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**Small break LOCA analyses of
Mochovce NPP VVER-440/213 with
operator action**

Prepared by: Tomáš Kliment, Boris Kvizda, Tibor Zold

Presented by: Tomáš Kliment

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Introduction

- **The safety analyses are one of the main tools of NPP safety assessment**
- **For deterministic assessment within the range of postulated accidents - the safety criteria for deterministic assessment have to be fulfilled**
- **The aim of analyses**
 - ⇒ to evaluate the safety function that prevents the core damage under LOCA conditions for defined scenarios
 - ⇒ to evaluate operator action, which leads to ensuring of core cooling
- **Initiating event - LOCA 80 and 40 mm**
 - ⇒ ECCS configuration: 0 HPI, 0 or 1 HA, 1 LPI

RELAP5/Mod3.2.2 β 6-loops model for Mochovce NPP

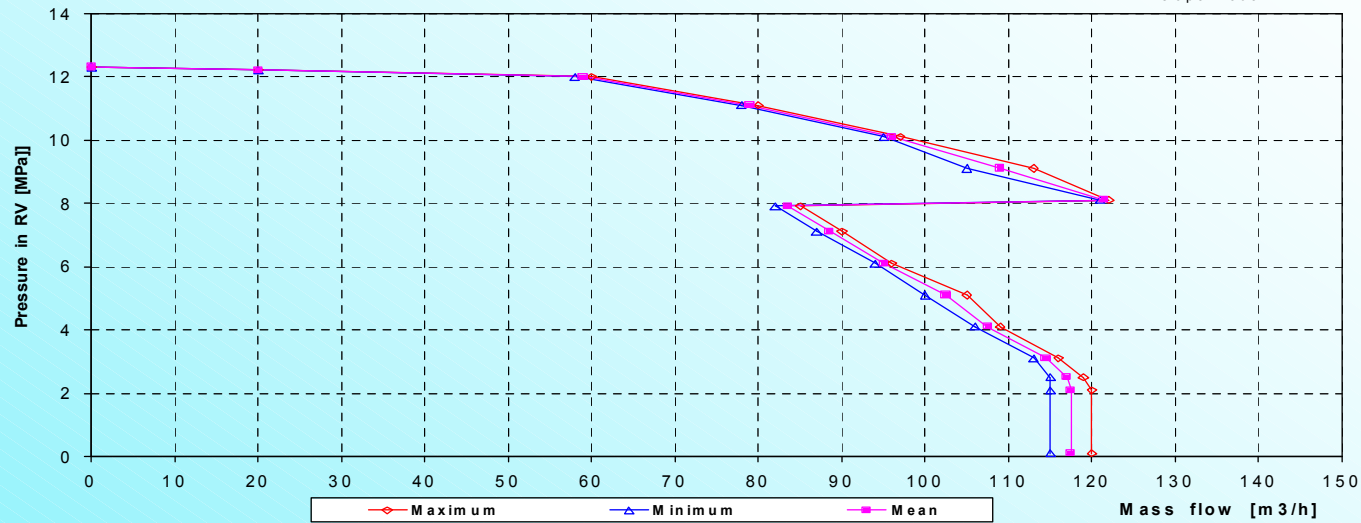
- ⇒ both primary and secondary circuit
- ⇒ safety important systems and controls

ECCS injection

- ⇒ 3 HPI pumps connected to the cold leg of loops 2, 3 and 5
- ⇒ 4 HA - 2HAs connected to the downcommer and 2 HAs connected to the upper plenum
- ⇒ 3 LPI pumps – 2 LPI pumps connected to the HA surge lines, 1 LPI pump connected to the cold and hot leg of loop 4
- ⇒ HPI and LPI pump characteristics were obtained from operational measurement at Mochovce NPP (maximum, minimum)
- ⇒ mean characteristic - calculated as an arithmetical average

