International Meeting on Equipment Qualification
In Nuclear Installations
UJV Rez, Czech Republic
May 20 – 23, 2019

Equipment testing
for severe accident conditions

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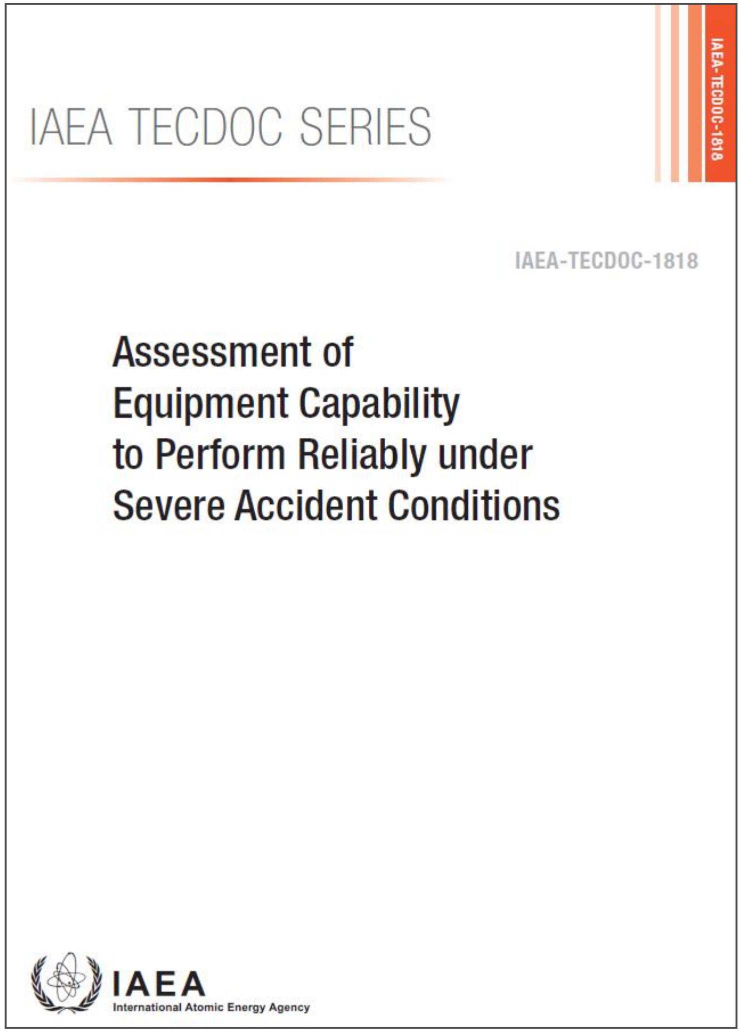
Equipment Testing upon design extension conditions.

- extended station black out,
- extreme natural hazards
- severe accident.

No standards, rules, recommendations, guides for testing.


IAEA TECDOC SERIES

IAEA-TECDOC-1818

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Assessment of
Equipment Capability
to Perform Reliably under
Severe Accident Conditions

IAEA
International Atomic Energy Agency

Assessment of Equipment Capability to Perform Reliably under Severe Accident Conditions, IAEA-TECDOC-1818, July 2017

Short history of SA testing at ÚJV Řež

Requirement to test equipment for Design Extension Conditions:

- Air plane crash, first time in 2009
- Hydrogen burning, first time in 2011
- SA accident dose + SA thermodynamic profile, first time in 2013

Testing procedure

Severe accident testing is based on same qualification process used for DBE qualification as described in international standards (e.g. IEC/IEEE 60780-323) or IAEA documents.

The main differences are following:

- They do not exist specific standards and rules for SA testing.
- The SA environmental conditions may be different comparing to DBE, e.g. hydrogen combustion. This may bring some technical complication with simulating.
- Large uncertainties affecting severe accident phenomena modeling.
- The acceptance criteria may differ.

Mission time and safety function

Mission time

How long the equipment is expected to be in operation.

All the time, action at the beginning, action at the end?

Safety function

It can be only **passive**, like prevent radioactive material release outside containment (cable penetrations)

or **active** like sensors that need work all the time. Need to be proved the functionality during whole SA.

Equipment, that is **active only during a short period** of time (e.g. valve opening).

Loading (electric, pressure)

Limiting el. loading, switch to batteries, overpressure

ACCEPTANCE CRITERIA

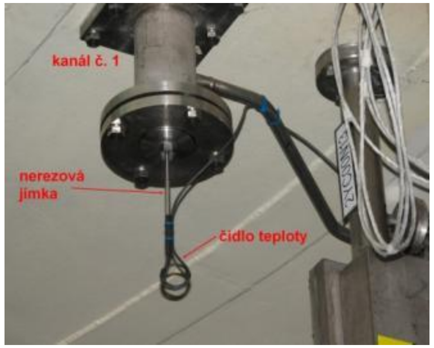
For example**, instrument accuracy during severe accident may be of less importance than trend indication**.

