ÚJV Řež, a. s.

Severe accidents: definitions, parameters calculations & equipment qualification

Miroslav Kotouč
Jiří Duspiva
Tomáš Janda
Dept. of Severe Accidents and Thermomechanics

**Equipment Qualification in Nuclear Installations,
20-23 May 2019, UJV Rez, CZECH REPUBLIC**

UJV Group
TECHNOLOGY I INNOVATION I PEOPLE

Outline

1. Definition of a severe accident (SA)
2. Processes in the course of a SA
3. Management & mitigation of SAs
4. Structures, systems & components (SSC) during a SA
5. Codes for SA analyses
6. Assessment of outcomes of SA analyses
7. Equipment qualification for SAs

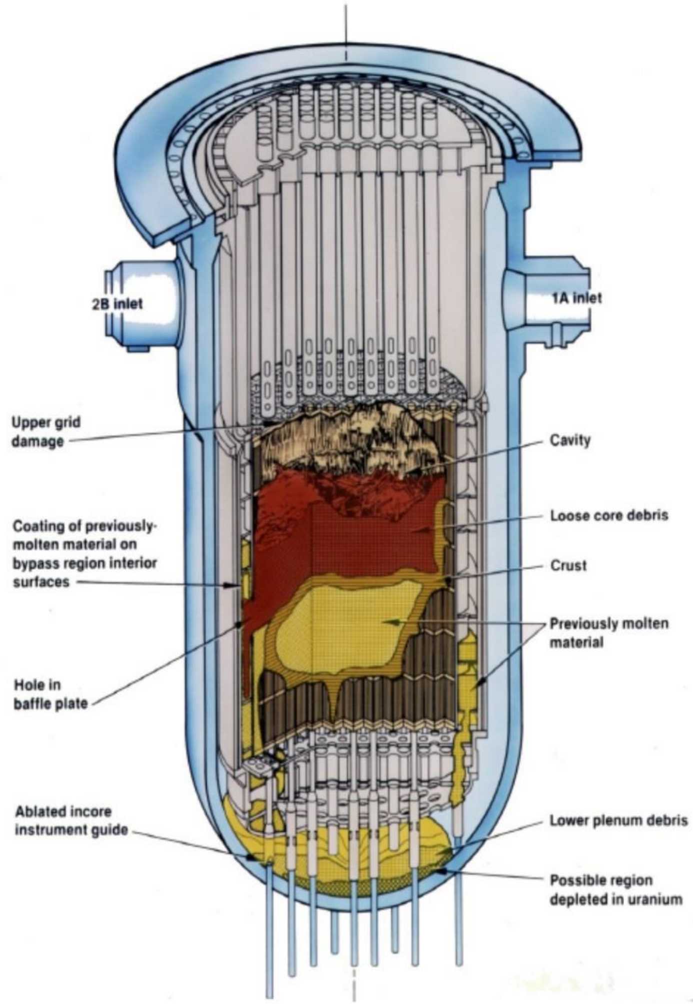
UJV Group
TECHNOLOGY I INNOVATION I PEOPLE

SA definition

- Severe accident
  - "Accident with substantial core damage"

- Former terminology
  - Design basis accidents (DBAs)
  - Beyond design basis accidents (BDBAs)
    - incl. SAs

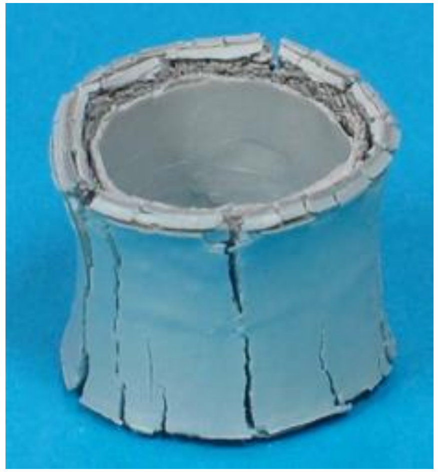
- Actual terminology (IAEA, WENRA)
  - Design basis conditions (DBCs)
  - Design extension conditions (DECs)
    - DEC-A – complex sequences (w/o core melt)
    - DEC-B – SAs (core melt)



UJV Group
TECHNOLOGY I INNOVATION I PEOPLE

Processes in the course of a SA (1)