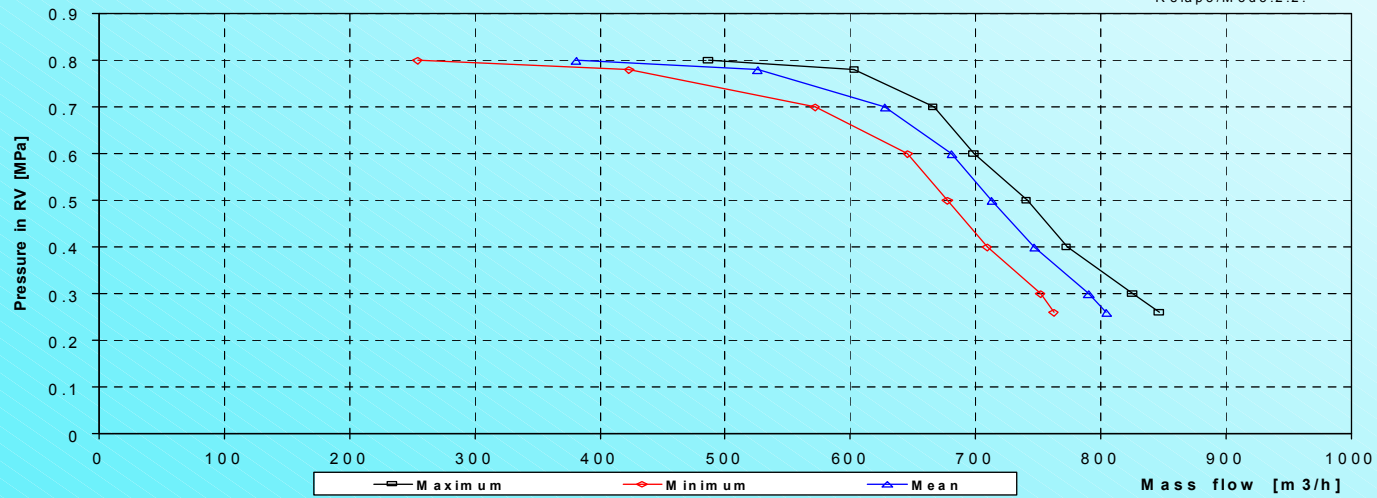
HPI pump characteristics - EMO NPP

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LPI pump characteristics - EMO NPP

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Description of selected analyses

Initial and boundary conditions

- ⇒ conservatism is applied for ECCS configuration only
- ⇒ nominal initial and boundary conditions - without uncertainties that could lead to conservatism of core cooling:
 - single failure and Loss Of Off-Site Power (LOOP) were not assumed
 - nominal value of scram and ESPAS signals setting
 - reactor power controller and turbine power controller were not assumed and operation of rest of non-safety systems was assumed in nominal mode

Configuration of ECCS and MAKE-UP system

⇒ ECCS configuration:

- none HPI pump
- one/none HA
- one LPI pump

⇒ MAKE-UP system:

- nominal mode => pumps are stopped after primary pressure decrease below 83.4 MPa
- operator action => 1 make-up pump is considered with mass flow 13.89 kg/s (50 t/hod) and capacity of make-up tang equals 100 m³

SCRAM signals

- ⇒ **Primary pressure < 9.32 MPa**
- ⇒ **Primary pressure < 11,77 MPa and PRZ level < 3.26 m**
- ⇒ **Hermetic compartments pressure > 0.108 MPa**

ESFAS signals

- ⇒ **Primary pressure < 8.34 MPa**
- ⇒ **Primary pressure < 10,77 MPa and PRZ level < 3.26 m**
- ⇒ **PRZ level < 2.76 m**
- ⇒ **Hermetic compartments pressure > 0.118 MPa**

Operator action

- ⇒ **necessary for recovering core cooling after initial event because HPIS is not assumed in any case**
- ⇒ **beginning of operator action - core outlet coolant temperature equal to 370 °C**
- ⇒ **delay between reaching of 370 °C and the first operator action was assumed about 10 minutes**
- ⇒ **operator action:**
 - secondary circuit depressurisation through all four BRU-Ks with the primary temperature decrease rate of 30 °C/hour or with maximum decrease rate (full opening of four BRU-A)
 - 1 make-up pump start up
 - start-up of two main circulation pumps

