INVESTIGATION OF H_2 GENERATION DURING A SBO FOR A VVER 1000 - 320 USING THE CODES RELAP5-SCDAP AND MELCOR

N. Muellner, W. Giannotti, F. D'Auria
University of Pisa, DIMNP
Via Diotisalvi 2, 56122 Pisa, Italy
nikolaus.muellner@univie.ac.at, w.giannotti@ing.unipi.it, dauria@ing.unipi.it

G. Kastchiev, W. Kromp
University of Vienna, IRF
Tuerkenschanzstrasse 17/8, A-1180 Wien, Austria
george.kastchiev@irf.univie.ac.at, wolfgang.kromp@irf.univie.ac.at

ABSTRACT

Modern computer codes play an important role in nuclear safety analysis. This paper presents the investigation of a station blackout accident at a VVER 1000 NPP with the codes Relap5 mod 3.2 Scdap and Melcor 1.8.5. A special interest was taken in the hydrogen production. A large amount of hydrogen could pose a serious threat to the containment. User choices have a considerable influence on the amount of produced hydrogen.

The results from the calculations are presented and discussed. The results show in general a good agreement between the calculations.

1 INTRODUCTION

Severe accident management relies heavily on code calculations. Experimental data deriving from severe accidents at NPPs is very limited - which again emphasises the need of computational tools to model severe accidents.

This paper presents two calculations done by University of Pisa (see [1]) which simulate a SBO transient at a VVER1000 NPP. One calculation uses the Code Relap5/Scdap, one Melcor. This paper focusses on the user choices made which influence the production of H2 during the invessel phase of the transient, since sensitivity analysis showed that user choices play an important role.

The further structure of the paper presents a description of the plant and relevant systems, a descripiton of the options influencing the H_2 production, the Melcor results, the Relap/Scdap results, and finishes with a conclusion.

2 PLANT DESCRIPTION

The following description is mainly taken from [3]. The NPP in consideration is the VVER-1000 Model 320. The primary coolant system (360.9 \cubm) consists of the reactor pressure vessel and four primary loops. The hot leg nozzles are located above the cold leg nozzles on the reactor vessel. Each loop has a horizontal SG and a shaft-sealed reactor coolant pump. The nominal primary system pressure is 15.7 MPa.

One loop contains the pressurizer, connected with two safety valves and a relief valve (PORV, with an automatic block valve) for overpressure protection. Two spring loaded safety valves (assisted by pilot valves) are mounted on top of the pressurizer with opening and closing set-points of 18.6/17.5 MPa and 19.2/17.9 MPa respectively, and a relief capacity of 270 t/h. There is one PORV (electrically supplied, battery backup) with a relief capacity of 180 t/h, and opening/closing set-points of 16.8/16.3 MPa. A block valve closes automatically when the pressure is below 16.3 MPa. The discharge of the safety valves and PORV goes to a 30 m^3 barbotage tank (water Volume of 20 \cubm). The reactor coolant pumps are controlled leakage pumps with a four-stage seal. Seal injection (2 \cubm/h) is provided between seal number one and seal number two of each pump by the charging system.

The total secondary side free volume of each SG is 127 \cubm. There are 11,000 SG tubes in each SG, with an outside diameter of 16 mm and a thickness of 1.5 mm. The normal water level is 2550 mm (2/3 of total height). There are two inside primary collectors on the SGs (hot side and cold side). The feed water collector for main and auxiliary feed water (AFW) feeds the feed water under nominal level.

2.1 The main safety systems

The plant safety system concept is, with some exceptions, a 3x100% redundancy design with three nominally identical trains of equipment for each system. The high pressure injection (HPI), low pressure injection (LPI), and containment spray (CS) systems take suction from a common containment sump, which is contained in an extension of the containment below the cavity basement.

The HPI system is designed to supply 130 \cubm/h at a primary pressure of 8.83 MPa. The HPI pumps are also used in what is termed "feed and bleed" cooling, in which the operators depressurise the primary system to a pressure below the HPI injection capability by opening the PORV, and injecting coolant with the HPI pumps. The fluid discharged from the PORV results in the barbotage tank including a rupture disk discharging the coolant into the containment sump. As the coolant is drawn from the sump by the HPI pumps, it is cooled by the residual heat removal (RHR) heat exchangers before being injected back into the primary coolant system. Feed and bleed cooling is used upon loss of secondary heat removalcapability (loss of all feed water).

The low pressure injection system (LPI) provide emergency coolant makeup in the event of a large pipe break. The system also can be operated in the RHR mode to remove decay heat from the reactor coolant system after shutdown.

Residual heat removal (RHR) is a mode of operating the LPI system to take the primary system to, and maintain it in, cold shutdown. Initiation of RHR cooling is a series of operator manual actions taken from the main or emergency control room.

There are four accumulators pressurized by nitrogen which automatically inject borated water into the reactor coolant system (RCS) at a pressure of 5.9 MPa. Two accumulators inject into the upper plenum and two into the down comer of the reactor pressure vessel. Each accumulator has a capacity of 50 \cubm of water.. Following injection, fast acting electric powered isolation valves close on low level in the accumulators to prevent injection of nitrogen gas into the primary system. The accumulators are located in two pairs on elevation level 27.0m and 36.0m in the containment.

The makeup system is part of the chemical and volume control system, which performs a variety of functions supportive of normal operation. From the standpoint of accident analysis the makeup pumps are important as regards steam generator tube rupture (SGTR) sequences and also in their role in providing reactor coolant pump (RCP) seal support functions to maintain RCP seal integrity. The system can be connected to the TB10 system which is made up of 2 tanks of 200 \cubm, each containing 40 g/kg (4 wt\% or 7000 ppm) boric acid. With all three TB10 system pumps operating, the system can achieve a maximum flow of 100 \cubm/h.

3 OPTIONS AFFECTING THE H_2 GENERATION

3.1 Melcor options

A very important result during the calculation of a SBO is the amount of generated hydrogen due to zircalloy oxidation (invessel phase). This paper focuses on the options which influence this result.

3.1.1 Oxidation of Zircalloy

Oxidation of zircalloy by both steam and oxygen is modelled by MELCOR and considered for H2 generation during the in-vessel phase of the transient [2]. The following relations are used by Melcor by default and can be changed with the sensitivity coefficent array C1001:

3.1.2 Oxidation of Steel

The reaction between steel and steam is considered. The for the oxidation rate the relation shown below is implemented as sensitivity coefficent array C1002.

3.1.3 Affects of starvation

and flow blockage are taken into account by Melcor when it calculates which amount of steam and oxygen are available for the Oxidation processes.

3.1.4 Materials:

Options which influence directly the H_2 production during the in-vessel phase are the oxidation rates for the various materials, for which the default-values have been used. The minimum flow area, which can be specified for each ring of the core and which is used to specify the available amount of steam for the oxidation process.

3.1.5 Debris-Oxidation

Once core damage did occur, core materials form a debris. The oxidation rate of the debris depend on the particle surface (and size), which can be specified by the user (CORijj04).

3.1.6 Time of cladding-failure

The H_2 production rate is indirectly influenced by the time of failure of the cladding. The user has the possibility specify a temperature at which the clad will fail.

3.2 Relap5/SCDAP – options

3.2.1 Number of Core Channels

An important factor influencing the generation of hydrogen turned out to be the number of channels for the core. The reason for this is the availability of steam: if the channel is obstucted, steam is not available to the upper part, and the hydrogen production is stopped. So the core was nodalised with three interconnected channels.

3.2.2 Oxide Shell Stability Parameters

Another value which turned out to show considerable inlfuence on the H2 generation are Oxide Shell Stability Parameters (basically temperature and shell thickness, see [4]). While the temperature in this transient seemed to be less important, the fraction of oxidation of fuel rod cladding for a stable oxide shell parameter could change the amount of produced hydrogen by a factor of two.

4 MELCOR SBO - CALCULATED RESULTS

The input deck which was used for this calculation was developed by Pisa Universtiy and is described in [1]. The core is modelled by 14 axial levels and 5 channels, the RCS is modelled utilising one detailed loop (loop no 1) and one lumped loop (loop 2,3,4). The Containment is modelled with 13 nodes.

A loss of offsite power is the initiating event at 0s. All three diesel generators are assumed to fail (SBO). Reactor scram takes place without failure. Battery power is assumed to be depleted within one hour. Within one hour, EOPs are still in effect because the steam generators will not yet have boiled dry. Accordingly, there is no reason to expect that the primary relief valve (PORV) and primary system vent valves have been opened by this time. In addition, the main coolant pump seals are qualified for 24 hours with no seal cooling or primary pressure relief that occur is if the primary system pressure reaches the set point of one or both pressurizer safety valves. This scenario evolves as a high pressure sequence and is expected to be most severe from the point of view of in-vessel hydrogen production.