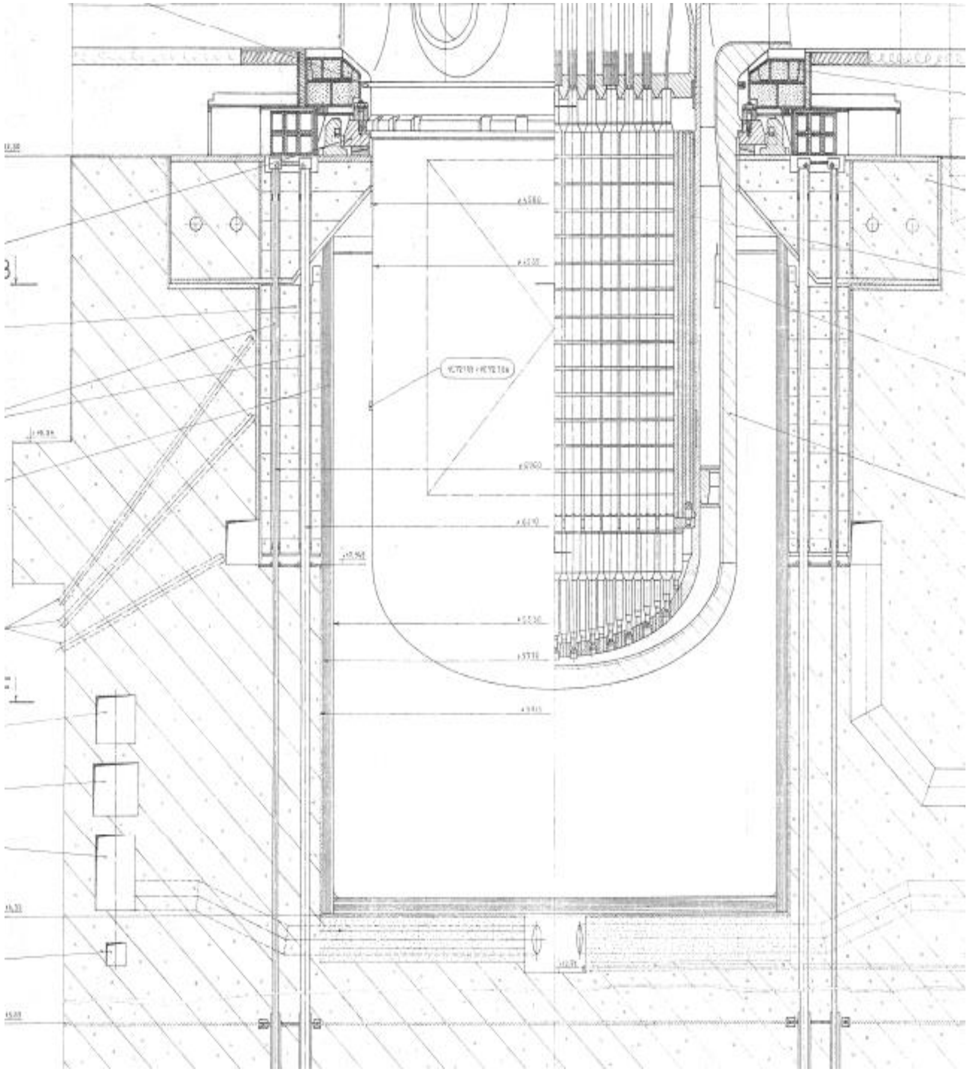
More important is **instrument functionality and availability in long term**. In most cases the instrumentation might not be replaced during and after a severe accident.