Core state assessment after initiating event

- ⇒ for LOCA analyses, maximum cladding temperature (1200 °C) - the crucial acceptance criterion from point of view of cladding (or fuel) damage
- ⇒ cladding temperature > 750 °C - plastic degradation of cladding (depends on core pressure and cladding temperature)
- ⇒ symptom-oriented emergency operating procedures - the core damage is predicted when core outlet coolant temperature exceeds 550 °C
- ⇒ following parameters were evaluated for the core state assessment:
 - cladding temperature - higher than 1200 °C
 - time when cladding temperature is higher than 750 °C
 - core coolant level
 - core outlet coolant temperature - higher than 550 °C

Core state assessment after initiating event

⇒ the core state after initiating event was evaluated using three levels:

I. level – NO core damage

Maximum cladding temperature does not exceed 1200 °C, time, when the cladding temperature is higher than 750 °C is shorter than ~ 300 s, core coolant level does not drop at 0.0 m and core outlet temperature is lower than 550 °C.

II. level – NO core damage but the probability of plastic degradation of cladding is high

Maximum cladding temperature does not exceed 1200 °C, time, when the cladding temperature is higher than 750 °C is longer than ~ 300 s, core coolant level drops at 0.0 m and core outlet temperature is lower than 550 °C.

III. level - core damage

Maximum cladding temperature exceeds 1200 °C and core outlet temperature is higher than 550 °C.

Specification of analysed cases

- ⇒ 80 mm and 40 mm LOCAs in cold leg of the loop 1 (where PRZ is connected) were analysed
- ⇒ 8 analysed cases differed from each other in break sizes, HA functioning and make-up system operation

Table of analysed cases

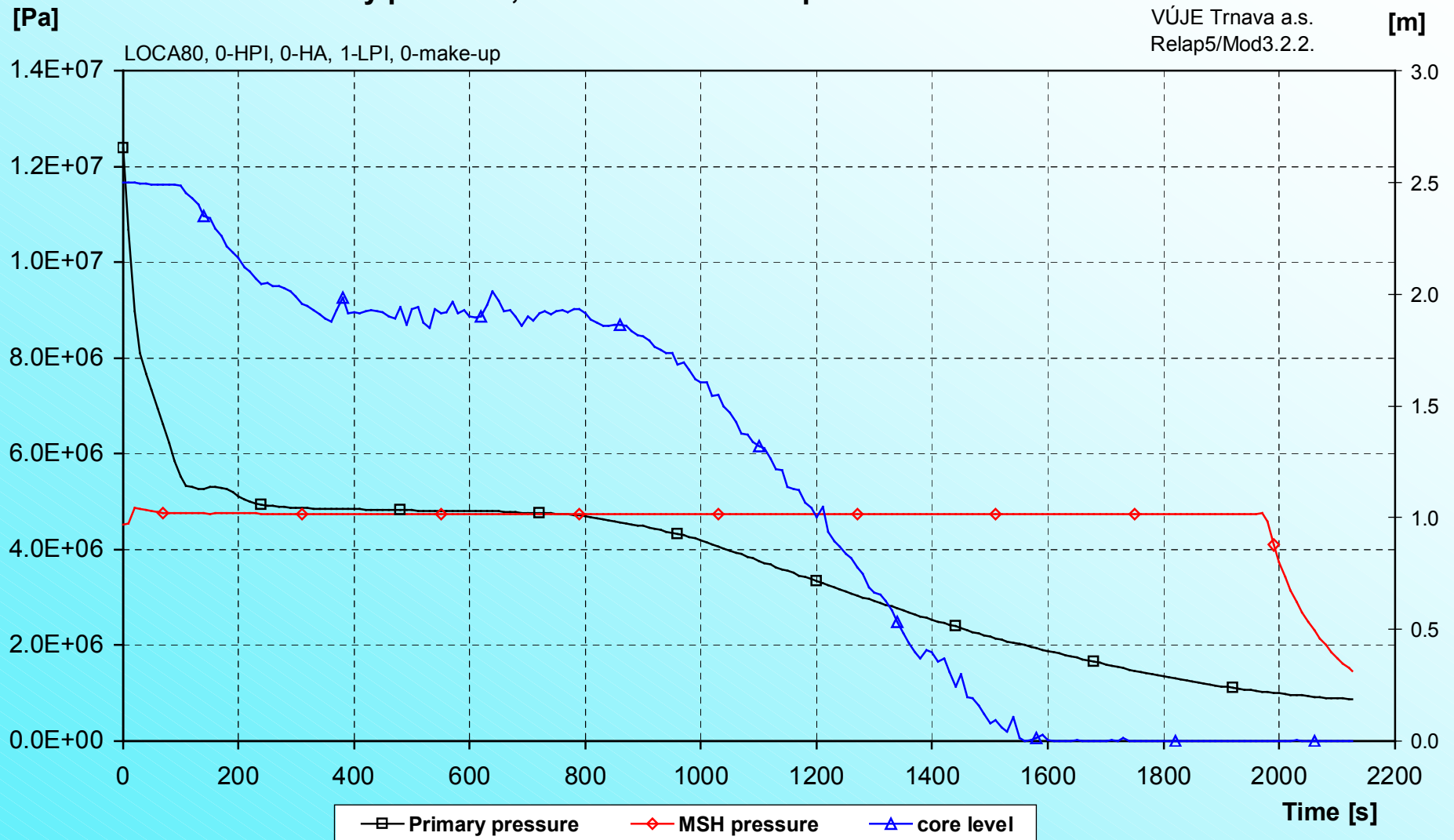
Case identification	H0-x1	H0-x3	H1-x1	H1-x3	I0-x1	I0-x3	I1-x1	I1-x3
Break equivalent diameter [mm]	80				40			
Number of HPI pumps	0	0	0	0	0	0	0	0
Number of HAs	0	0	1	1	0	0	1	1
Number of LPI pumps	1	1	1	1	1	1	1	1
Make-up system start up after $t_{c-c} > 370$ °C	No	Yes	No	Yes	No	Yes	No	Yes

