the RCS at the time of spray.

However, from fig. 03, 04, JRC and TRACT calculated a cold leg temperature close to the measured cold leg temperature, and hence a correct subcooling, and yet obtained a depressurisation in excess of the measured value.

The other RELAP V users (ENEA, DCHN, IJS and TRCR) calculating excessive RCS subcooling, logically calculate a larger spray efficiency and even a larger depressurisation.

The tendency to overpredict the depressurisation (assuming correct flow and subcooling) must be related to the RELAP condensation model or to an inadequate nodalisation for the pressuriser. Sensitivity studies on this point have not been made.

Upon a slow depressurisation, one could expect near thermal equilibrium conditions whereby vapour condensation and water flashing leads to a homogeneous fluid vapour temperature in the pressuriser corresponding to the saturated fluid temperature.

For a fast depressurisation, as measured in the plant, it is plausible to suppose that vapour and water do not obtain thermal equilibrium which would lead to a reduction in the spray efficiency, as if not all the spray water participates fully in the process.

This assumption of too homogeneous pressuriser conditions is backed-up by the results from CEA with a different condensation model in the CATHARE code.
The CEA calculated RCS cold leg temperatures close to the measured data (fig. 03, 04) and yet the depressurisation (fig. 06) falls short of the measured depressurisation, most probably due to insufficient condensation in the CATHARE volume model which is not represented in fig. 12.

5.5. Affected SG pressure (after 1800 sec).

It is important to be able to predict the correct pressure evolution for the faulted SG in a plant to determine the effectiveness of operator procedures in limiting steam releases to the atmosphere by lifting the SG relief and safety valve on high SG pressure.

This exercise however manifests a very large discrepancy in post calculating the affected SG pressure (fig. 31), with a spread over 30 bar.
The plant pressure shows an increasing trend induced by the filling of the steam generator by the break flow. This clearly points to some piston effect whereby a dome of vapour is superheated by the fluid compression. This is only possible if condensation of hot steam on colder fluid layers is limited.

This effect is obtained by CEA (by suppressing any condensation) and TRACT (by subdividing the SG dome in multiple volumes thereby allowing for better temperature stratification).

Since no internal heat structures were modeled in the CATHARE input deck, no condensation of steam on the structures was calculated. This shows up as an excessive piston effect in the affected SG upon complete isolation of this SG between 900 and 1500 sec. (fig.31).

Other RELAP V users (DCHN, ENEA, JRC and TRCR) do calculate a stagnating pressure most probably due to excessive condensation in the affected SG as is evidenced by the temperature differences between the dome vapour temperature (fig.41) and the dome fluid temperature (fig 40).

Large deviations from measured pressure values in the affected SG exist in the RELAP 5/MOD1 (IJS) and SMABRE (TRCS) calculations which, contrary to the plant transient, show a continuous drop of secondary pressure up to the end of the prediction (Fig. 31). This behaviour has also an equivalence in the predicted fluid temperatures (Figs 40 and 41). However, it cannot finally be concluded whether this deficiency is caused by the limitation in modelling of thermal non-equilibrium conditions in RELAP 5/MOD1 or SMABRE, or if it originates from not-adequate nodalisation or from errors in initial and/or boundary conditions.

The RELAP-V reference deck, available to all participants contained anomalous large values for the SG downcomer reverse form loss factors. This has an impact on the reverse internal circulation ratio in the faulted SG, but once the separator is liquid full, this did no longer have an impact on the faulted SG pressure evolution.

However, since the faulted SG acts as an heat source during periods of the transient, the anomalous large values for the reverse form loss factors produced erroneous values for the primary to secondary heat transfer as was demonstrated by a sensitivity study presented by TRCR.
6. **CODE RUN TIME STATISTICS.**

For all calculations, table 6.1 summarises the code run statistics, indicating average time step, effective CPU-time, equivalent CPU time (normalised to a 10 Mips computer), the number of time steps and the number of volumes. Finally, the table gives an indication of the relative performance of the codes by defining a performance factor (PF) as the ratio of problem time to normalised CPU time.