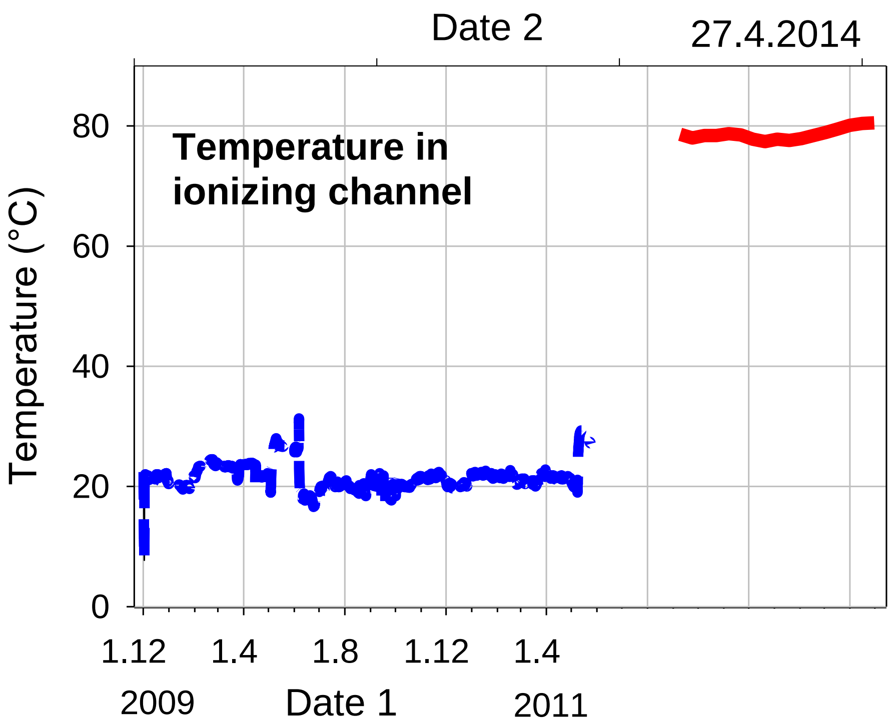
The **reliability on functionality** of the equipment is essential for the strategy to mitigate the effects of a severe accident by for instance opening or closing valves, starting pumps, electrical conductivity, containment penetration integrity etc.