Results of analyses

Event	Case H0-x1		Case H1-x1	
	Time [s]	Value	Time [s]	Value
Initiating event	0	-	0	-
SCRAM Signal „pressure in HZ > 0.108 MPa ^{abs} “	7	-	7	-
Signal „PC pressure < 11.77 MPa and L _{KO} < 3.26 m“	18	-	18	-
Signal „pressure in HZ > 0.118 MPa ^{abs} “ – MCP tripped	20	-	20	-
Primary pressure < 5.89 MPa	89	-	89	-
HA empty	-	-	1440	integ 36.1 t
T_{core-coolant} of core outlet > 370 °C	1333	22.2 min.	3494	58.2 min.
Max. cladding temperature (T _{core-coolant} = 370 °C)	1333	645.0 °C	3494	712.0 °C
Coolant level in core (T _{core-coolant} = 370 °C)	1333	0.57 m	3494	0.88 m
Primary pressure (T _{core-coolant} = 370 °C)	1333	2.79 MPa	3494	1.13 MPa
Minimum of coolant level in core	1610	0.0 m	4185	0.0 m
The first secondary circuit depressurisation	-	-	4034	67.2 min.
Minimum of coolant level in core	-	-	4185	0.0 m
Primary pressure < 0.82 MPa (LPI pump)	-	-	4206	70.1 min.
T_{core-coolant} of core outlet > 550 °C	1627	27.1 min.	4227	70.4 min.
Max. cladding temperature (T _{core-coolant} = 550 °C)	1627	923 °C	4227	1055 °C
Coolant level in core (T _{core-coolant} = 550 °C)	1627	0.0 m	4227	0.2 m
The first secondary circuit depressurisation	1990	33.2 min.	-	-
Primary pressure < 0.82 MPa (LPI pump)	-	-	-	-
Maximum cladding temperature	1824	>1200°C	4230	1056°C
Max. cladding temperature < 200 °C	-	-	4760	79.3 min
End of calculation	2127	-	7200	-