The MELCOR 1.8.5 simulation of the Temelin SBO ran to completion and all results appeared to be reasonable. After the assumed initiating event, the primary system coolant heats as the reactor pressure increases to the ~18MPa SRV set-point at 56 minutes. The primary system pressure was then maintained at that level as the SRVs cycled, while the pressure in the secondary side is determined by opening and closing set point of the BRU-A valves. As the SRVs relieved pressure and discharged coolant to the containment, the water level in the reactor vessel dropped until the core was exposed.

Following uncovery, the core heated rapidly until fuel relocation began from the uppermost region of the core. MELCOR 1.8.5 predicted relocation of portions of the fuel as heatup occurred. However, as particulate debris moved downward, it spilled into the water pool that remains in the core. This debris is quenched producing steam which had a cooling effect on the remaining intact fuel. This continued until complete vessel dryout occurred just before 300 minutes. At that time, the fuel experienced a nearly adiabatic heatup (due to the comparative absence of cooling steam flow) and massive core collapse occurred at approximately 320 minutes. During core heatup, the zirconium cladding was oxidized, producing about 420 kg of hydrogen.

The effluent from the primary system (i.e., the SRV water flow) and the lower head expelled core debris, water, and gases all contributed to the pressurization of the containment. Note that containment pressure response is nearly identical for all containment nodes, except for the cavity where a rapid pressurization occurs at vessel failure, causing the opening of the steel door which closes the cavity. Core debris ejected from the reactor vessel began to erode the concrete of the reactor cavity following vessel failure at a rate of about 30 cm/h, contributing to containment pressurization due to hydrogen, carbide monoxide, water and carbide dioxide generation. The calculation was stopped before the cavity was completely filled by corium layer, with a thickness of about 1 m still intact.

Please refer to Figure 1 to Figure 11 for the main trends. Table 1 shows the timeline of main events.