Temperature measurement in ionizing channel

Long-term reliable measurement





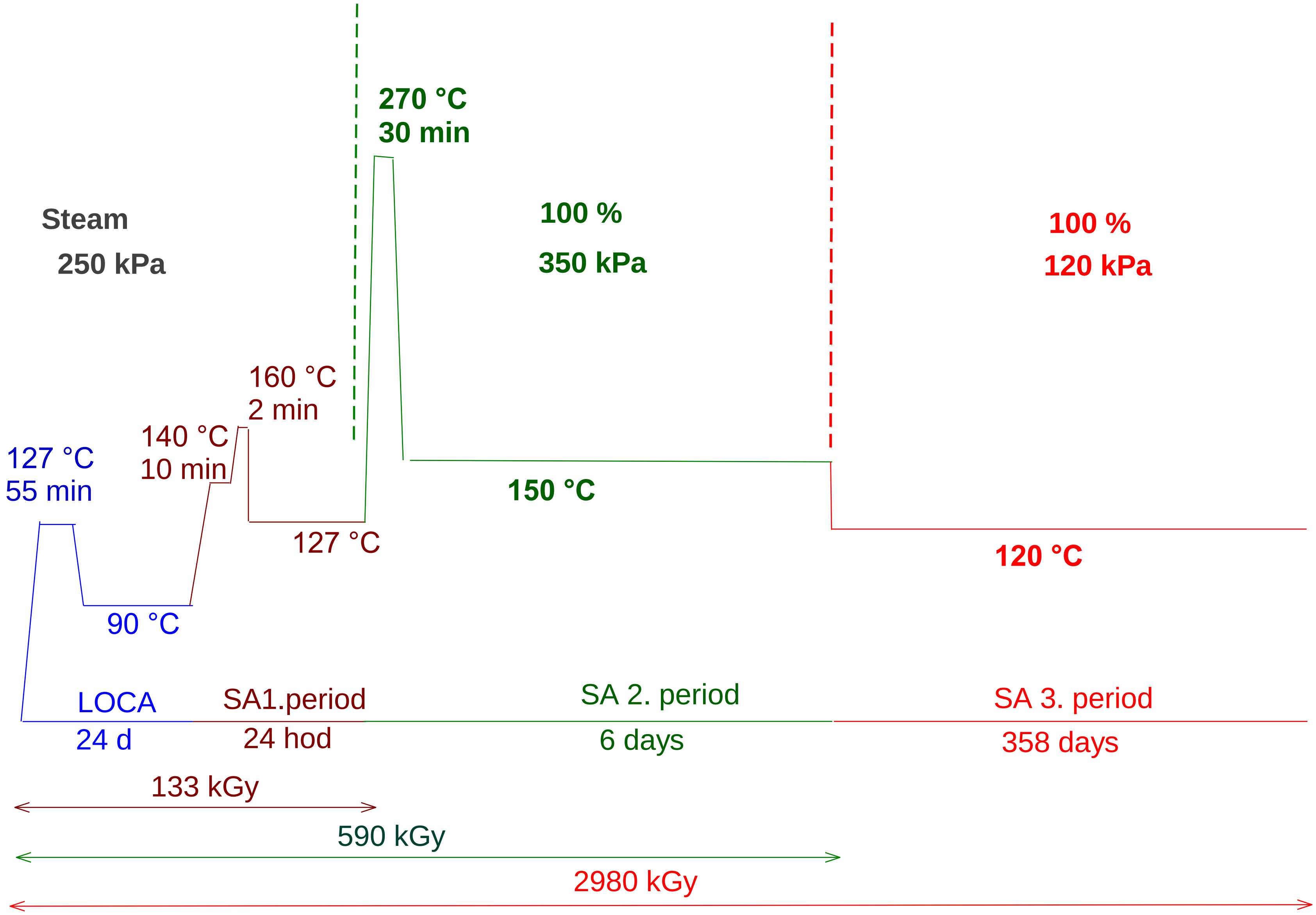


SA – Environmental parameters

- Radiation; beta, gamma, neutrons, change of energy with accident progress, dose rates, doses of individual contributors, total integrated dose
- Temperature; profile for the whole accident
- Pressure; whole long term pressure profile, impulse pressure
- Fire if any,
- Atmosphere; steam, overheated steam

Environmental parameters

- Flooding; how long is equipment flooded, at which temperature pressure, water level
- Hydrogen combustion and other explosive gases; temperature and pressure increase during such a phenomena
- Chemical processes; chemical spray solution, composition during flooding, smoke
- Vibration; internal and/or external origin
- Strategy to mitigate accident (water injection)



Steam
250 kPa
270 °C
30 min
100 %
350 kPa
100 %
120 kPa
160 °C
2 min
140 °C
10 min
127 °C
55 min
150 °C
127 °C
120 °C
90 °C
LOCA
24 d
SA1.period
24 hod
SA 2. period
6 days
SA 3. period
358 days
133 kGy
590 kGy
2980 kGy