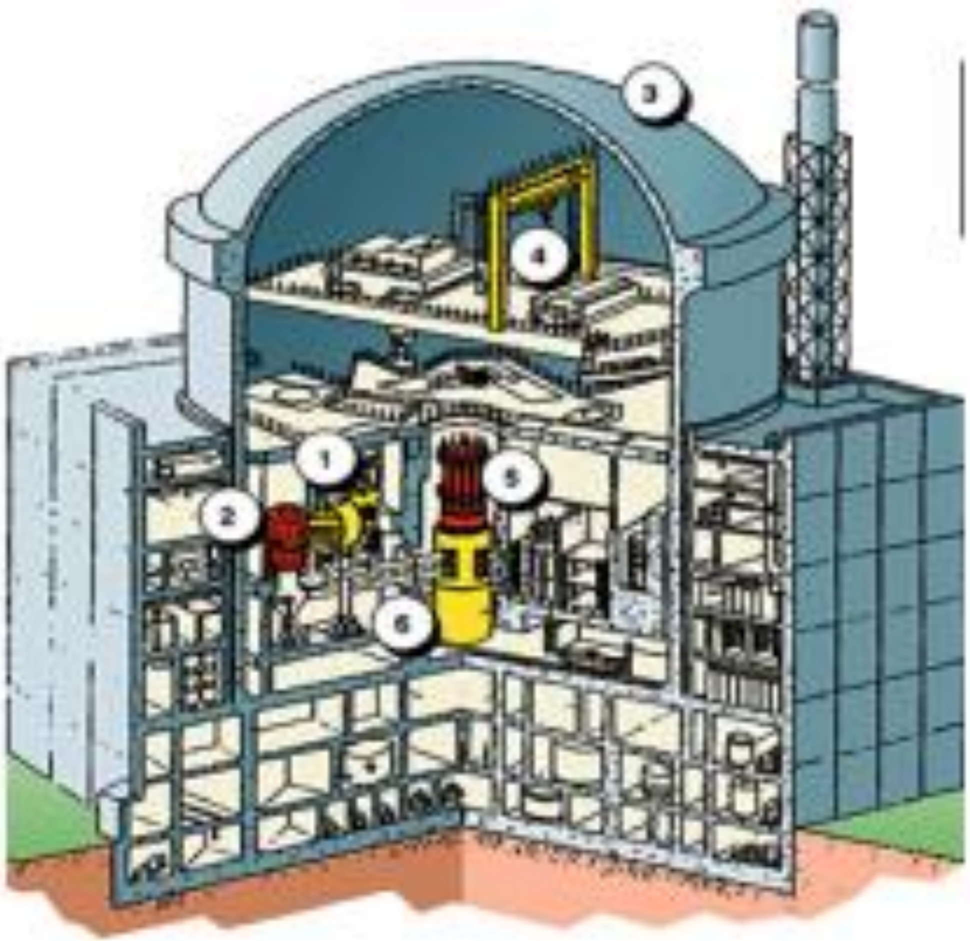
- Unmitigated SA
  - Phase just after an initiating event (IE) – identical to DBAs
    - initiated by e.g. loss of cooling accident (LOCA), station black-out (SBO)...
  - Core degradation = consequence of the absence of core cooling
    - Cladding oxidation – exothermic process, H_2 production
    - Cladding rupture – release of gaseous and highly volatile fission products (FPs)
    - Loss of fuel geometry – release of moderately volatile FPs
    - Fuel relocation into the lower plenum (LP) ⇨ reactor pressure vessel (RPV) ablation ⇨ RPV integrity loss ⇨ debris/molten materials (corium) release into the reactor cavity
      - High-pressure melt ejection (HPME) – aerosols dispersion into the containment (CTMT) volume
      - Low-pressure melt ejection – "slow" release of debris/corium into the pit
    - Molten core-concrete interaction (MCCI) – release of non-volatile FPs, H_2 production



UJV Group
TECHNOLOGY I INNOVATION I PEOPLE

Processes in the course of a SA (2)

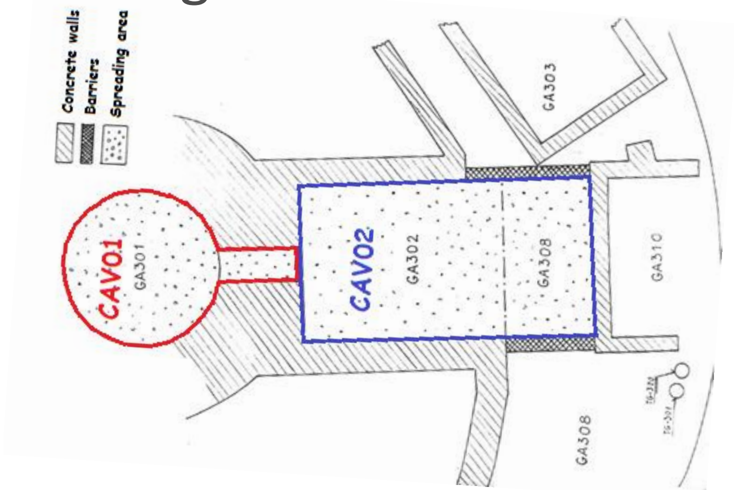
- Challenges for the CTMT
  - Pressurization – steam, H_2 and non-condensable gases
  - Over-heating
  - Radiation – gaseous FPs, aerosols & vapors