Due to automatic time step adjustments RELAP 5-MOD1 has an average time step smaller than RELAP 5-MOD2 which uses a constant average time step throughout the analysis.

The CATHARE calculation shows a strong reduction in performance between 1150 sec and 2100 sec when one of the primary coolant pumps is tripped.

The table indicates that all RELAP-5 MOD.2 calculations (except ENEA) show a performance factor around 0.3 (i.e. about three times slower than real time). A lower performance is observed for CATHARE and RELAP 5-MOD 1, while a very good performance is obtained with the SMABRE code, as is expected for a real time simulation code.
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(*) CPU*-time : normalised to 10 MIPS computer.

(**) PF = problem time
CPU*-time
7. CONCLUSION AND RECOMMENDATIONS.

For the International Standard Problem n° 20, the DOEL-2 steam generator tube rupture transient which occurred on June 25th 1979, has been selected. This is the first time a standard problem is based on the available data from a transient in a full scale nuclear plant (two loop, Westinghouse PWR of 392 MWe, operating since 1975). This clearly manifests some shortcomings (such as limited data with relatively large imprecision, and lack of precise initial and boundary conditions), but also some advantages for code assessment because of the full scale nature of the problem.

To avoid the dissemination of plant data in the form of drawings and system descriptions, it was decided to distribute the data in coded form, based on an available RELAP 5-MOD 2 deck for the DOEL-2 plant.

While such data, readily usable for all RELAP 5-MOD 2 users, required a large effort for users of other codes (CATHARE, SMABRE), it was observed that some RELAP-5 users did not make the effort to analyse carefully the available data, nor attempted to make some sensitivity studies as was discussed in former ISP-20 workshops.

The following conclusions are based on the results of 8 participants with three different codes: RELAP-5, CATHARE and SMABRE, and drawn at the third ISP-20 workshop in Paris on December 7-8 1987.

1. This ISP-20 clearly illustrates the special problems related to simulating transient behaviour of a real power plant such as:
   - Limited access to precise plant data: local geometrical dimensions, nominal pressure drops, structural heat losses, etc.
   - Lack of precise knowledge of all sources and sinks of mass and heat. Indeed many systems, considered to be of minor importance at full power, may influence the plant behaviour at very low power (e.g. charging system, steam generator blowdown system).
   - Signal interpretation: many participants had problems to translate a mass inventory to a recorded water level in the plant (pressuriser, SG) since it requires a detailed knowledge of sensor behaviour, calibration and localisation.

Hence this ISP-20 underscores very well the need for the code users, not only to have a good understanding of the code and its limitations, but also to acquire a detailed knowledge of the plant and system behaviour.
2. Most participants succeeded in reaching an acceptable simulation of the primary system parameters (pressure, temperatures, inventory), while for the steam generator parameters a large spread in the data was noticed, although the main trends were acceptable. The large spread in the data from the RELAP-5 users must be attributed to the modifications the users introduced in the reference RELAP-5 data deck available for this ISP. The modifications concerned mainly
- variations in flow loss factors in the downcomer
- variations in the SG dome nodalisation
- variations in the timing and capacity of the SG relief valves.

No participant succeeded however in obtaining a quantitative good overall agreement, and this may be attributed more to the uncertainty in the boundary conditions and plant data precision, than to the inability of the codes.

An exception to this conclusion are the results of the compact and fast running code SMABRE, which manifests larger divergent results than other codes. This is partly due to the wrong plotting data transmitted and due to lack of isolation capability of the SG in the used version of SMABRE.

3. The largest differences between the three codes RELAP-5, CATHARE and SMABRE show up in the treatment of the condensation phenomena both in the primary system and the steam generators. Although large differences are observed in the condensation and vapour generation rates between different codes, the resulting pressure differences in the primary system are small, while large pressure differences are found in the affected steam generator.

