NUCLEAR
RESEARCH
INSTITUTE

ÚJV Řež, a.s.

Modeling of Radionuclide Release from Water Pool During IVMR and Recent Issues Encountered for the MELCOR 2.2 21402 Release

Ing. Jozef Baláž Ph.D.
14.04.2023

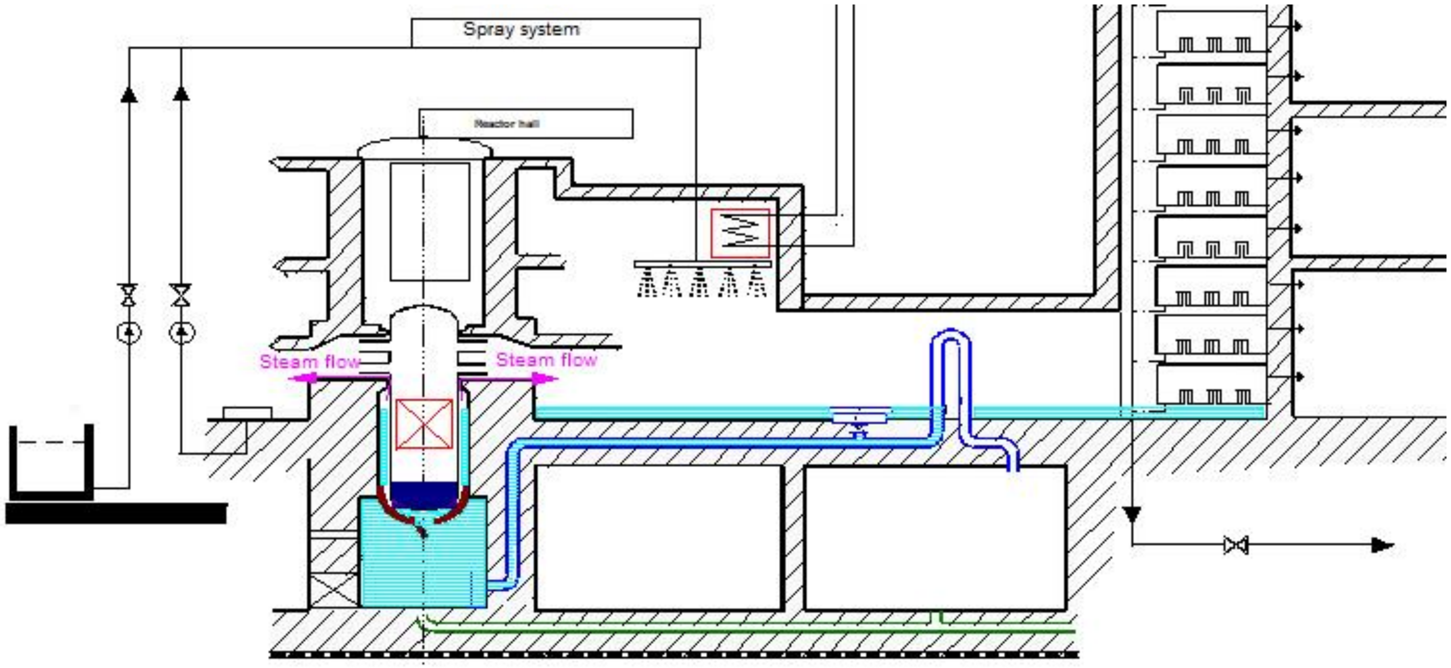
UJV Group
TECHNOLOGY | INNOVATION | PEOPLE

Content:

- **Modelling of the resuspension of radionuclides from the reactor cavity during IVMR**
- **Recent identified issues for MELCOR 2.2 21402**