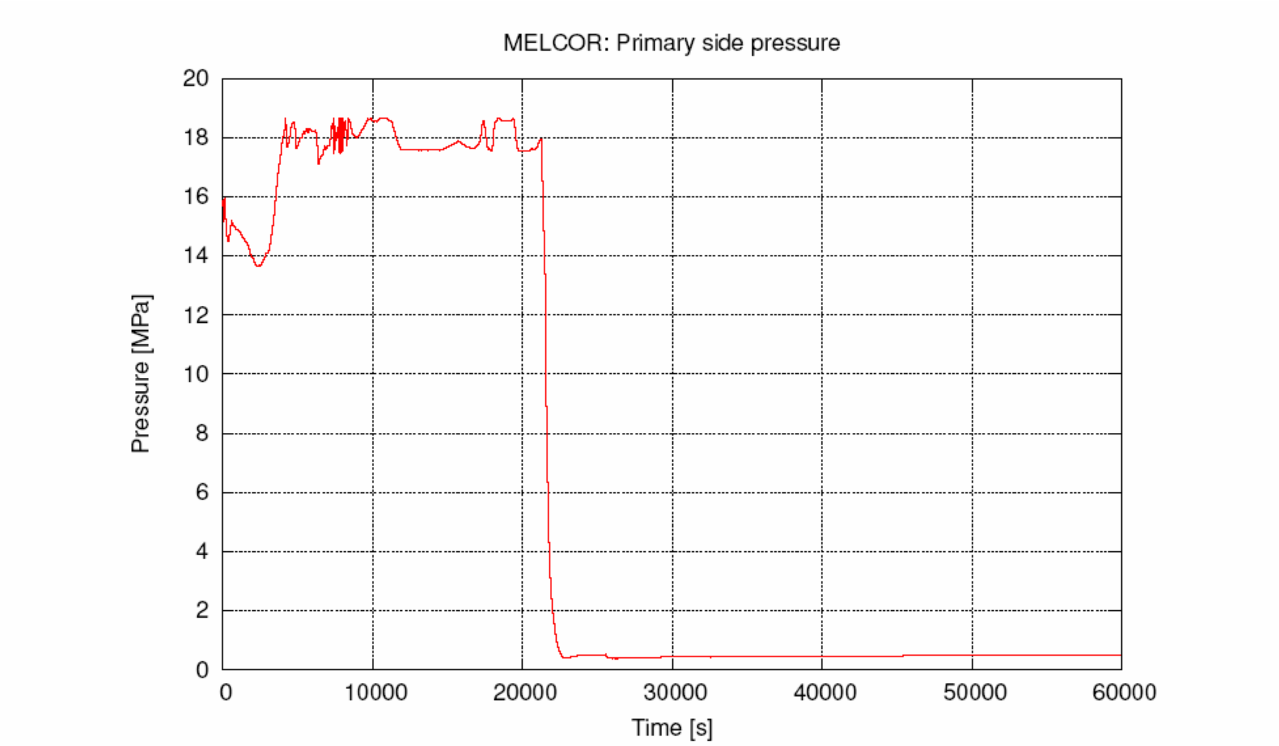

Figure 1: Primary side pressure from the Melcor calculation

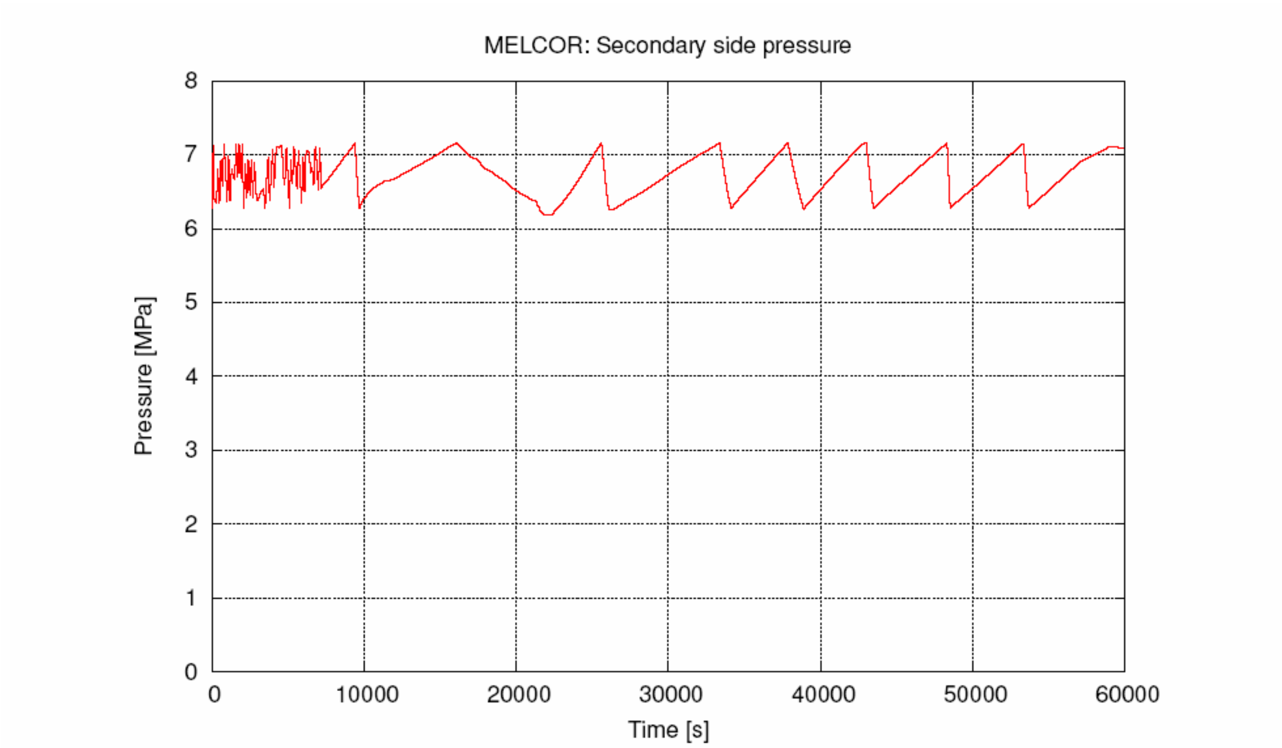

Figure 2: Secondary side pressure from the Melcor calculation

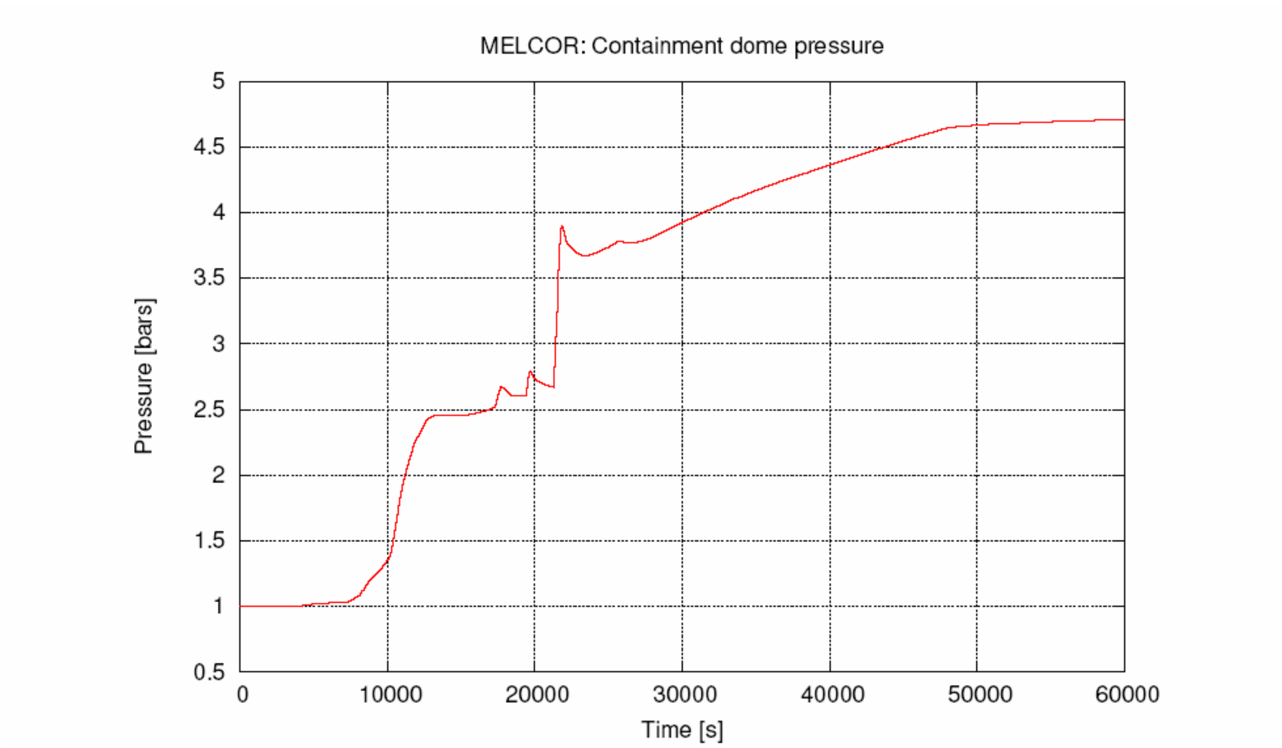

Figure 3: Pressure in the containment, upper dome. After the failure of the RPV the peak of pressure has the same magnitute in all compartments except the reactor cavity.

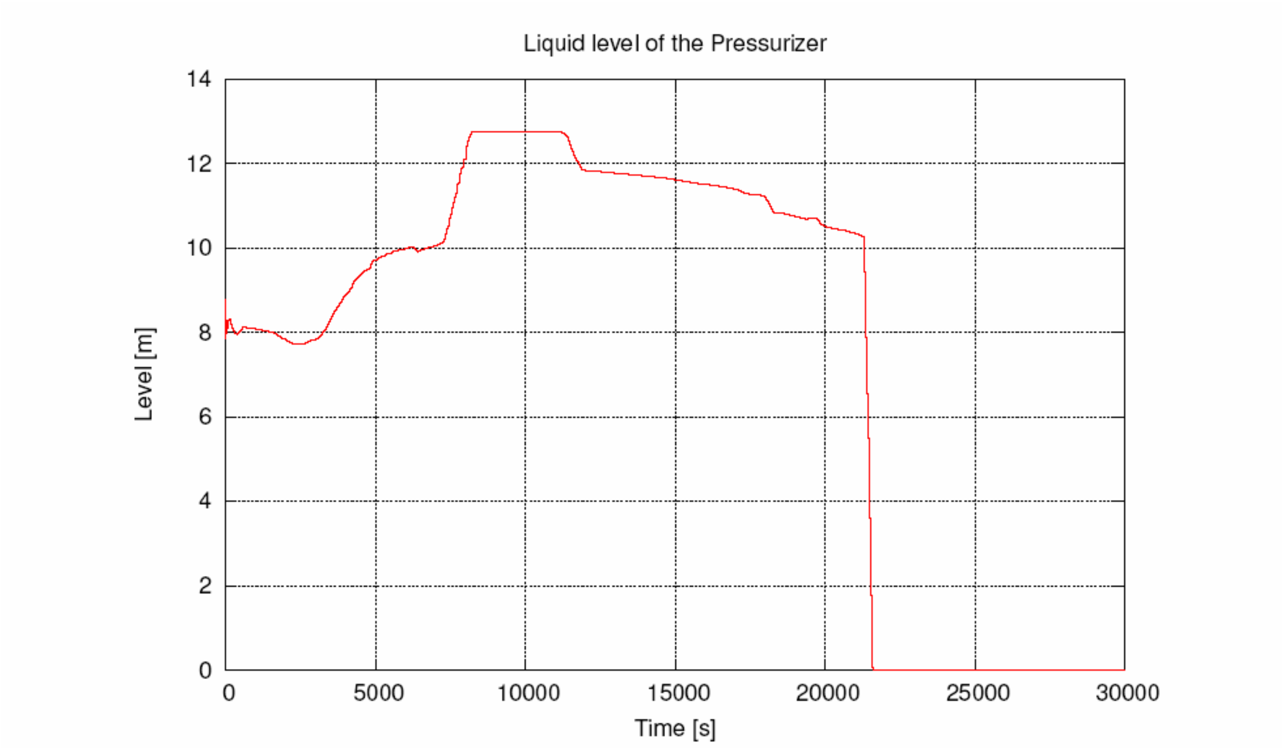

Figure 4: Liquid level of the pressurizer in the Melcor calculation. As can be seen in Figure 5: Liquid mass of the PS from the Melcor calculation. The loss of inventory becomes significant after the PRZ turned solid, the loss of PS inventory becomes significant after the pressurizer turned solid.

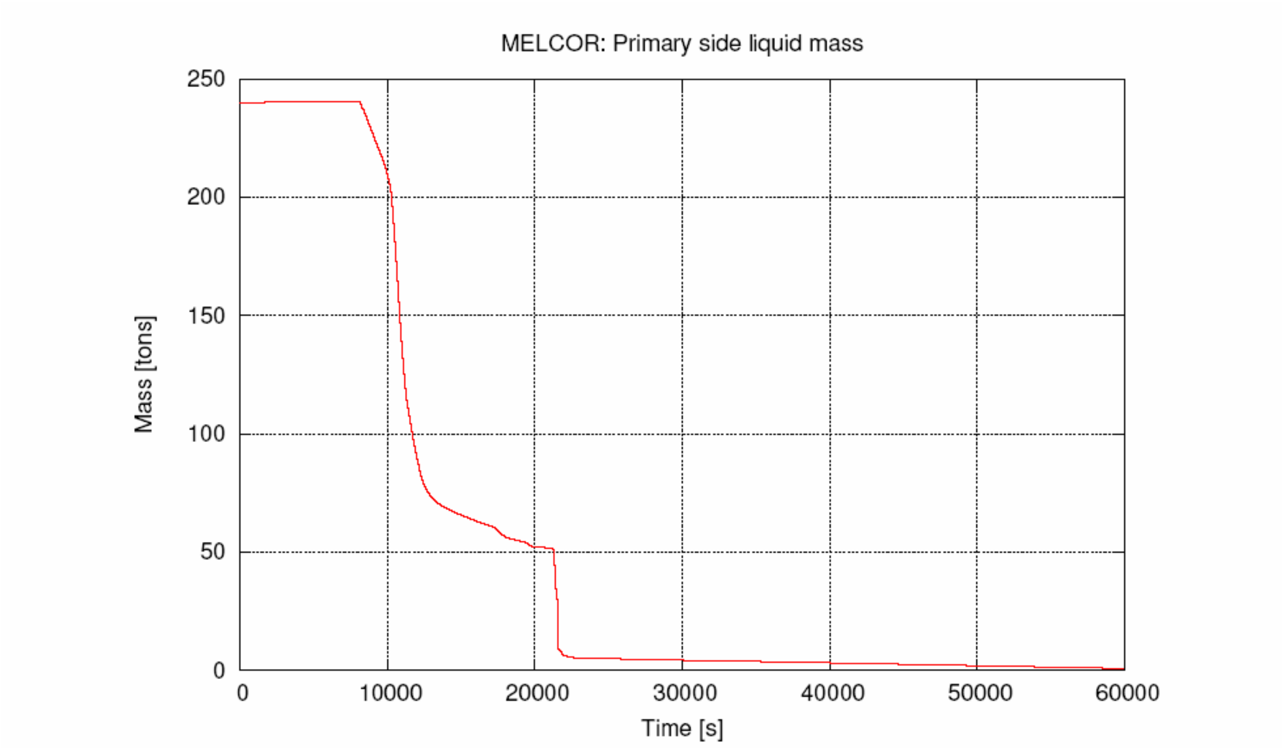

Figure 5: Liquid mass of the PS from the Melcor calculation. The loss of inventory becomes significant after the PRZ turned solid