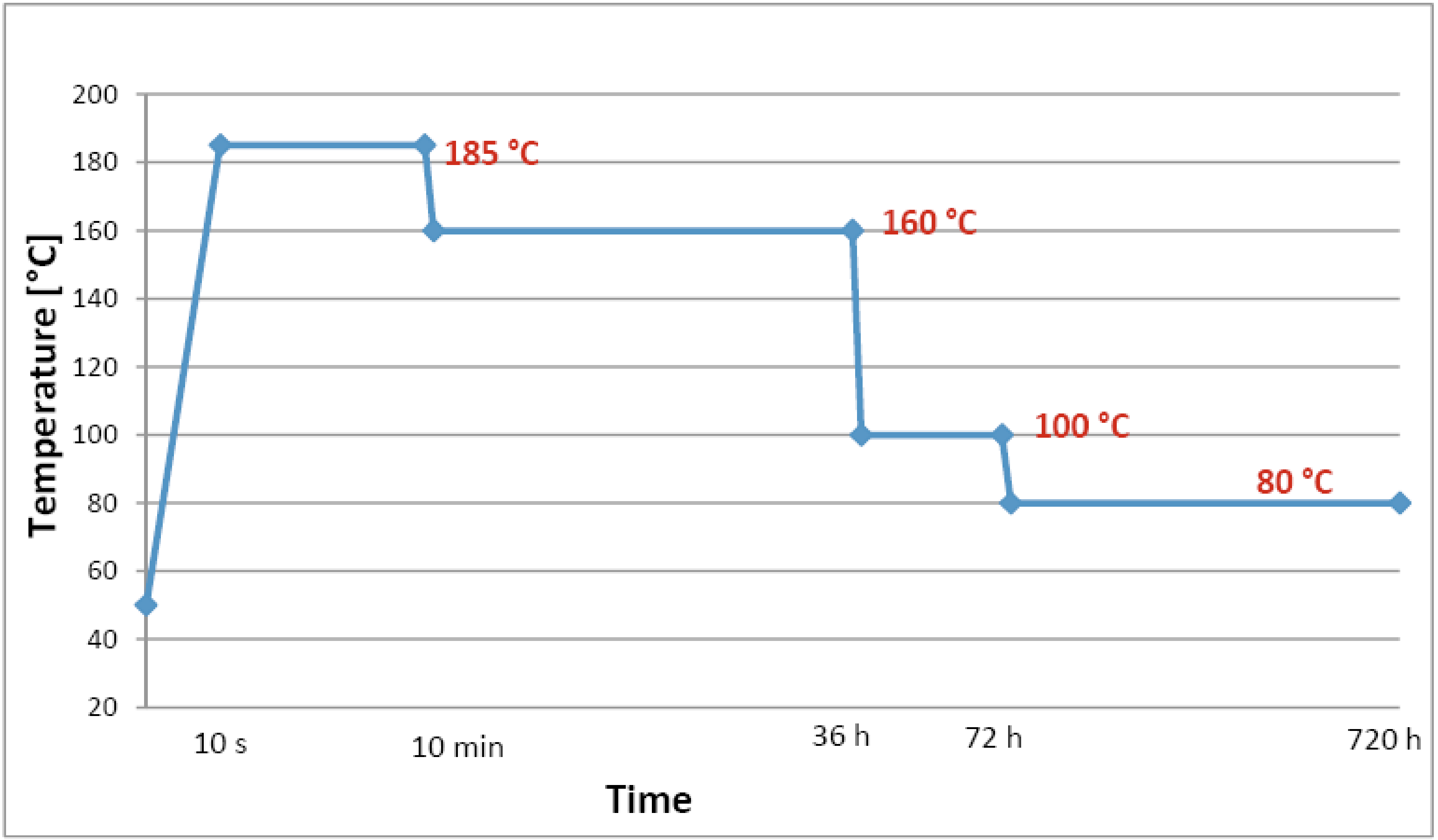


Figure 1: Generic test profile for the gas temperature in the reactor containment after a severe accident.