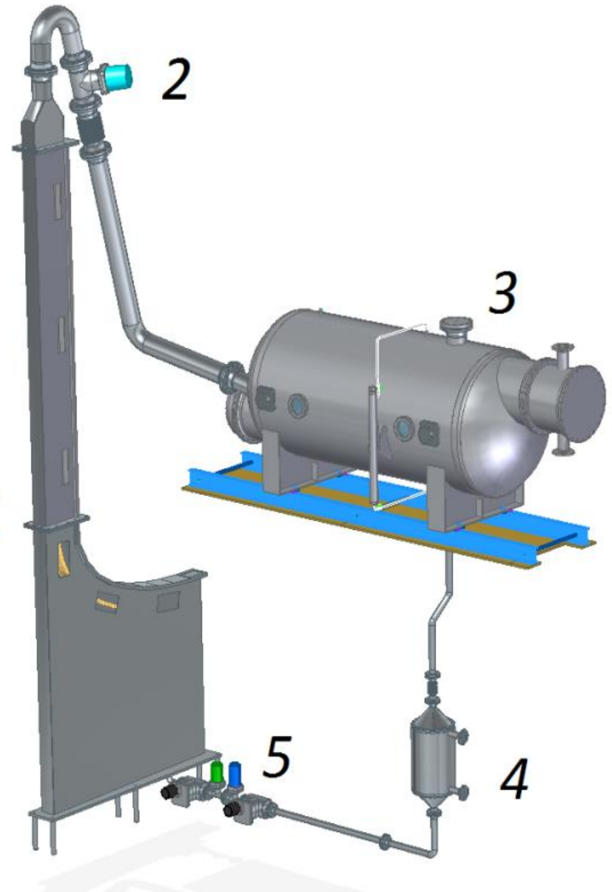


UJV Group
TECHNOLOGY I INNOVATION I PEOPLE

Management & mitigation of SAs

- SA management (SAM)
  - Coolant injection into the core
  - Corium confinement:
    - In-vessel melt retention (IVMR)
    - Ex-vessel corium cooling
  - Long-term CTMT heat removal
  - Over-pressurization mitigation measures
  - FPs confinement





- SSCs intended for the above-mentioned functions:
  - Need of qualification?
  - To which conditions?

UJV Group
TECHNOLOGY | INNOVATION | PEOPLE

SSCs during a SA

(1)

- Question? which SSCs are being used in the course of SAs? For:
  - Unmitigated SAs vs.
  - SAs with SAM application
- Answer! determined by the SA evolution
  - A *bunch* of scenarios must be analyzed

- SSCs used in the course of SAs:
  1. ***Systems for physical parameters/plant state measurement***
  2. ***Components for SA mitigation***
     - Primary circuit (PC) depressurization measures
     - Systems for in-core coolant injection
     - Passive autocatalytic recombiners (PARs)
     - Core-catcher
     - Valves
     - Mobile devices

UJV Group
TECHNOLOGY I INNOVATION I PEOPLE

SSCs during a SA

(2)

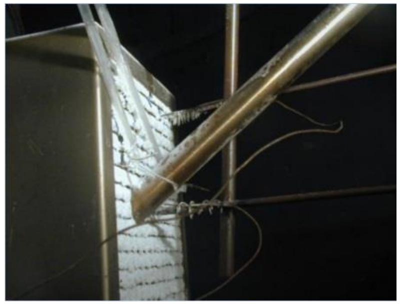
1. Systems for physical parameters/plant state measurement

- Core exit temperature (CET) – used for determination of the entrance into SA management guidelines (SAMGs)
  - Low range; will be destroyed after core degradation onset; no qualification
- PC loops temperatures – used for determination of the entrance into SAMGs
  - Low range; will be destroyed after core degradation onset; no qualification
- Liquid level in spent fuel pool (SFP), steam generators (SGs), CTMT – sump
  - Possibility of clogging ⇨ measurement devices need to be qualified
- Pressure in the CTMT – qualified for DBCs, wider range in SAs
- H_2 concentration in CTMT – qualified for DBCs, wider range in SAs; low O_2 conc.!!!
- Dose rate in CTMT
  - Data acquired during normal operation, in SAs used alternatively if CET unavailable
  - Qualification to higher ranges of dose rates (to capture EOPs ⇨ SAMGs)
- Radioactivity (RA) release into environment
  - Outside CTMT; no qualification

- Generally: qualification needed for cables and those devices which help to identify whether a certain system's operation is hampered by clogging

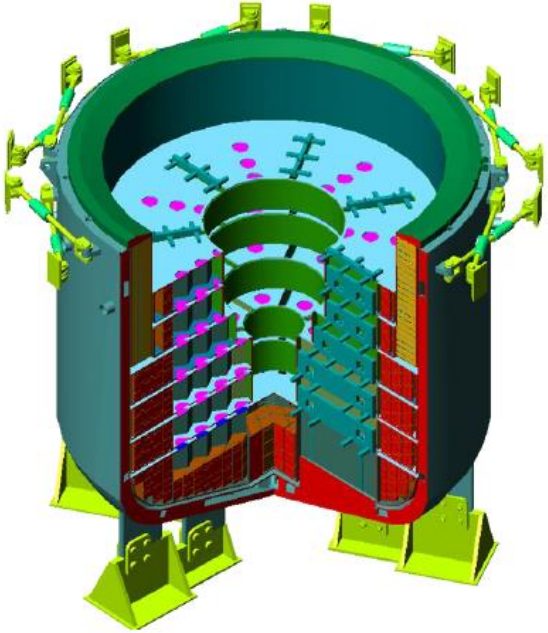
UJV Group
TECHNOLOGY | INNOVATION | PEOPLE