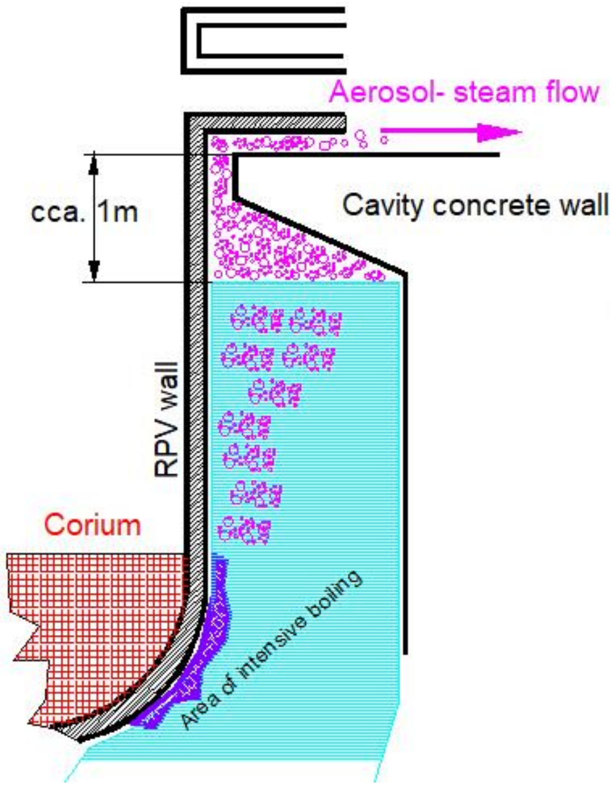
Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

- **IVMR mitigation strategy in our region is introduced for VVER440/V213 reactors**
- **Successful implementation of the strategy requires:**
  - Identification of the accident development into DEC-B
  - Depressurization of the secondary circuit
  - Depressurization of the primary circuit
  - Drainage of bubble tower trays
  - Flooding the reactor cavity



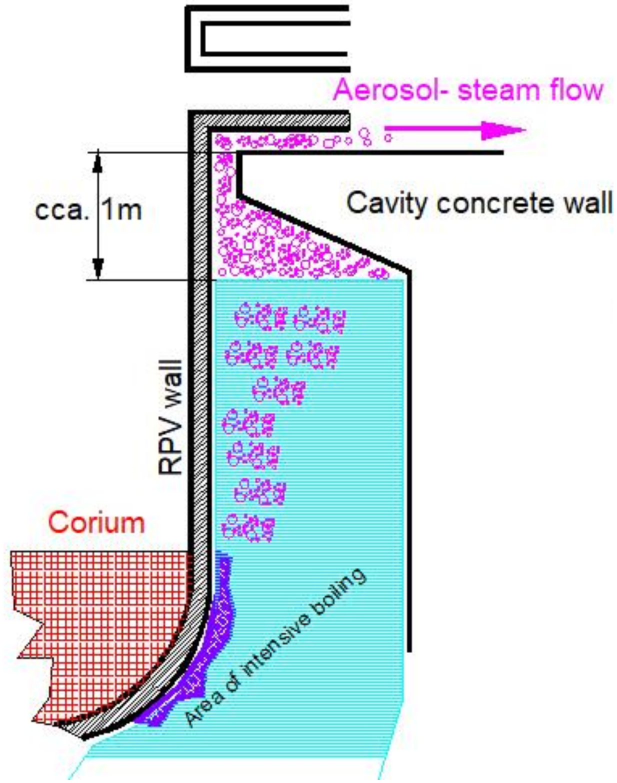
Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

- **Applied measures does not stop core degradation**
- **However, after core degradation and relocation into lower plenum, the corium is cooling and stabilized via heat transfer through reactor pressure vessel wall**



Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

- **Considering long term point of view**
  - Coolant is boiling in reactor cavity pool
  - Bubbles of steam are due to buoyancy forces transported from area of heat transfer up to the water level
  - Intense boiling intensively swirls the water level in the boiling channel between reactor pressure vessel wall and reactor cavity wall and form and drift away aerosols particles from the cavity