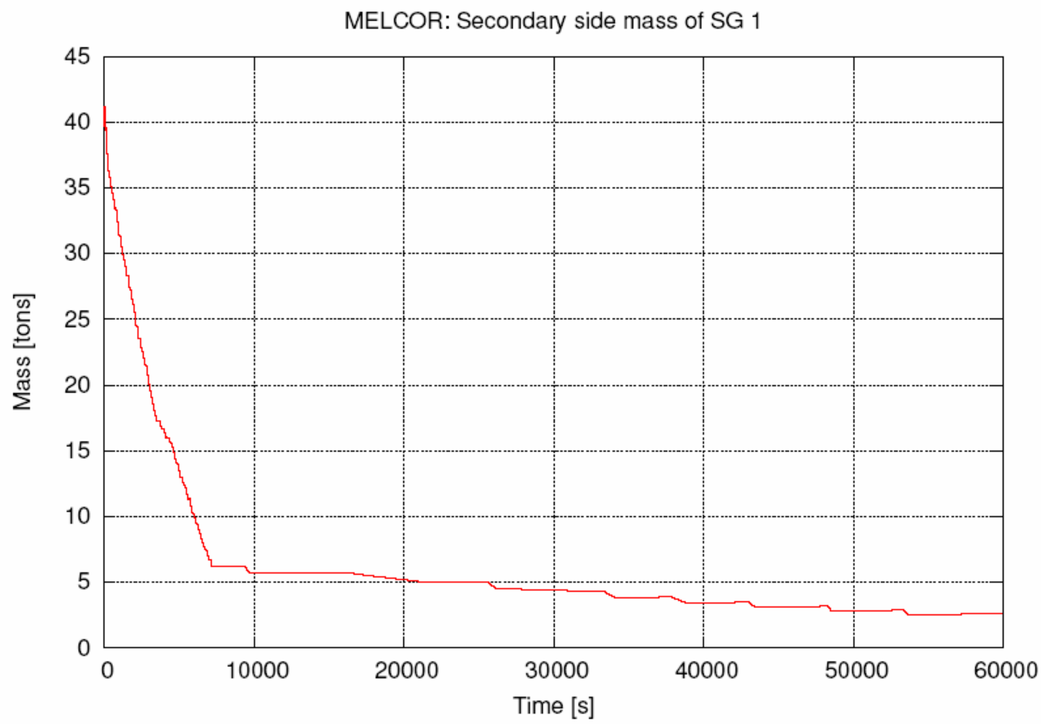

Figure 6: Mass of the SG A (detailed loop) of the Melcor calculation. After about 8000s the liquid level is not sufficient to allow heat removal from the PS.

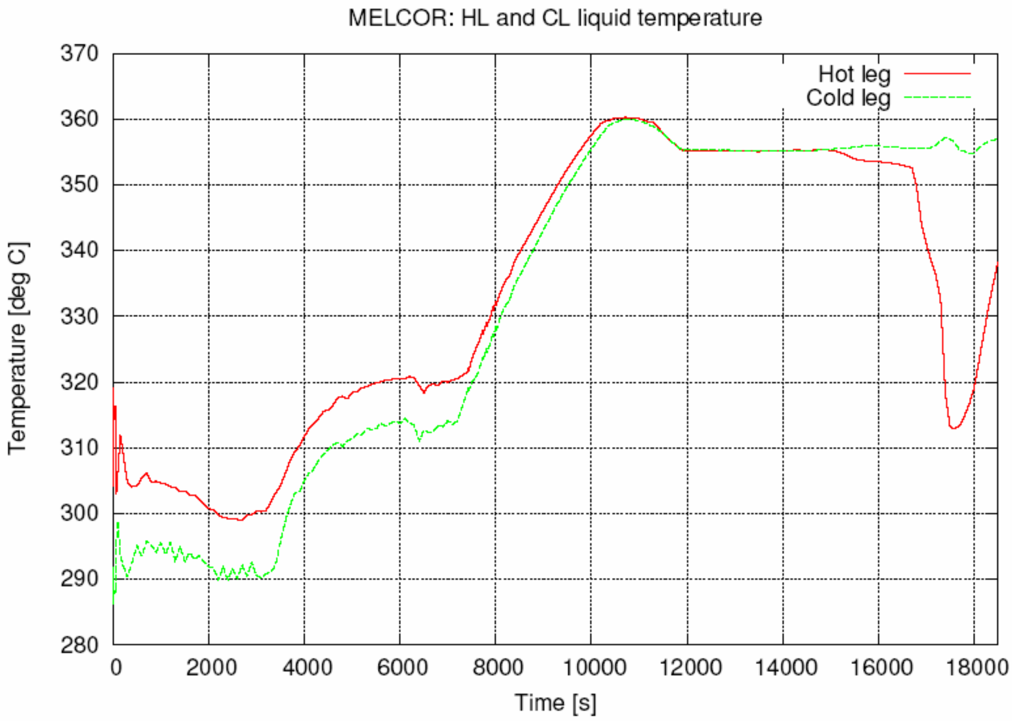

Figure 7: HL and CL temperature, Melcor results. After the SG is empty, the PS temperature and the PS pressure start to rise very sharply. After 19000s HL and CL are completely filled with steam.

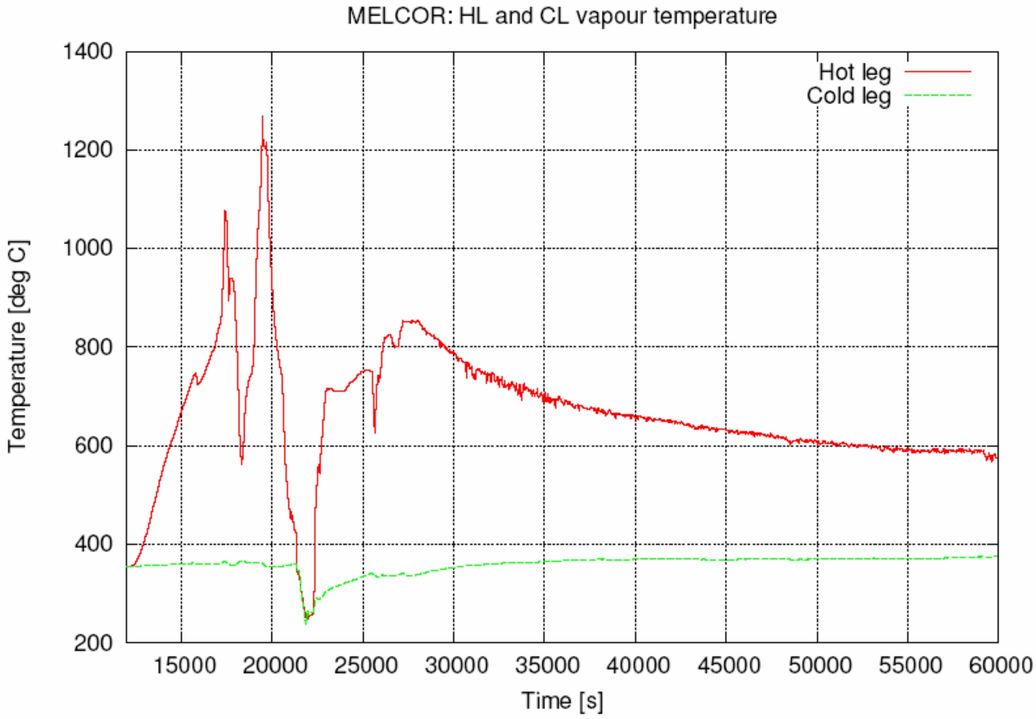

Figure 8: Melcor results, HL and CL steam temperature. The drop at 21000s is connected to the failure of the RPV.