SSCs during a SA



2. Components for SA mitigation

- PC depressurization – PORV, SRV
  - Periodical operation, very hot gases carrying aerosols
- Systems for in-core coolant injection
  - Localized outside the CTMT, however, water intake from the sump ⇨ liquid is likely to contain much aerosols
- PARs
  - Designed for SAs
- Core-catcher
  - Designed for SAs
- Valves
  - Steam dump to atmosphere valve
- Mobile devices
  - Located outside the CTMT



- Generally: qualification needed in order to be able to carry out the required functions during SAs

Codes for SA analyses (1)

- Integral codes
  - IE ⇨ SA progression ⇨ FPs release into environment (source term; ST)
  - "Lumped parameter" approach
  - FPs behavior (release from fuel ⇨ transport in circuits ⇨ behavior in CTMT ⇨ ST)
  - FPs grouping into "classes"
    - Similar chemical behavior

Class	Class Name	Chemical Group	Representative	Member Elements
1	XE	Noble Gas	Xe	He, Ne, Ar, Kr, Xe, Rn, H, N
2	CS	Alkali Metals	Cs	Li, Na, K, Rb, Cs, Fr, Cu
3	BA	Alkaline Earths	Ba	Be, Mg, Ca, Sr, Ba, Ra, Es, Fm
4	I2	Halogens	I_2	F, Cl, Br, I, At
5	TE	Chalcogens	Te	O, S, Se, Te, Po
6	RU	Platinoids	Ru	Ru, Rh, Pd, Re, Os, Ir, Pt, Au, Ni
7	MO	Early Transition Elements	Mo	V, Cr, Fe, Co, Mn, Nb, Mo, Tc, Ta, W
8	CE	Tetravalent	Ce	Ti, Zr, Hf, Ce, Th, Pa, Np, Pu, C
9	LA	Trivalents	La	Al, Sc, Y, La, Ac, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Am, Cm, Bk, Cf
10	UO2	Uranium	UO_2	U
11	CD	More Volatile Main Group	Cd	Cd, Hg, Zn, As, Sb, Pb, Tl, Bi
12	AG	Less Volatile Main Group	Ag	Ga, Ge, In, Sn, Ag
13	BO2	Boron	BO_2	B, Si, P
16	CSI	Cesium iodide	CsI	CsI
17	CSM	Cesium Molybdate	CsM[1]	CsM[1]

- Main integral codes:
  - **MELCOR**
    - Sandia National Laboratories
    - for US Nuclear Regulatory Commission
  - **ASTEC**
    - IRSN+GRS
  - **MAAP5**
    - for EPRI
  - **SOCRAT**
    - IBRAE

UJV Group
TECHNOLOGY | INNOVATION | PEOPLE

Codes for SA analyses (2)

- Main output variables from SA computational analyses in relation with EQ – temporal evolution of:
  - *p* in CTMT
  - *T* in CTMT
  - Gas composition entering the CTMT or environment
  - Humidity in the CTMT
  - Surface *T* of solid structures
  - Occurrence of deflagrations
  - FPs distribution

- Still missing as an outcome from integral SA analyses:
  - Dose rates acting on SSCs
  - Recent analyses at UJV Rez:
    - MELCOR analysis ⇨ FPs distribution in the reactor hall of VVER-1000 reactor CTMT ⇨ MCNP5 evaluation of dose rate at 2 spots (RA measurement probes)
      - for a SA in open reactor & SFP (no CET measurement): EOPs ⇨ SAMGs
    - MELCOR analysis ⇨ FPs distribution in the reactor hall of VVER-1000 reactor CTMT ⇨ MAVRIC/ORIGEN-S evaluation