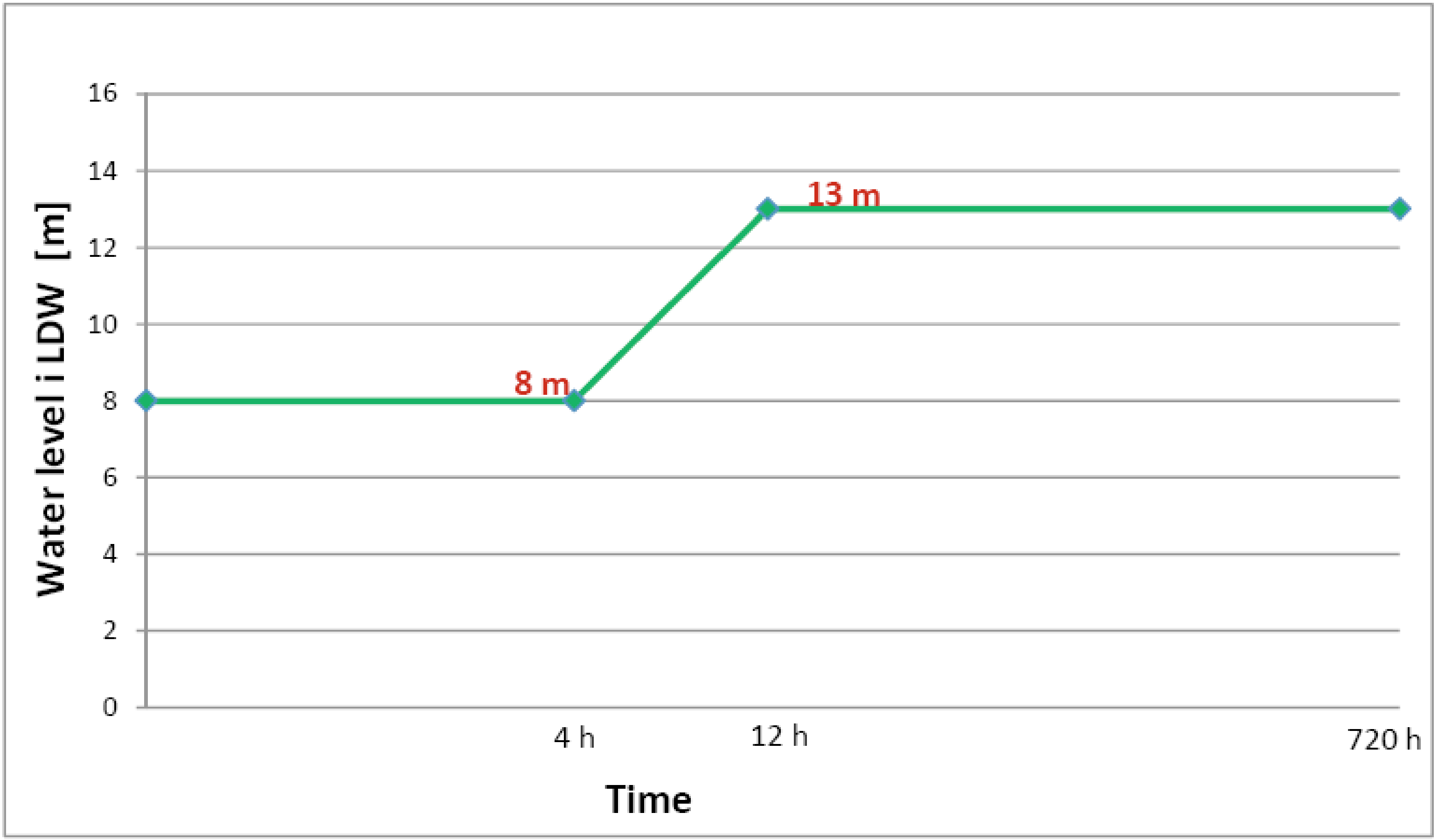
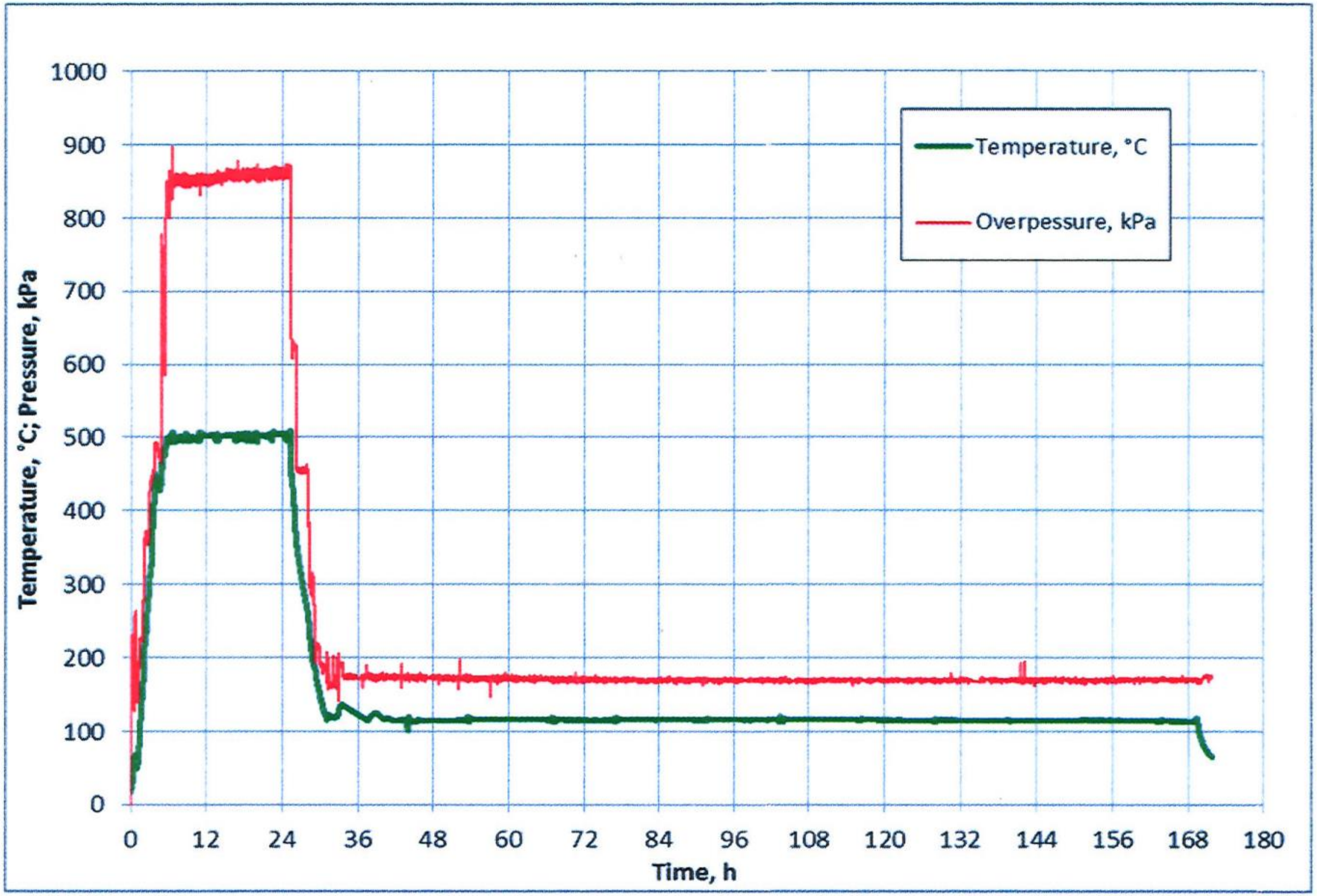


Figure 3: Generic water level profile in the reactor containment after a severe accident.



Temperature, °C; Pressure, kPa
1000
900
800
700
600
500
400
300
200
100
0
0
12
24
36
48
60
72
84
96
108
120
132
144
156
168
180
Time, h
Temperature, °C
Overpessure, kPa

T/P profile simulation

- **Shall we apply margin on T/p/t:**
  E.g. temperature margin for LOCA is +8 °C. Typically +1.5 °C is added due thermometer uncertainty (i.e. +9.5 °C).
- **Post accident period** 1 - 3 years, how to accelerate, simultaneous action of temperature, pressure, chemical systems, electric. Loading
- **Sequence of testing**:
  - LOCA followed by SA (i.e. is LOCA initial event for SA)
  - only LOCA and only SA
  - seismic simulation – shall be simulated before SA

Accident and post-accident simulations

Following the accident, a post accident period in submerged conditions has to be simulated. This may take 1 year and even more. Such a long period needs to be accelerated.