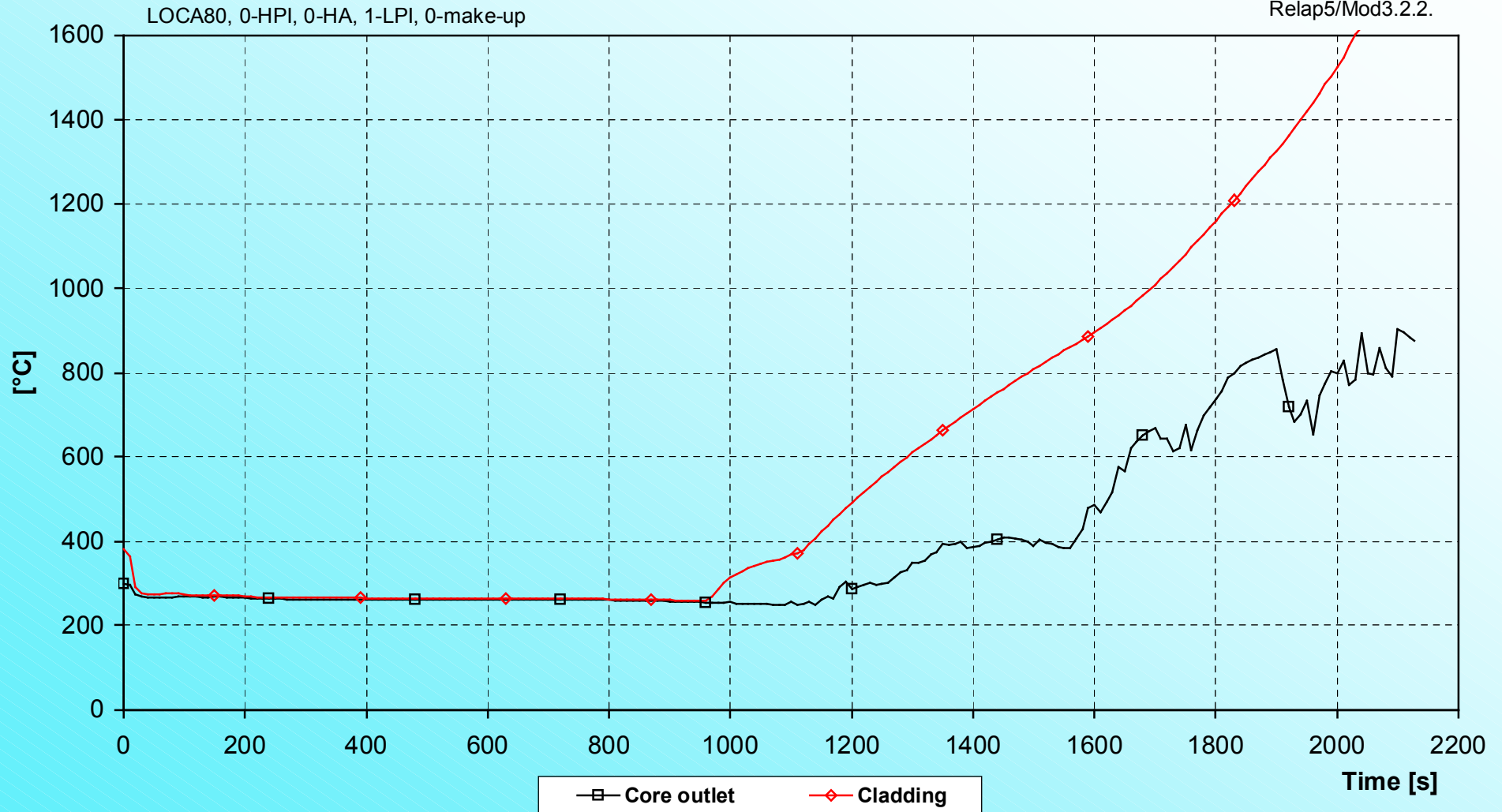
Primary pressure, main steam header pressure and core level

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Core outlet coolant temperature and maximum cladding temperature