UJV Group
TECHNOLOGY I INNOVATION I PEOPLE

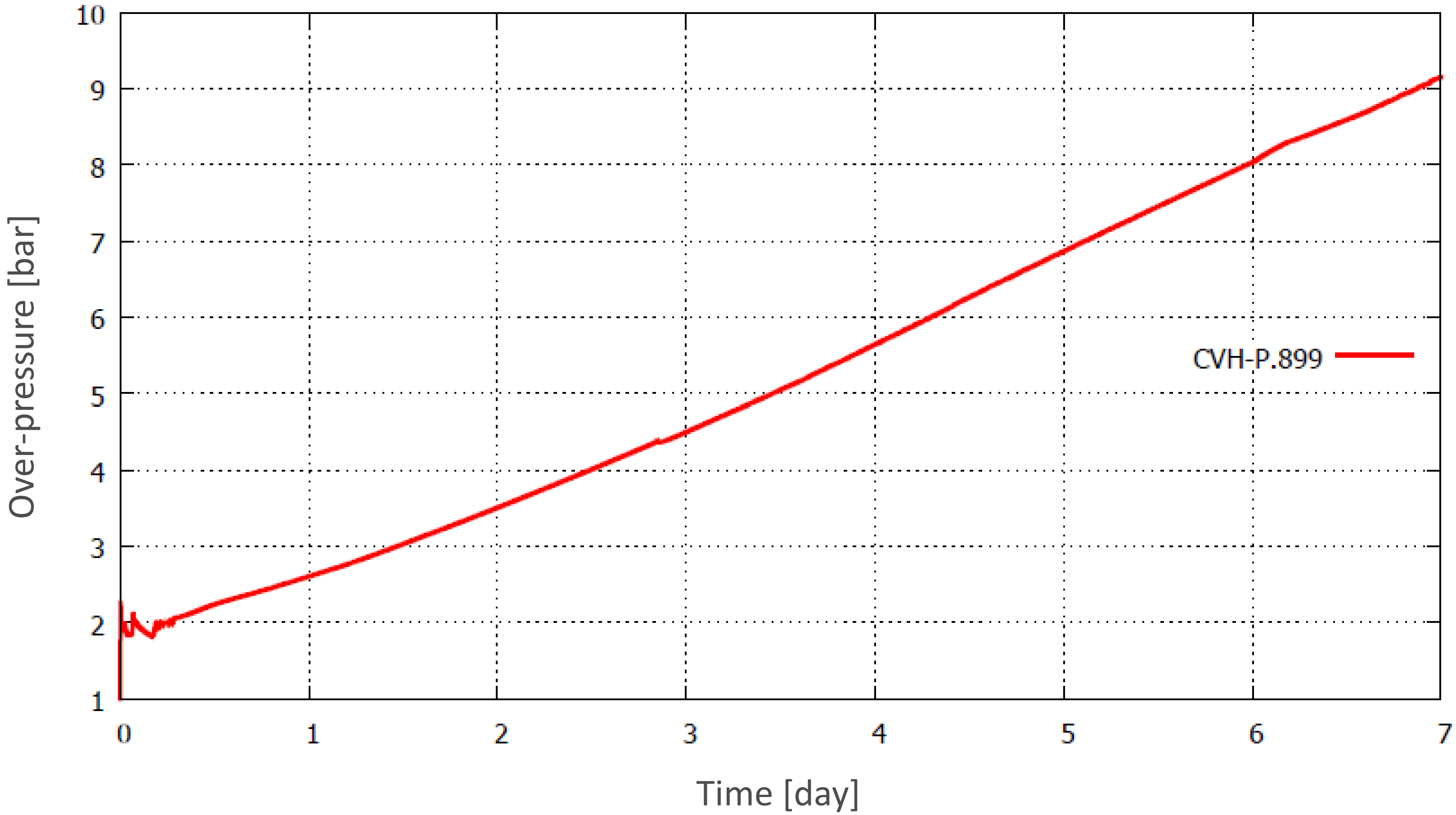
Assessment of outcomes of SA analyses (1)

- Typical temporal evolution of crucial parameters for an unmitigated SA – example:
  - VVER-1000/320 (Temelin NPP)
  - IE: large break LOCA + SBO
  - CTMT failure by over-pressurization not considered
  - MCCI ongoing
  - PARs taken into account

UJV Group
TECHNOLOGY I INNOVATION I PEOPLE

Assessment of outcomes of SA analyses (2)