This is (commonly) achieved using the Arrhenius approach at elevated temperature.

Several questions about appropriate time for simulation. How to accelerate the test. What is the minimum time for testing?

Accident and post-accident simulations

During this test, the equipment (e.g. cables) shall be loaded with appropriate voltage and current.

Influence of voltage on cables in spray solution at elevated temperature.

Accident dose irradiation

During accidents, the equipment is also exposed to:

- **gamma**
- **beta**
- **neutron radiation**

Chinese AP1000

Total dose **3 100 kGy**, 2 700 kGy from beta (87 %) and 400 kGy from gamma (13 %)

Mochovce NPP, VVER 440

Total dose up to **2980 kGy**, beta contribution is not mentioned

J.Bohunice NPP, VVER 440

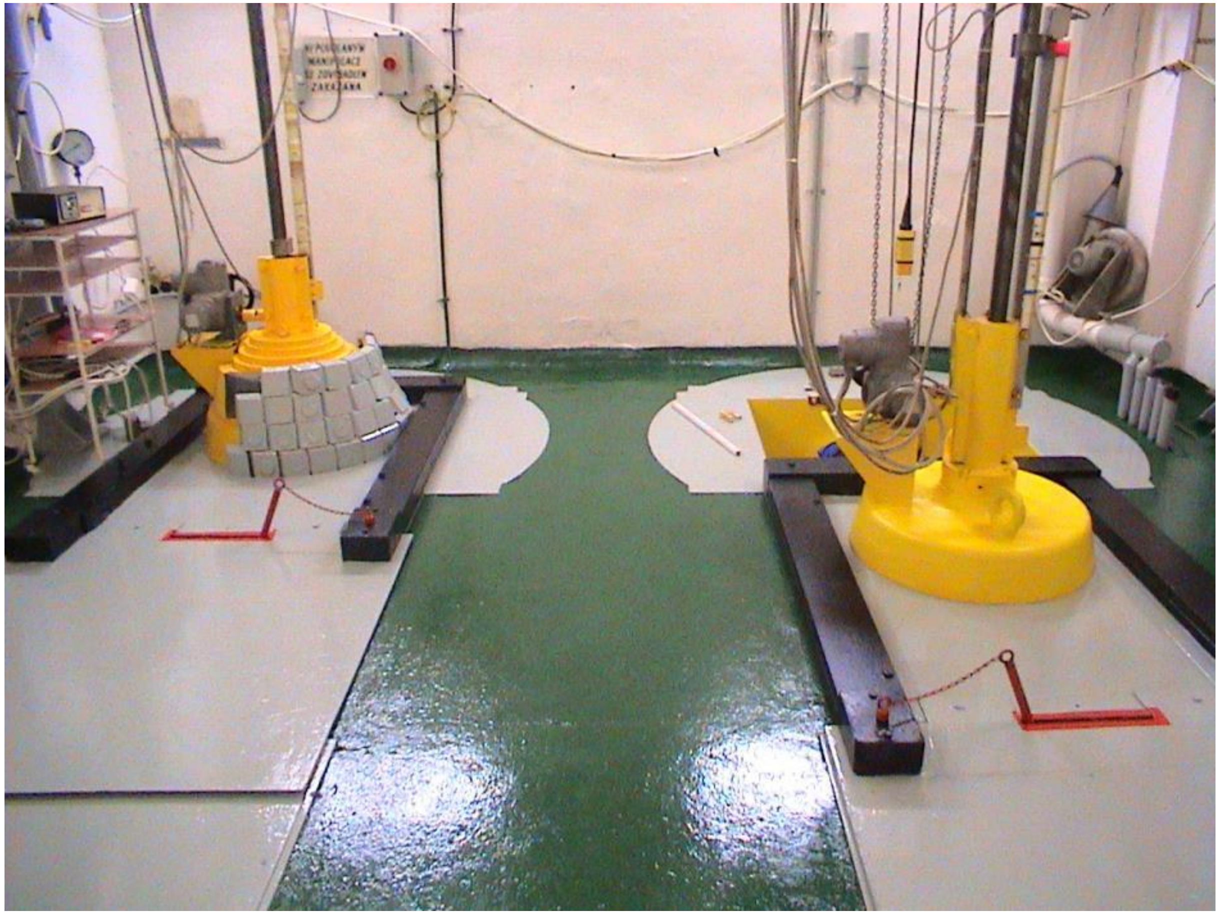
Total SA dose **135 kGy.**

Japan

BWR up to **5 000 kGy**, PWR up to **2 000 kGy**

Accident dose, beta vs. gamma

Electron beam accelerator for beta irradiation



Two gamma irradiation facilities

MARGIN

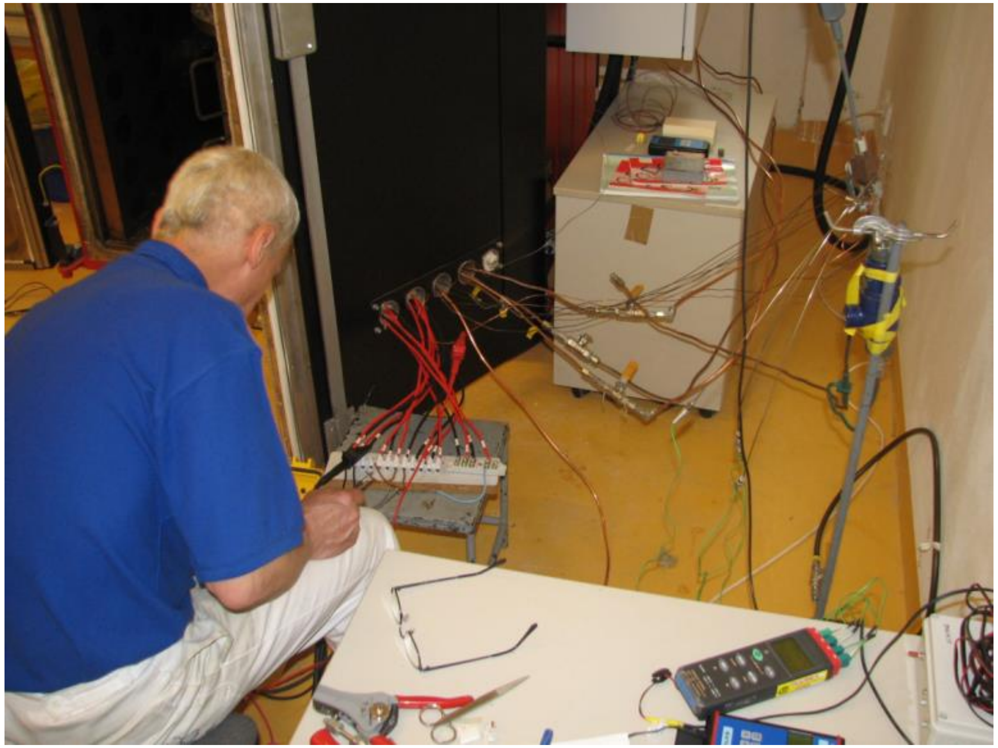
The standards and international guides recommend **margins to apply during DBE** service conditions.

But severe accident conditions do not necessarily apply these margins, do not require the same rigorous demonstration and the same conservatism a standard qualification process.

The SA condition are often quite “hard” and increasing the severity due to margin application (typically + 8 °C) may be demanding.

Total dose + 10 %: 3300 kGy + 10% gives 3630 kGy

Some NPP apply the margins to the SA profile.
Some NPP do not require margins, as it is not stated in Standards.



SUMMARY