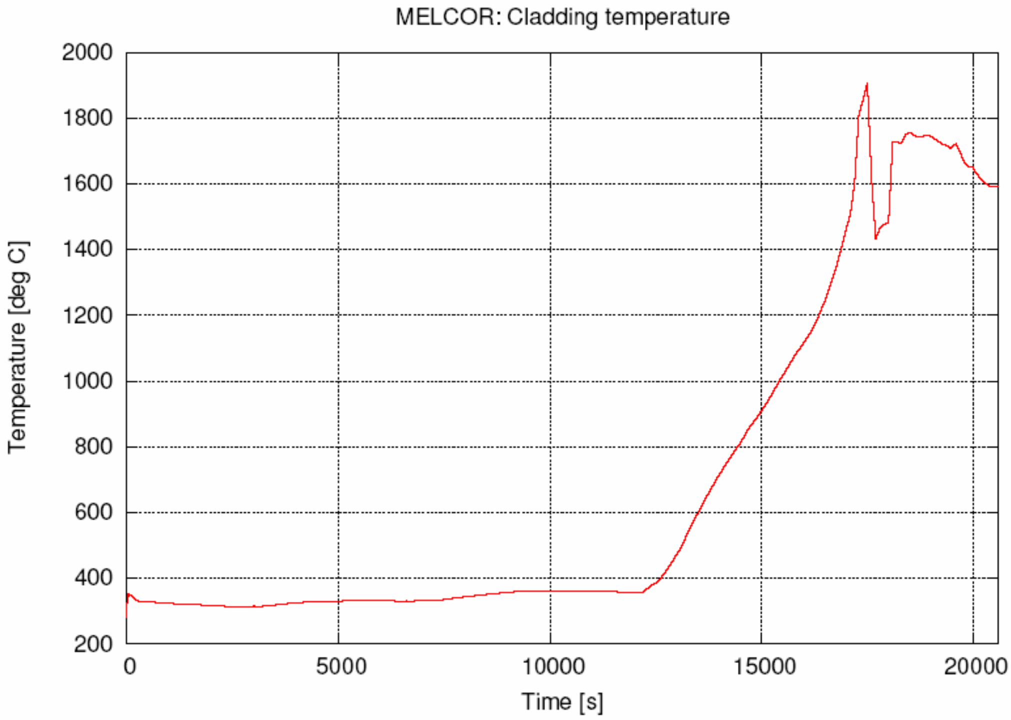

Figure 9: Melcor results, peak cladding temperature.

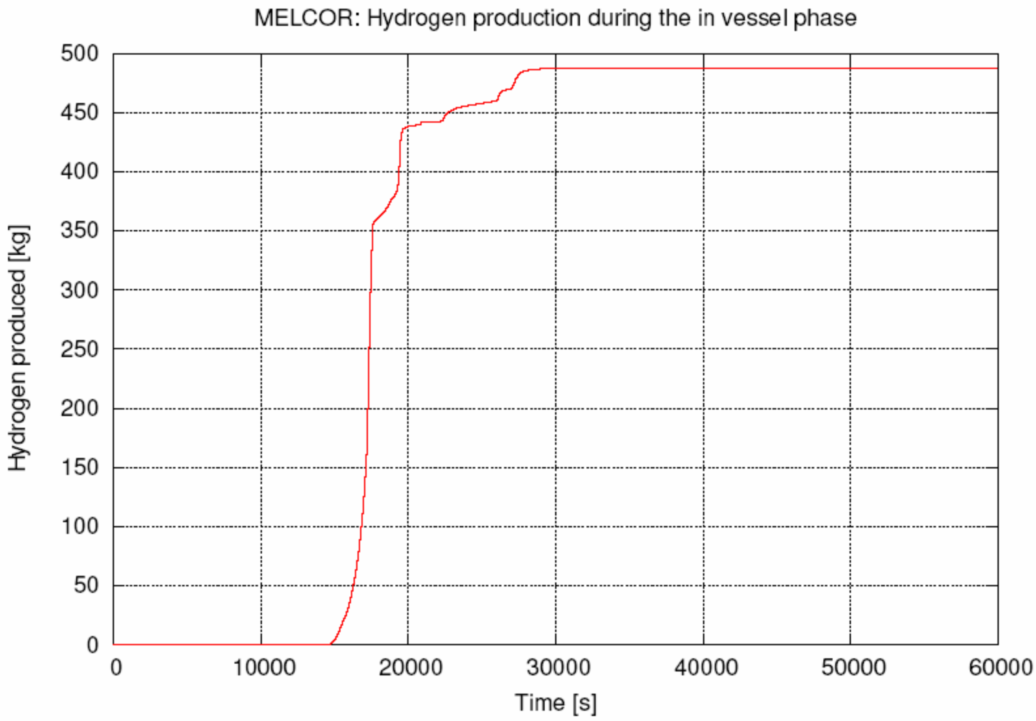

Figure 10: Hydrogen generation according to Melcor during the in vessel phase of the calculation.

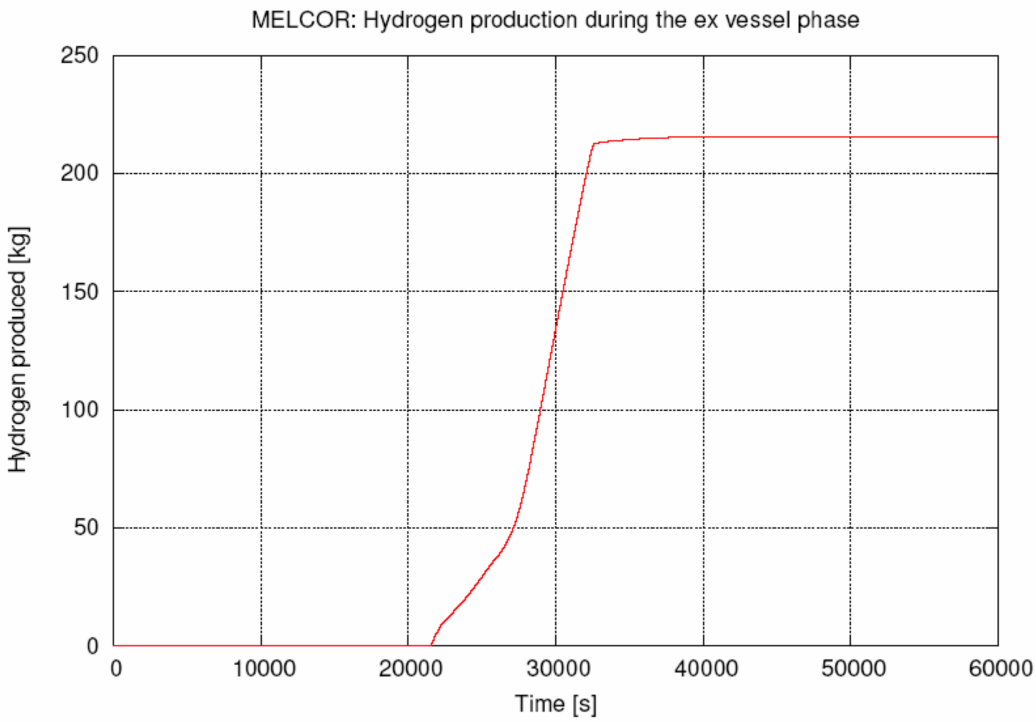

Figure 11: Hydrogen generation according to Melcor during the ex vessel phase of the calculation

5 RELAP5/SCDAP SBO - CALCULATED RESULTS

The results from RELAP/SCDAP show in principle the same behaviour, but differ in two important respects: firstly, core dryout and an increase in the hot-rod temperature is reached significantly earlier, and secondly, the amount of hydrogen produced in the in-vessel face is significantly slower.

A reason for the slower reaction rate might be found in [5]: the PRZ SRV valves as well as the SG SRVs are modelled in Relap5/Scdap as junctions (no physical volume). This leads to a L/D ratio to zero which will be used in the critical flow modell, while Melcor always uses a value different from zero. The result might be a faster higher flow rate through the safety valves.

Please refer to for the some important trends and figures.

Table 1gives a comparision between relap and Melcor main events.