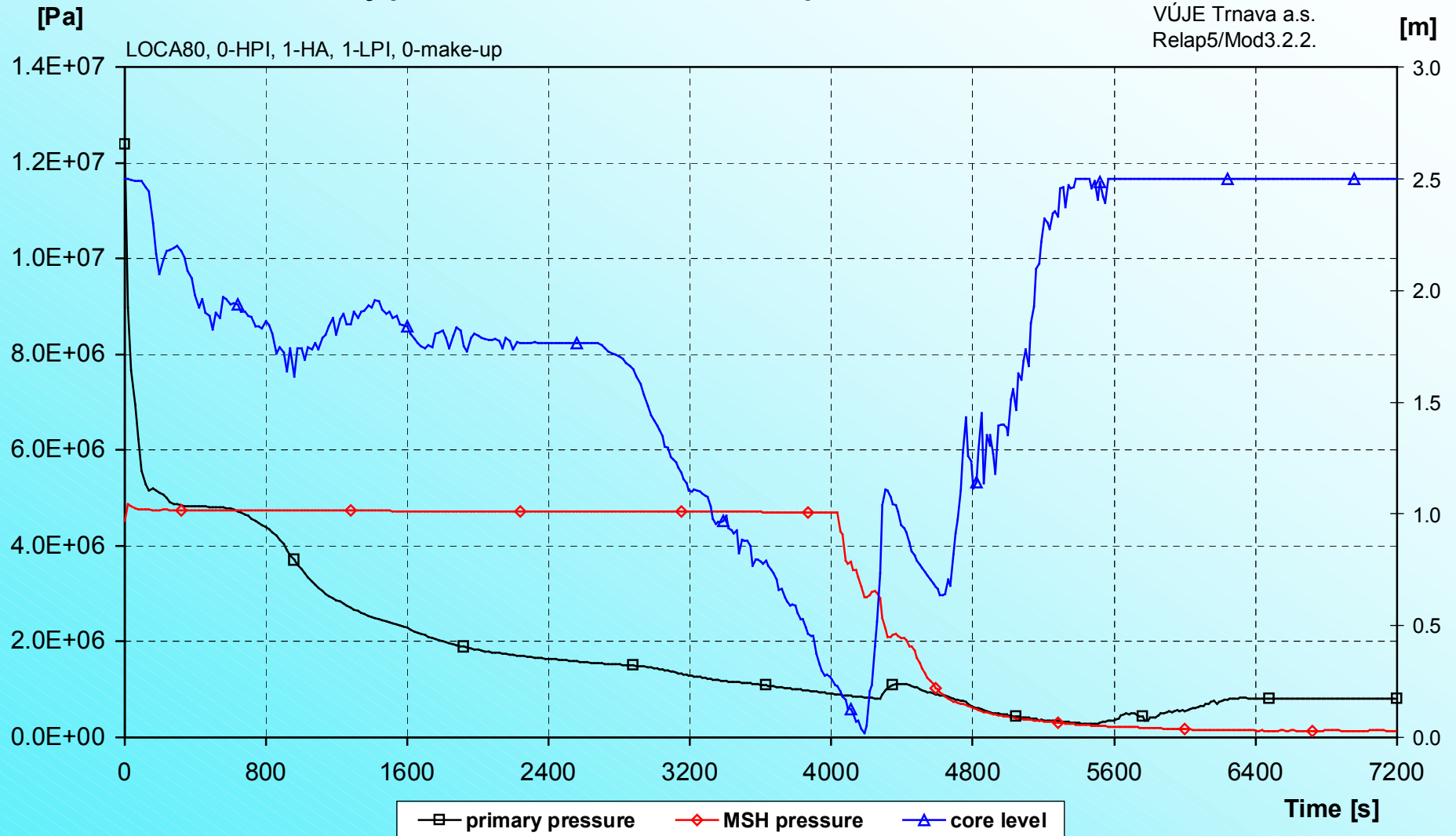
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Results of analyses