The equipment dedicated to severe accident mitigation need to be tested.

The anticipated environmental conditions during DBE are well defined in the plant safety analysis, environmental loading conditions, profiles and test procedures experienced in **severe accidents are not addressed yet.**

SUMMARY, Issues

Some issues concerning the SA testing procedure are following:

- Quite clear rules and regulations. There is not wide spreading agreement how to test the equipment for SA conditions.
- Knowledge of the environmental parameters during SA that shall be simulated. In some cases, the procedure may be quite complicated and new test procedures have to be developed. For example, the case of hydrogen combustion.

SUMMARY, issues

- The required mission time may be quite long, more than 1 year. Simulation needs to be accelerated to achieve reasonable testing time. Nevertheless, models and procedures need to be developed. Minimum testing time is 30 days???
- Simulation of irradiation conditions with the definition the role of gamma, beta and neutron irradiation. Moreover, the energies of the irradiation and the dose rates dramatically change during the SA. Therefore, the influence of the irradiation on the equipment change.
- Acceptance criteria could differ from the criteria for DBA.
- Qualification margin need to be defined, if any. Standards recommend some margins for DBA. However margins for SA should be developed.

SUMMARY, issues

- LOCA and SA or only LOCA + only SA on separate samples
- Seismic test. Perform a seismic test before SA? Or more samples, one for seismic only and another for SA.

Thank you for your attention

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