Table 1

Event	Melcor at [s]	Relap/Scdap at [s]
Loss of onsite and offsite Power	0	0
Reactor Scram	0	0
SG dryout	7200	5000
PRZ full	8200	5500
Cladding temperature starts to rise	12200	8300
Start of H_2 production in the core	14600	8900
Lower head failure	21300	

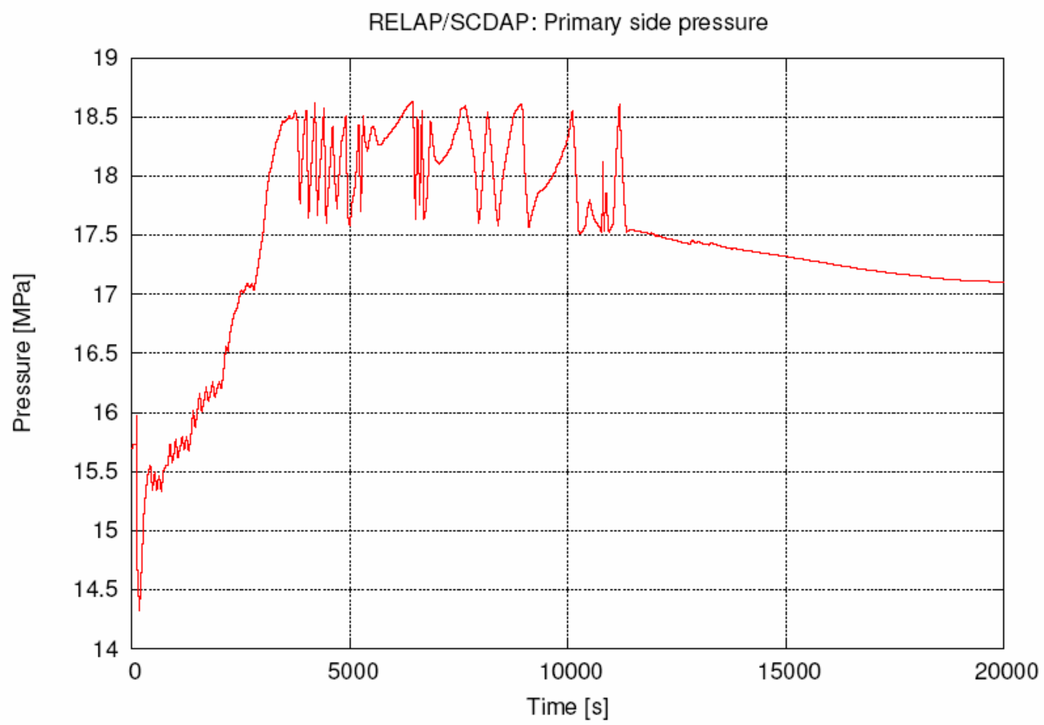

Figure 12: Relap5/Scdap results, PS pressure

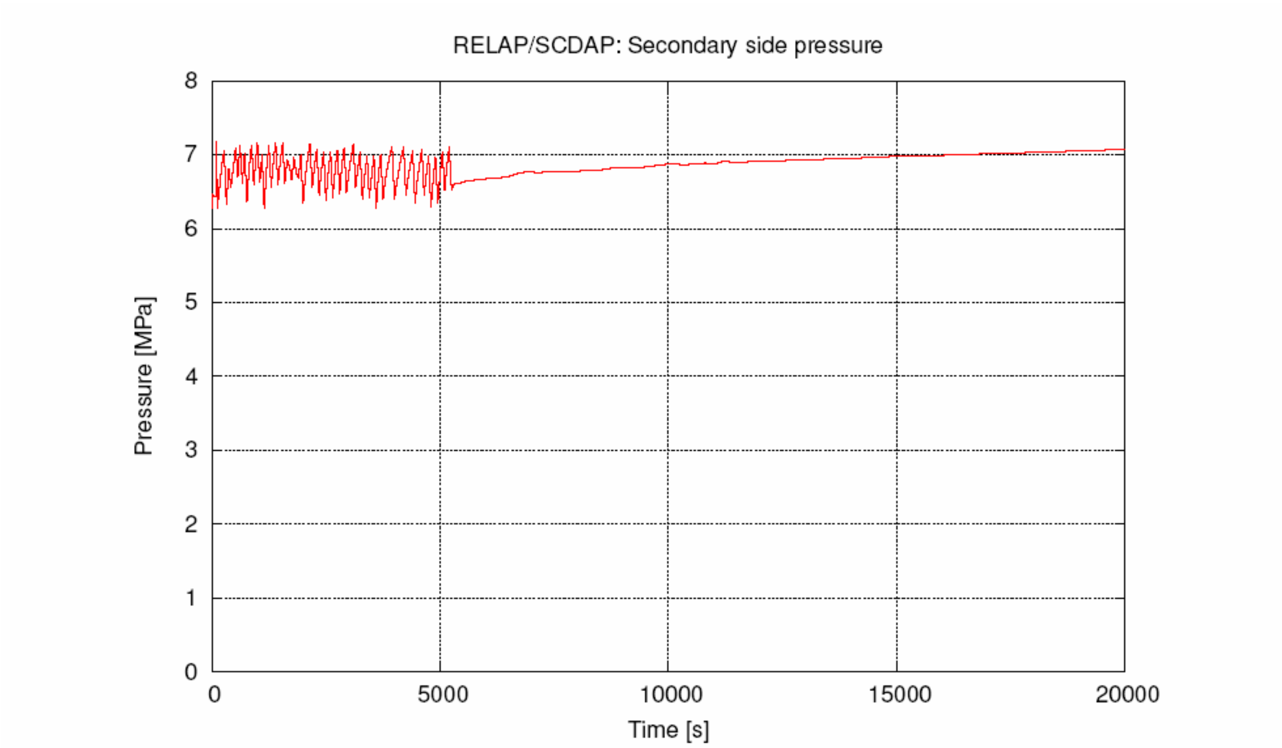

Figure 13: Relap5/Scdap results, SS pressure

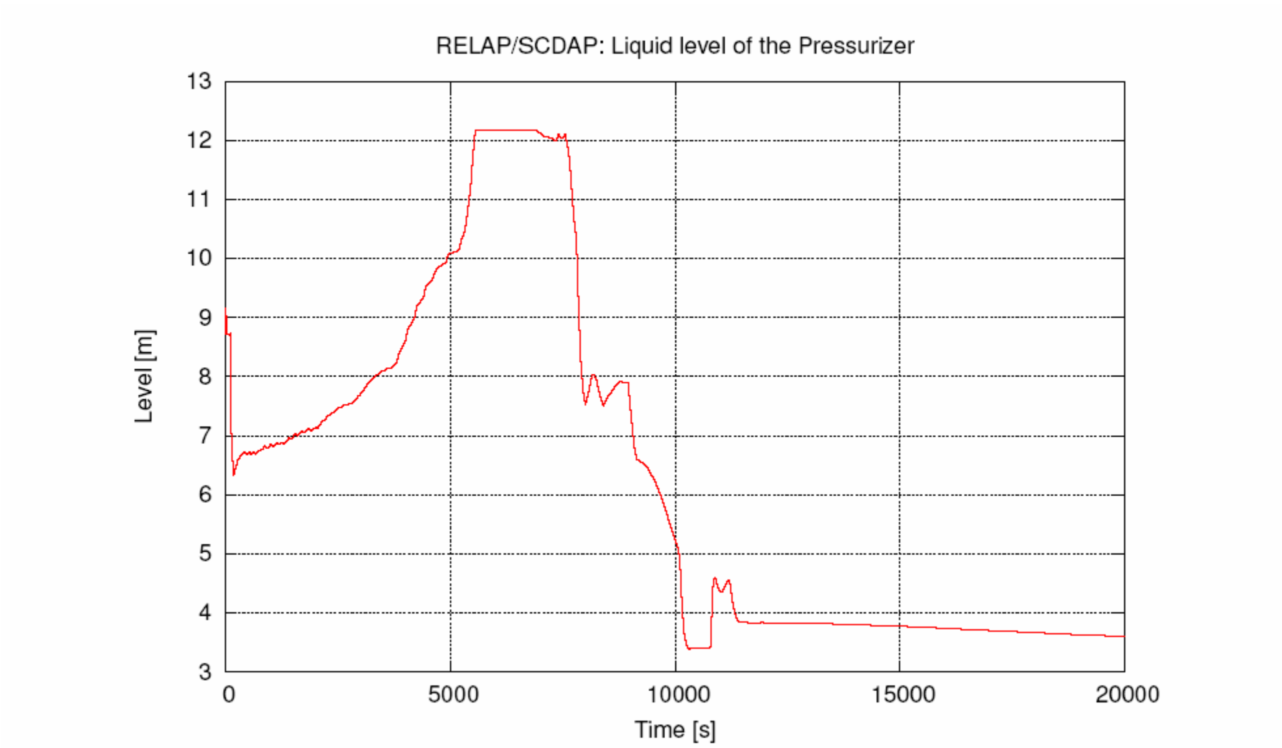

Figure 14: Relap/Scdap results, level of the PRZ.