- CTMT pressure

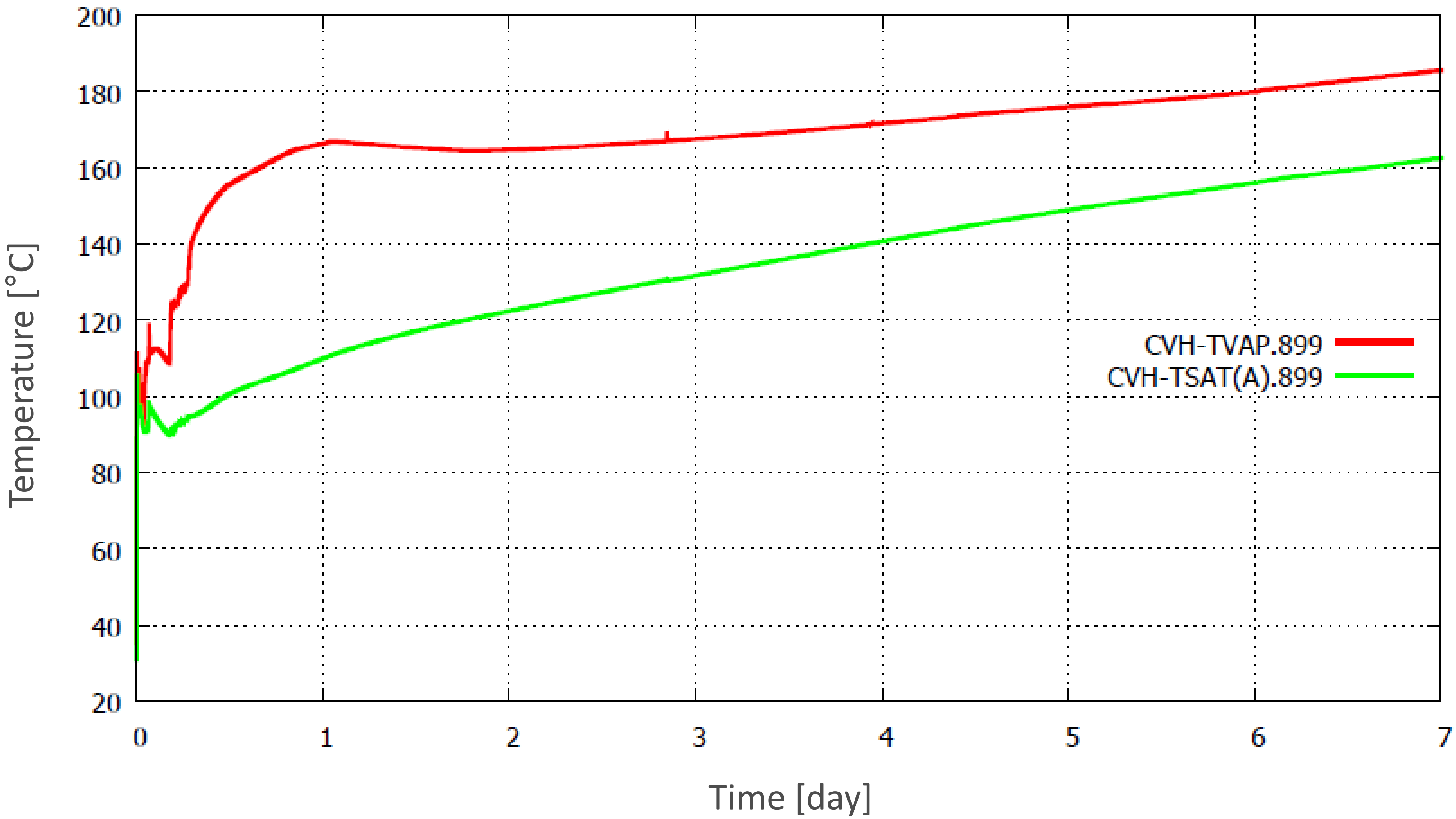


UJV Group
TECHNOLOGY I INNOVATION I PEOPLE

Assessment of outcomes of SA analyses

(3)