The TRACTEBEL study illustrates the sensitivity of the code results on nodalisation concepts and it shows clearly how such code deficiencies can be compensated by a change in the nodalisation. This raises the question of nodalisation guidelines for the code users, based on code assessment exercises.
4. An important aspect of any standard problem is to assess the impact on the critical safety parameters for the plant subjected to an accident.
For a steam generator tube rupture, the critical safety parameters are:
- Core criticality (due to backfill)
- Core subcooling
- Water inventory (in pressuriser and intact SG)
- Pressurised thermal shock for reactor vessel
- Releases of steam to the environment due to SG overfill or inadvertent discharge to atmosphere.

For this transient scenario the above parameters have all been properly evaluated by all participants for the time frame that has been analysed. This gives an indication of the capability of the best estimate codes to assess these safety issues.
Furthermore, a parametric study presented by ENEA dealing with variations in operator interventions illustrates that the scenarios analysed did not present a real safety concern during the first 45 minutes of the transient.

5. The lack of precision in the plant recorded data and in the plant initial and boundary conditions, should preclude any attempt to improve the physical models in the code, not even by further analysis of this event. However, full scale plant data have been used to check the overall validity of the code models in function of a given nodalisation scheme and, most important, give a qualitative indication of the scalability of the code models to full scale 3D plant geometries.

This ISP indicates some shortcomings, in all codes for simulating the SG water level evolution (dynamic level swell and shrink) in the intact SG, which may be caused by improper interphasial shear between the phases. Furthermore, the condensation models, which have been derived in function of the existing flow requirements, are unable to represent the plant behaviour when stratified flow conditions prevail.

6. For most RELAP 5 MOD 2 calculations, the performance ratio (PF), expressed as the ratio of problem time to CPU time (normalised to a 10 Mips computer) is about 0.3 (i.e. three times slower than real time).
For a comparable quality, the CATHARE code has a lower performance (PF = 0.14).
While the quality of the SMABRE code is less, the performance however is much larger (PF = 2.3) as is expected from a real time simulation code.
RECOMMENDATIONS FOR FUTURE ISP SELECTION.

1. When selecting ISP's based on full scale plant data, the transfer of plant data in the form of coded input data offers an acceptable alternative when the plant data are considered proprietary and restricted from public disclosure. In such case however the available data should be reliable and validated on the basis of all available plant performance data. For real plants the commissioning tests offer an interesting data base for qualifying the data deck.

2. The transient treated by ISP-20, as most transients occurring in nuclear power plants, are highly conditioned by the secondary side steam and feedwater components (for PWR), and related systems such as: Atmospheric steam relief valves, steam dump system, feedwater level control system. Without a qualified data deck incorporating these components and control systems, it is practically excluded to simulate correctly the early part of most plant transients. Since most integral scaled facilities are operated without these systems, and as such cannot yield useful user guidelines, then it is essential to use all available plant fingerprints and some plant commissioning tests for assessing the quality of the simulation of these components and systems.

3. With the advances in numerical techniques for data gathering, plant dedicated digital acquisition systems can considerably enhance the quality and quantity of the plant database available for code assessment. In screening future ISP's based on real plant transients, it is strongly recommended to select available transients from power plants which are equipped with such high quality recording systems.

4. Full scale plant transients are highly desirable to complement the available data base for code assessment. Indeed, validating 1D codes (e.g. RELAP, CATHARE, ATHLET) on the basis of data from essentially 1D test facilities (e.g. LOBI, SEMISCAL, BETHSY, ROSA, PKL...) questions the scalability of the code models and the capability for simulating hydraulic phenomena in highly 3D power plant components. Except for full scale separate effect tests (e.g. UPTF), full scale plant data are the best way to test the scalability of the advanced system codes. Hence it is recommended to stress the need for including more plant transients in the code validation matrix, and to select more thermalhydraulic ISP's on the basis of available real plant transients.
REFERENCES.