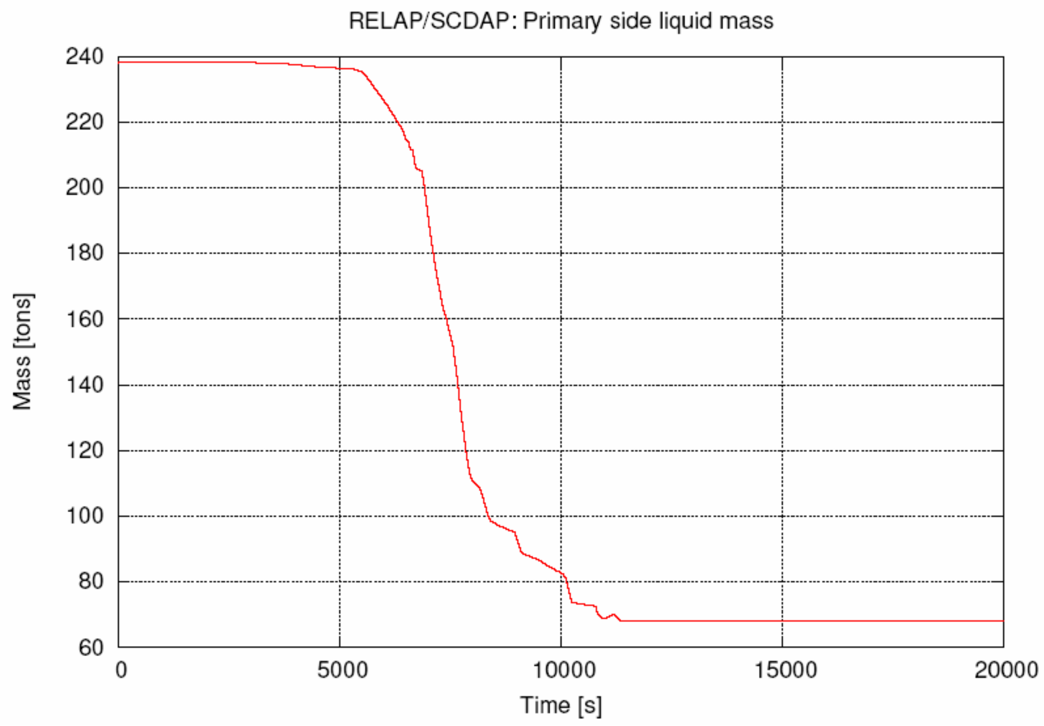

Figure 15: Relap/Scdap results, PS liquid mass

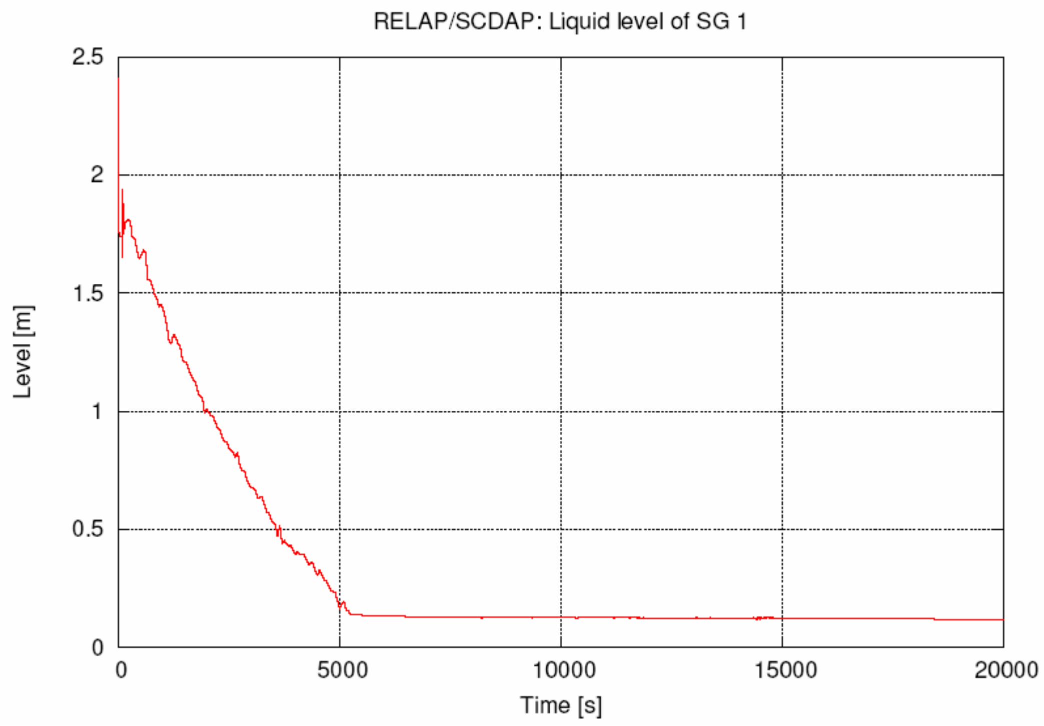

Figure 16: Relap5/Scdap results, level of the SG 1

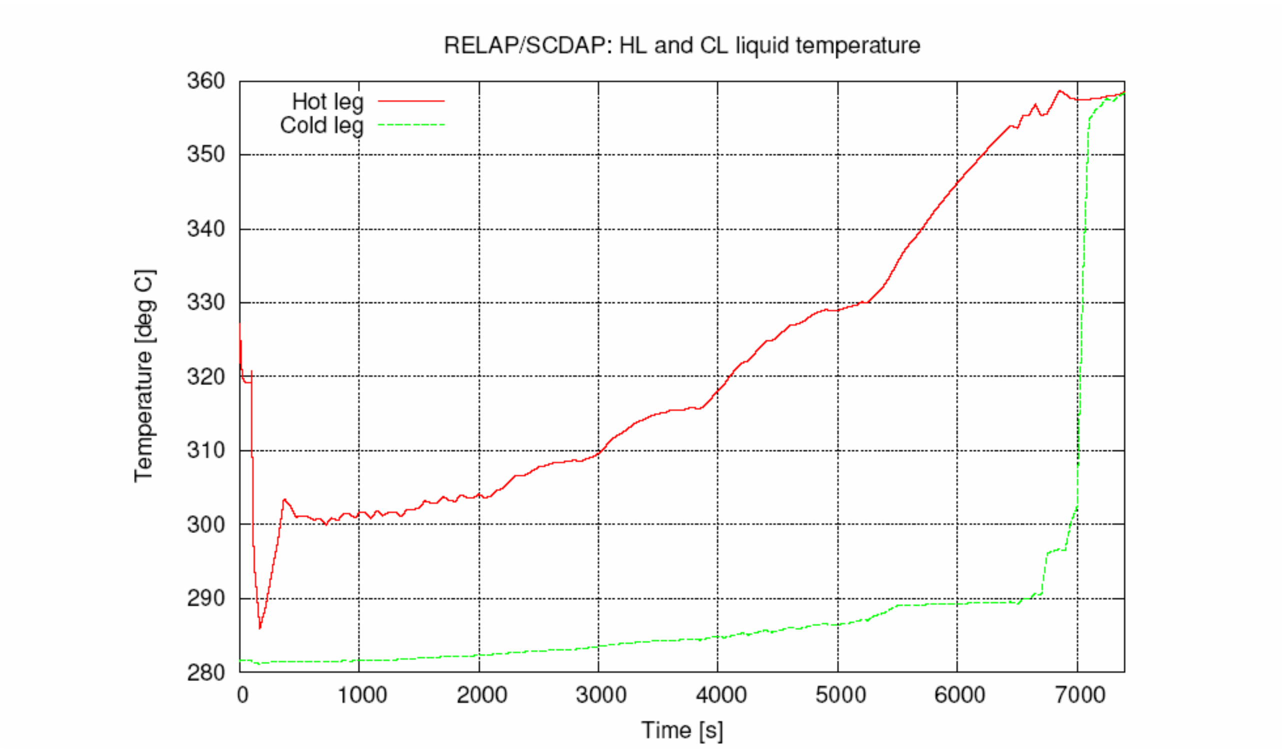

Figure 17: Relap5/Scdap results, fluid temperature of HL and CL in loop 1. After 7500s only steam is present.