- CTMT atmosphere temperature, dew point temperature

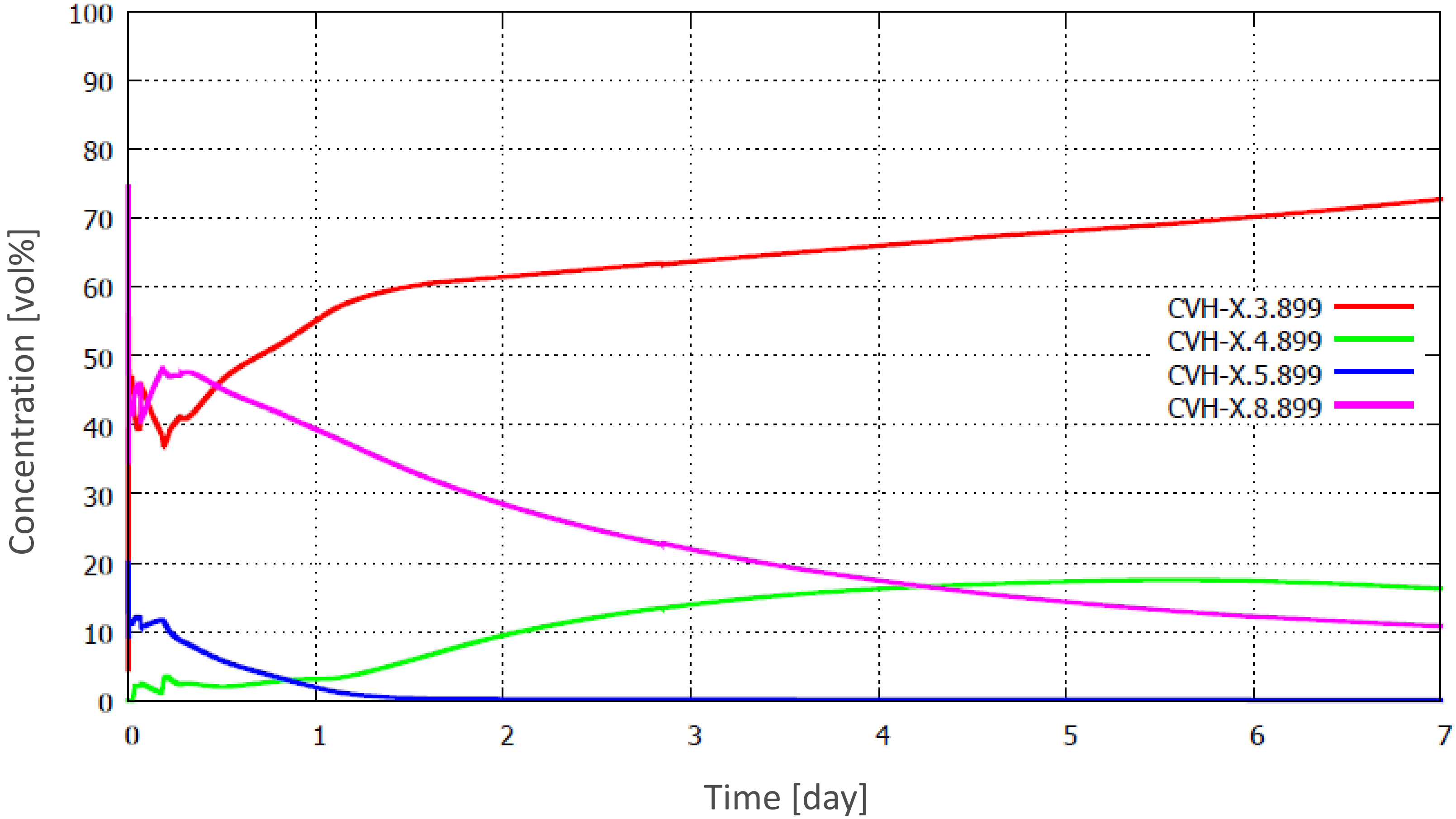


UJV Group
TECHNOLOGY I INNOVATION I PEOPLE

Assessment of outcomes of SA analyses

(4)

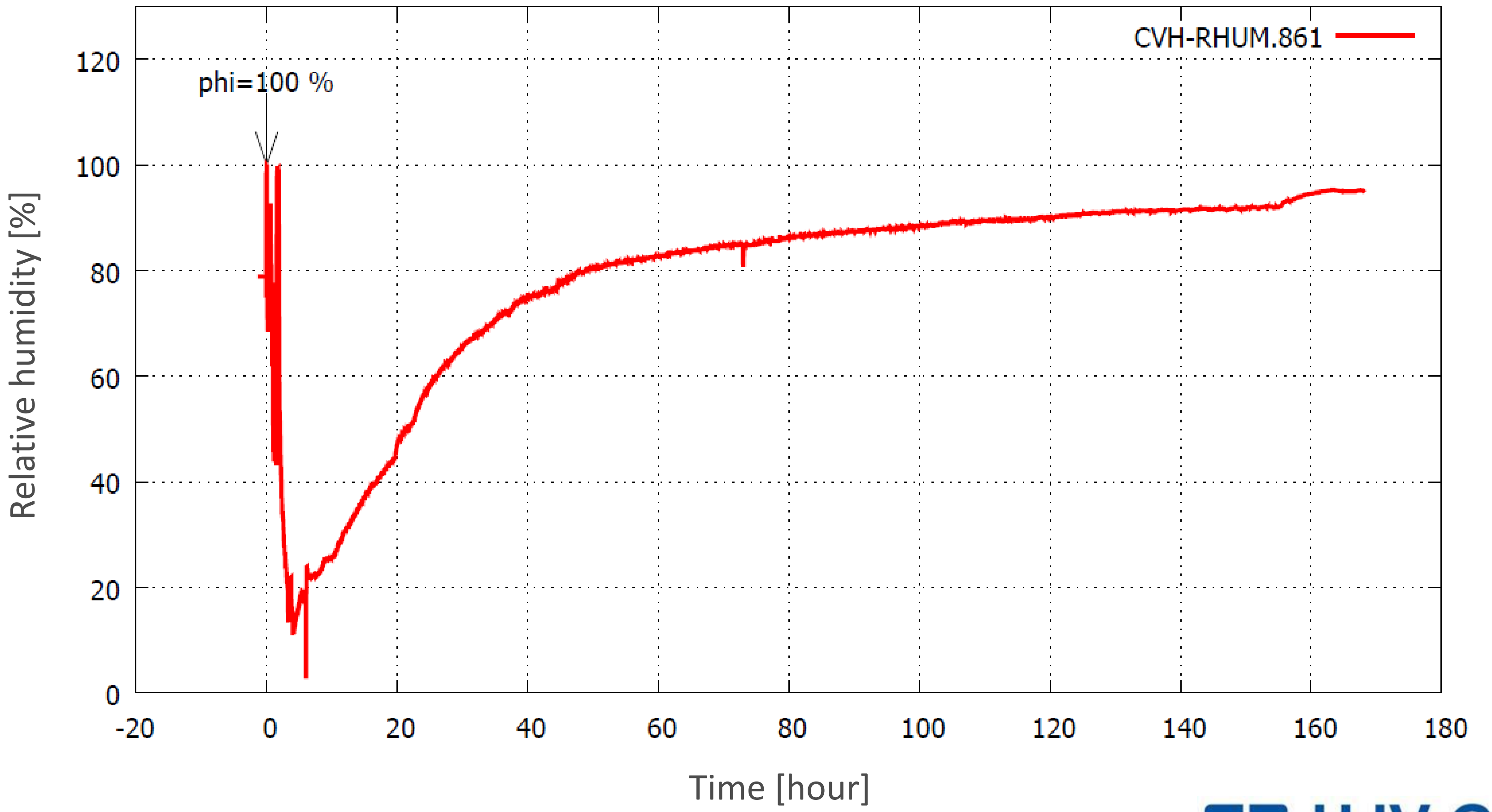
- Concentration of steam, H_2, O_2 and N_2 in the CTMT atmosphere