(1) OECD Nuclear Energy Agency
CSNI Standard Problems Procedures
CSNI Report n° 17 (rev.2 - september 1983)

(2) E. STUBBE
ISP-20 : Doel 2 - Steam generator tube rupture event of June 1979.
TRACTIONEL - BRUSSELS - MARCH 1986.

(3) OECD - Nuclear Energy Agency.
Summary Record of the first workshop on International Standard Problem
Exercise n°20, held at OECD Headquarters in Paris, France, on 13th June
1986.
OECD - NEA : SEN/SIN (86)32.

(4) OECD - Nuclear Energy Agency.
Summary Record of the second workshop on Exercise n° 20, held at OECD
Headquarters in Paris, France, on 1st and 2nd december 1986
OECD-NEA : SEN/SIN(87)1.

(5) REPORT ON THE INCIDENT AT DOEL 2 NUCLEAR POWER PLANT :
SEVERE LEAKAGE IN STEAM GENERATOR B ON JUNE 25, 1979.
TRACTIONEL - BRUSSELS - 25.10.1979 - PD/VEF rev.A.
### ISP-20 List of Parameters to Be Calculated Versus Time

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<th>Identifier</th>
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#### Remarks
- Equivalent to RELAP-5!
- Package: Fig. 4.1

**ANNEX I**
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Equivalent to RELAP-5!

Package Fig. 4.1!
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ANNEXE 2.

OVERLAY-PLOTS OF THE PARAMETERS TO BE CALCULATED.

CEA : Commissariat à l'Energie Atomique - Paris.

DCMN : Dipartimento di Construzioni Meccaniche e Nuclear - Universita' degli Studi di Pisa.

ENEA : Comitato Nazionale per la ricerca e per lo sviluppo dell' Energia Nucleare e delle Energie Alternative - Roma.

IJS : Institut Jozef Stefan - Ljubljana.

JRC : Joint Research Center - Ispra.

TRACT : TRACTEBEL - Brussels.

TRCR : Technical Research Center of Finland - Helsinki (RELAP-calculation).

TRCS : Technical Research Center of Finland - Helsinki (SMABRE-calculation).

EXPE : Plant data (when available).
Fig. 01: Fluid Temperature Hot Leg Loop A

Fig. 02: Fluid Temperature Hot Leg Loop B
Fig. 03: Fluid Temperature Cold Leg Loop A

Fig. 04: Fluid Temperature Cold Leg Loop B
Fig. 05: Pressure in Pressurizer

Fig. 06: Pressure in Hot Leg Loop A
Fig. 07: P level Pressurizer

Delta P Level (%)

Time (s)

LEGEND
- CEA
- DCMN
+ ENEA
X LS
- JRC
V TRACT
■ TRCR
□ TRCS
* EXPE

Fig. 08: Collapsed water level Pressurizer

Collapsed Water Level (m)

Time (s)
Fig. 09: Vapour Temperature Pressurizer Dome

Fig. 10: Saturation Temperature Pressurizer Dome
**Fig. 11**: Fluid Temperature  Pressurizer Spray Volume

**Fig. 12**: Vapour Generation Rate  Pressurizer Spray Volume
Fig. 13: Vapour Void  Surgeline T-Branch

Fig. 14: Vapour Generation Rate  Surgeline T-Branch
**ISPS 20**

**Mass Flow Rate (kg/s)**

- **CEA**
- **DCMN**
- **ENEA**
- **US**
- **JRC**
- **TRACT**
- **TRCR**
- **TRCS**

*Fig. 15: Mass Flow Rate  Surgeline*

**ISPS 20**

**Break Mass Flow Rate (kg/s)**

- **CEA**
- **DCMN**
- **ENEA**
- **US**
- **JRC**
- **TRACT**
- **TRCR**
- **TRCS**

*Fig. 16: Break Mass Flow Rate  Break*
Fig. 17: HPSI Mass Flow Rate Cold Leg A+B

Fig. 18: Upstream Break Volume
ISP 20

Charging Mass Flow Rate (kg/s)