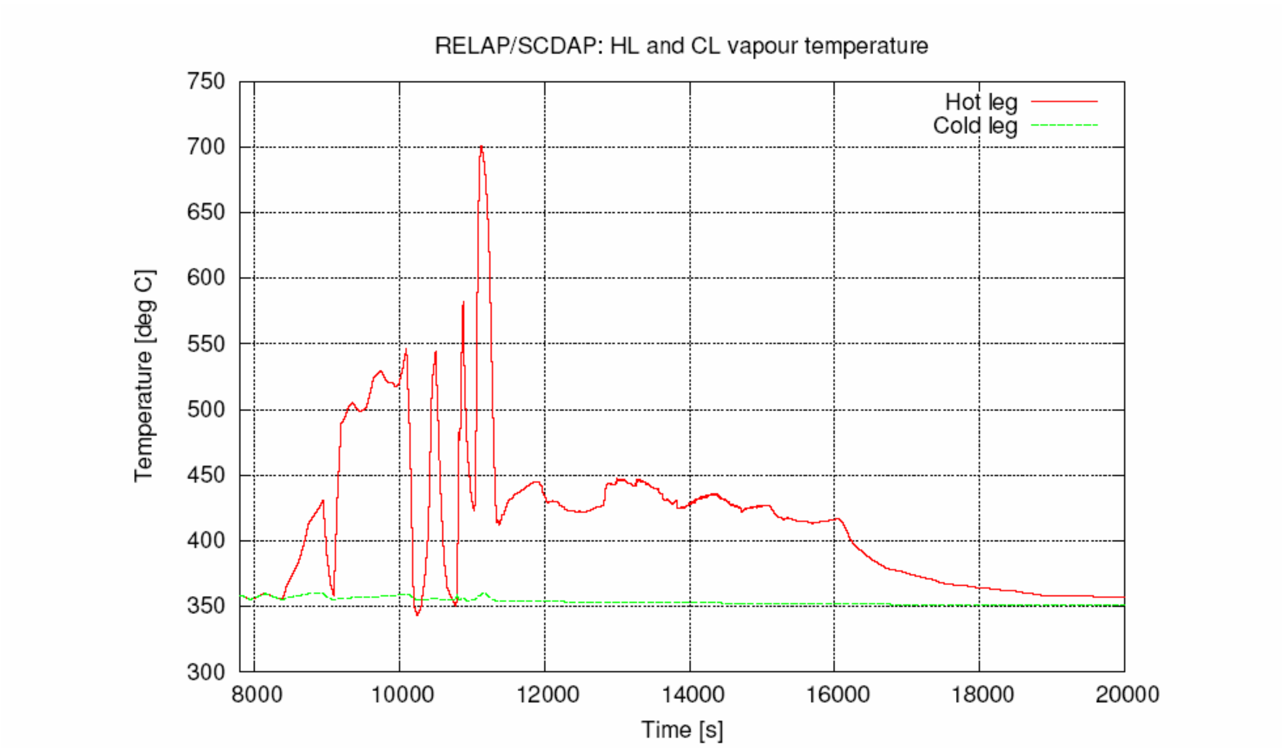

Figure 18: Relap5/Scdap results, vapor temperature of HL and CL in loop1.

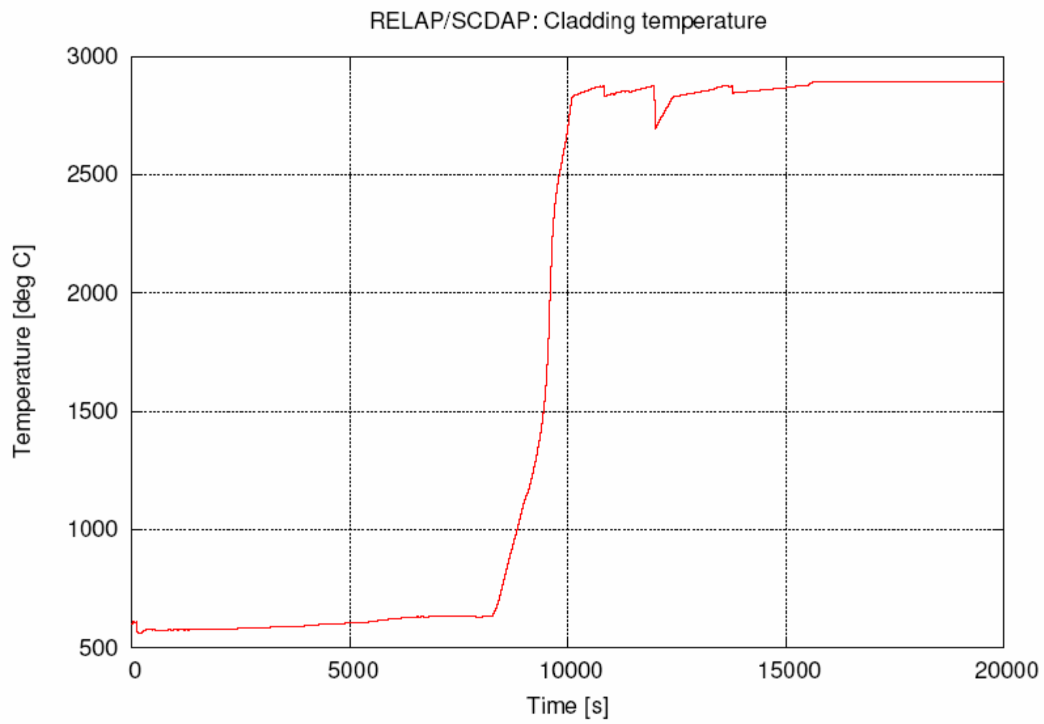

Figure 19: cladding temperature according to the Relap5/Scdap calculation

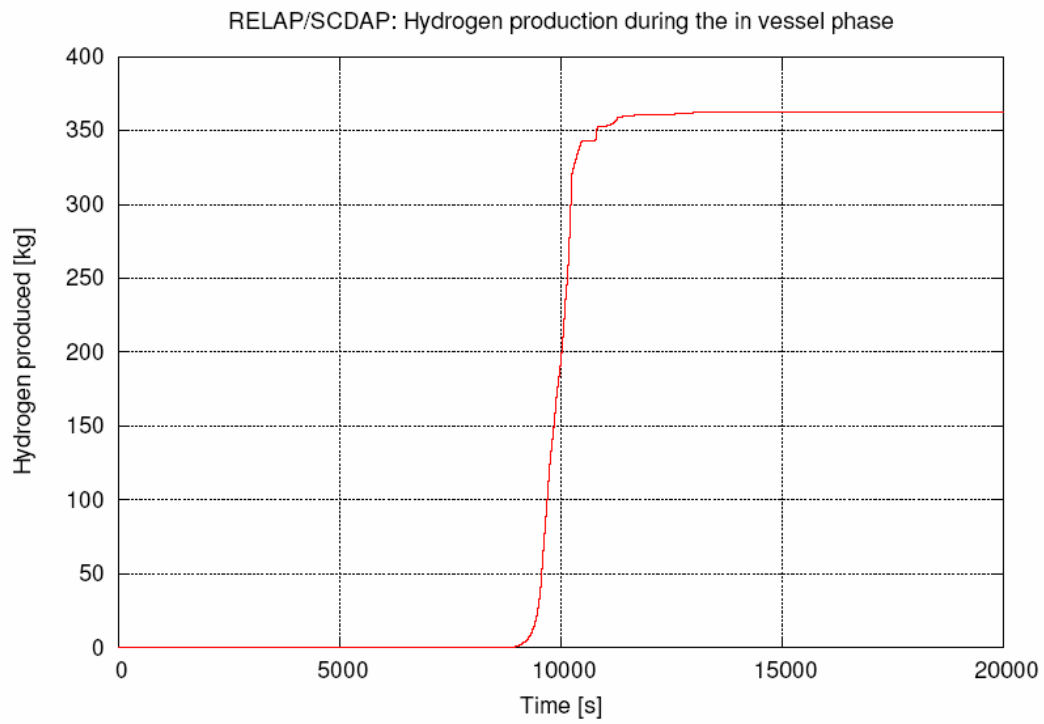

Figure 20: Amount of hydrogen prcoduced during the in vessel phase of the transient according to Relap/Scdap.

6 CONCLUSIONS

This paper presents a station blackout simulation by the codes Melcor and Relap5/Scdap. Both codes predict the same sequence of events, i.e. heat up of the primary side after the SGs are boiled empty and an increase of PS pressure up to the set points of the PRZ SRV valves, an extended period of SRV valve cycling, finally when the major part of the PS inventorty is lost heat up of the core, formation of a molten pool, which slumps to the lower plenum. Only Melcor was used to investigate further the penetration of the lower plenum an the build up of pressure in the containment.

While the same qualitative behaviour is predicted by both codes, the chain of events is accelerated in the Relap/Scdap calculation. The amount of hydrogen produced during the invessel phase differs (about 360kg Relap/Scdap and 460kg Melcor).

Summarising it is safe to say that although the results seem to be resonable in in both calculations, user choices play an inportant a role.

REFERENCES

[1] APPLICATION OF THE MELCOR 1.8.5 CODE TO THE ANALYSIS OF SEVERE ACCIDENT SCENARIOS FOR TEMELIN NPP, A..Manfredini, Pisa, July 2003, DIMNP NT 510(03)

[2] Melcor Core Package Reference Manual, Rev 2, COR-RM-1, NUREG/CR-6119

[3] Personal Communication 26 January 2001 S. Sholly

[4] SCDAP/RELAP5/MOD3.2 CODE MANUAL, NUREG/CR-6150 INEL-96/0422 Revision 1

[5] INTEGRATED ANALYSIS FOR A SMALL BREAK LOCA IN THE IRIS REACTOR USING MELCOR AND RELAP5 CODES, Alessandro Del Nevo, Antonio Manfredini, Francesco Oriolo, Sandro Paci