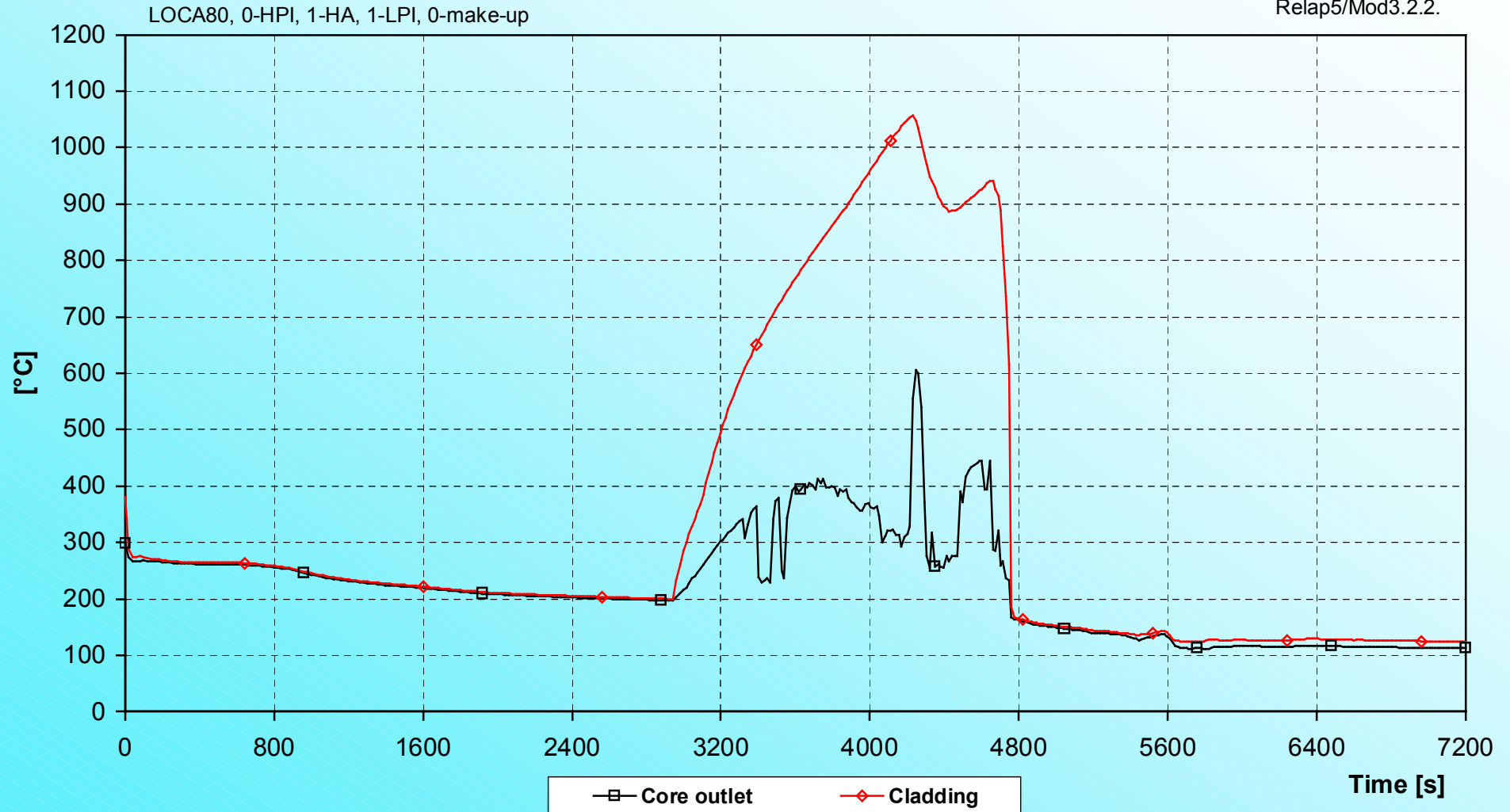
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Maximum cladding temperature	1824	>1200°C	4230	1056°C
Max. cladding temperature < 200 °C	-	-	4760	79.3 min
End of calculation	2127	-	7200	-