Fig. 19: Charging Mass Flow Rate  Cold Leg B

ISP 20

Letdown Mass Flow Rate (kg/s)

Fig. 20: Letdown Mass Flow Rate  Pump Suction B
Fig. 21: Mass Inventory Total RCS

Fig. 22: Spray Mass Flow Rate Pressurizer Spray
Fig. 23: RCP Pump Speed  Coolant Pump A

Fig. 24: RCP Pump Speed  Coolant Pump B
ISP 20

Loop A Mass Flow Rate (t/s)

LEGEND
○ CEA
△ DCMN
+ ENEA
× IJS
○ JRC
▼ TRACT
■ TRCR
□ TRCS

Time (s)
-300 0 300 600 900 1200 1500 1800 2100 2400 2700 3000

Fig. 25: Loop A Mass Flow Rate Reactor Vessel Inlet

ISP 20

Loop B Mass Flow Rate (t/s)

LEGEND
○ CEA
△ DCMN
+ ENEA
× IJS
○ JRC
▼ TRACT
■ TRCR
□ TRCS

Time (s)
-300 0 300 600 900 1200 1500 1800 2100 2400 2700 3000

Fig. 26: Loop B Mass Flow Rate Reactor Vessel Inlet
Fig. 27: Structural Heat Input Pressurizer and Surgeine

Fig. 28: Structural Heat Input Total Primary System
Fig. 29: Core Thermal Power  Core to Coolant

Fig. 30: Steamline Pressure  Steamline SGA
Fig. 31: Steamline Pressure Steamline SGB

Fig. 32: Delta P Water Level SGA
ISP 20

Delta P Water Level (%)

Time (s)

Fig. 33: Delta P Water Level  SGB

ISP 20

Collapsed Water Level (m)

Time (s)

Fig. 34: Collapsed Water Level  SGA - Downcomer
Fig. 35: Collapsed Water Level  
SGB - Downcomer

Fig. 36: Collapsed Water Level  
SGA - Riser
Fig. 37: Fluid Temperature SGB - Bottom

Fig. 38: Fluid Temperature SGB - Top U Bundle
Fig. 41: Vapour Temperature  SGB - Dome

Fig. 42: Auxiliary Feed Water Flow  SGA
**Fig. 43**: Auxiliary Feed Water Flow  
**ISP 20**  
Legend:  
- CEA
- DCMN
- ENEA
- LJS
- JRC
- TRACT
- TRCR
- TRCS

**Fig. 44**: Steam Mass Flow Rate  
**ISP 20**  
Legend:  
- CEA
- DCMN
- ENEA
- LJS
- JRC
- TRACT
- TRCR
- TRCS
**ISP 20**

**Steam Mass Flow Rate (kg/s)**

- CEA
- DCMN
- ENEA
- IJS
- JRC
- TRACT
- TRCR
- TRCS

**Fig. 45 : Steam Mass Flow Rate SGB**

**ISP 20**

**Recirculation Mass Flow Rate (kg/s)**

- CEA
- DCMN
- ENEA
- IJS
- JRC
- TRACT
- TRCR
- TRCS

**Fig. 46 : Recircul. Mass Flow Rate Inlet Riser SGA**
Fig. 47: Recirculation Mass Flow Rate Inlet Riser SGB

Fig. 48: Vapour Generation Rate Dome SGB
Fig. 51: Heat Transfer U-Tubes  Loop A  SGA

Fig. 52: Heat Transfer U-Tubes  Loop B  SGB
Fig. 53: Structural Heat To Fluid of SGA

Fig. 54: Structural Heat To Fluid of SGB