UJV Group
TECHNOLOGY | INNOVATION | PEOPLE

Assessment of outcomes of SA analyses

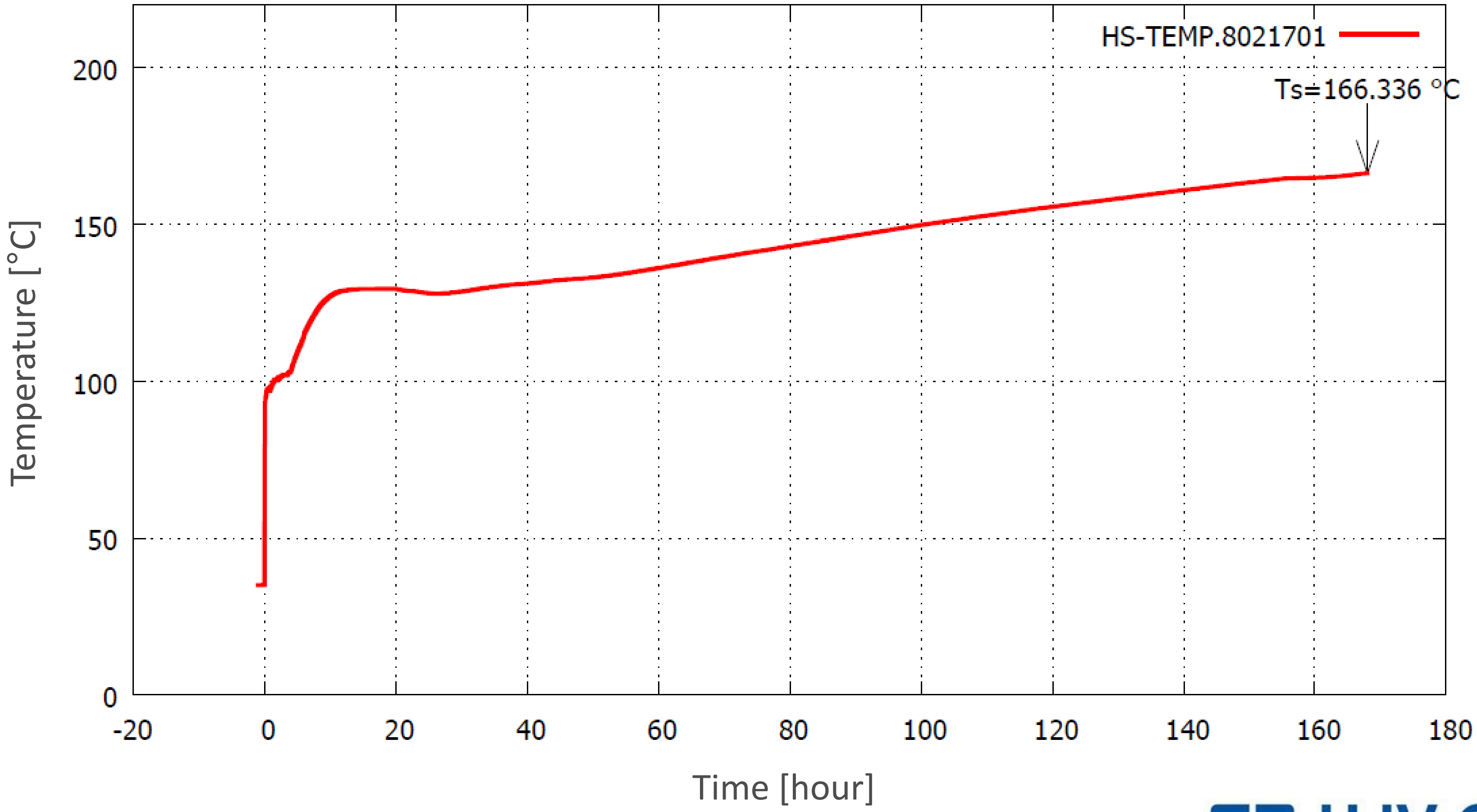
- Relative humidity in the CTMT atmosphere



Assessment of outcomes of SA analyses

(6)

- Surface temperature of a solid structure in the reactor hall



Equipment qualification for SAs

- 2014: project for EQ for both Czech NPPs
  - 4x VVER-440/213 – Dukovany NPP
  - 2x VVER-1000/320 – Temelin NPP)
- Identified were:
  - Equipment to be qualified
  - Relevant SA scenarios
  - Readings of maxima of decisive parameters, such as:
    - Atmosphere & component surface temperature
    - Pressure
    - Humidity
    - Water level
    - Hydrogen deflagration identification
    - RNs distribution (vapors, aerosols and gases)
      - in the air
      - in sumps and
      - settled on structures
- For SAs, crucial is the dose rate evaluation
  - up to several days of duration
  - new methodology under development, using the code SCALE/MAVRIC seq.

Thank You for Your Attention!

UJV GROUP