Primary pressure, main steam header pressure and core level



Core outlet coolant temperature and maximum cladding temperature

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Results evaluation

Variant	$T_{c-c} > 370\text{ °C}$	Cladding temper. $> 750\text{ °C}$	$T_{c-c} > 550\text{ °C}$	Maxim. cladding temper.	The first operator action	Core state level
H0-x1 ($\phi 80$, 0-HPI, 0-HA, 1-LPI, 0-make-up)	22.2 min	24.0 min	27.1 min	30.4 min $> 1200\text{ °C}$	33.2 min SC depress.	III.
H0-x3 ($\phi 80$, 0-HPI, 0-HA, 1-LPI, 1-make-up)	22.2 min	24.0 min	27.1 min	30.4 min $> 1200\text{ °C}$	33.2 min 1 make-up pump	III.
H1-x1 ($\phi 80$, 0-HPI, 1-HA, 1-LPI, 0-make-up)	58.2 min	59.4 min	70.4 min	70.5 min 1056 °C	67.2 min SC depress	II.
H1-x3 ($\phi 80$, 0-HPI, 1-HA, 1-LPI, 1-make-up)	58.2 min	59.4 min	70.7 min	76.7 min 1086 °C	69.2 min 1 make-up pump	II.
I0-x1 ($\phi 40$, 0-HPI, 0-HA, 1-LPI, 0-make-up)	78.4 min	70.1 min	-	82.1 min $> 1200\text{ °C}$	does not come to it (SC depress.)	III.
I0-x3 ($\phi 40$, 0-HPI, 0-HA, 1-LPI, 1-make-up)	78.4 min	70.1 min	-	82.1 min $> 1200\text{ °C}$	does not come to it (1 make-up pump)	III.
I1-x1 ($\phi 40$, 0-HPI, 1-HA, 1-LPI, 0-make-up)	68.1 min	188.0 min	-	188.3 min 847 °C	77.1 min SC depress.	II.
I1-x3 ($\phi 40$, 0-HPI, 1-HA, 1-LPI, 1-make-up)	68.1 min	-	-	81.2 min 671 °C	79.1 min 1 make-up pump	I.

Results evaluation - cont'd

- ⇒ **1 HA is available (H1-x1, H1-x3, I1-x1, I1-x3) - core damage is not predicted. The operator action is effective from point of view of core cooling**
- ⇒ **H1 cases (1 HA a LOCA ϕ 80)**
 - HA is empty before the first operator action
 - after HA emptying, core outlet temperature starts to grow but secondary circuit depressurisation and consequently primary pressure drop below 0.82 MPa leads to LPI pump start up

Results evaluation - cont'd

⇒ **1 HA is not available (H0-x1, H0-x3, I0-x1, I0-x3) - core damage is not predicted. The operator action is effective from point of view of core cooling**

- rapid increase of core outlet coolant temperature as well as cladding temperature
- operator cannot realise the first action sooner as 9 min from time when the core outlet coolant temperature reaches 370 °C
- H0 cases (H0-x1, H0-x3) - time interval between point when the core coolant outlet temperature reaches 370 °C and point when maximum cladding temperature equals 1200 °C is only 8.2 min.
- I0 cases (I0-x1, I0-x3) - time interval between point when the core coolant outlet temperature reaches 370 °C and point when maximum cladding temperature equals 1200 °C is only 3.7 min

Results evaluation - cont'd

⇒ **no substantial differences were found when 1 make-up pump starting was assumed as the first operator action instead of secondary circuit depressurisation**

- if SC depressurisation was effective then 1 make-up pump starting was effective too (H1-x1 and H1-x3; I1-x1 and I1-x3)
- if SC depressurisation was not effective then 1 make-up pump starting was not effective too (H0-x1 and H0-x3; I0-x1 and I0-x3)

Results evaluation - cont'd

⇒ **efficiency of two main circulation pumps start-up from point of view of core cooling is disputable. Operator can put into operation MCP only when the previous steps do not lead to core cooling recovery.**

- 1 HA is available - operator action is effective and LPI pump operating ensures core cooling. There is no reason to start-up of main circulation pumps
- 1 HA is not available - core damage is predicted before the first operator action and, likewise, there is not reason to start-up of main circulation pumps

Conclusion

The results of LOCA 80 and 40 mm analyses indicate that operator action in term of core cooling is effective in case where 1 HA and 1 LPI pump are available. After reaching core outlet coolant temperature of 370 °C, operator action leads to core cooling recovery and cladding temperature does not exceed 1200 °C. In the case where only 1 LPI pump is available and none HA and HPI pump is assumed, operator steps are not effective from the point of view of core cooling recovery and cladding temperature exceed 1200 °C. Core outlet coolant temperature equal to 370 °C or 550 °C is too high as criterion for execution of effective steps leading to the core cooling recovery.

THE END

Thank you for your attention