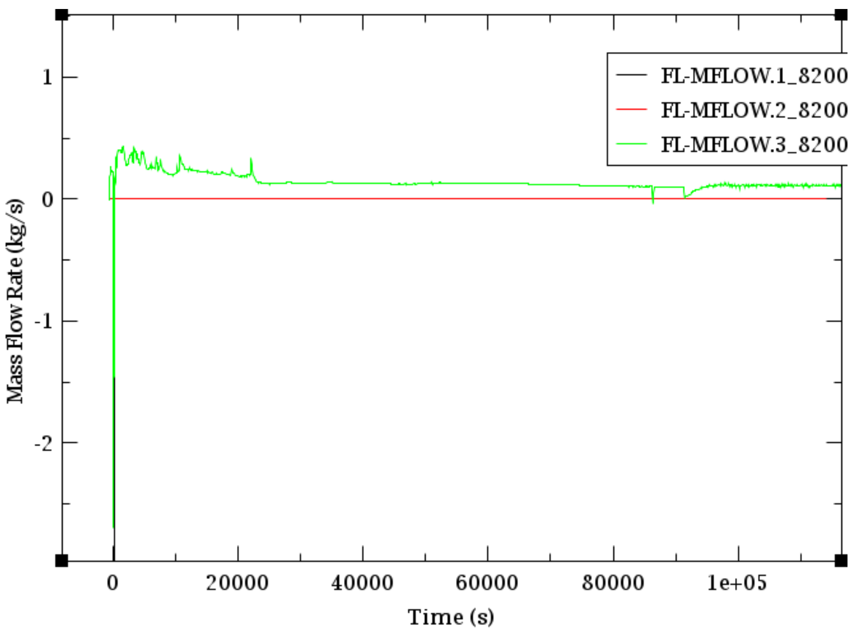


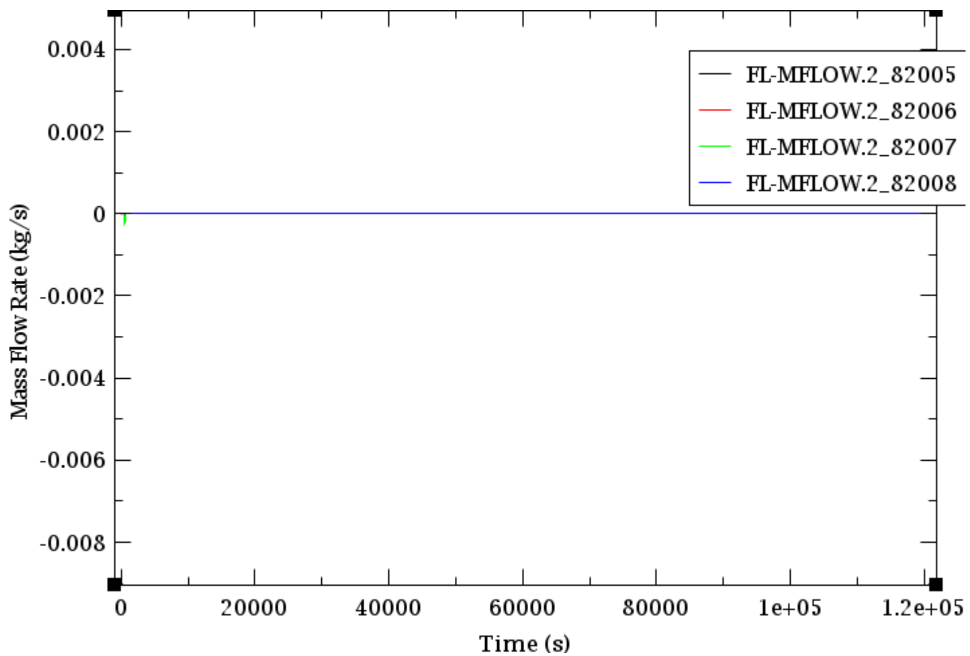
Coolant flowing into the cavity also contains soluble radionuclide chemical compounds – therefore the resuspension of the radionuclides should be expected

Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

- **MELCOR packages internal interaction**
  - Boiling in the cavity, formation of steam and transport of steam and “fog particles” are in the MELCOR code treated via CVH and FL packages
  - Aerosol particle growth, agglomeration, deposition etc. is treated by stand alone model MAEROS within RN package. MAEROS introduce basic distribution of the aerosol particle size consisting of a few size classes.

However, since steam flow from the cavity is significant and corresponding to the heat transfer through RPV wall, there is practically zero flux of ”fog particles” from the cavity from long term point of view





Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

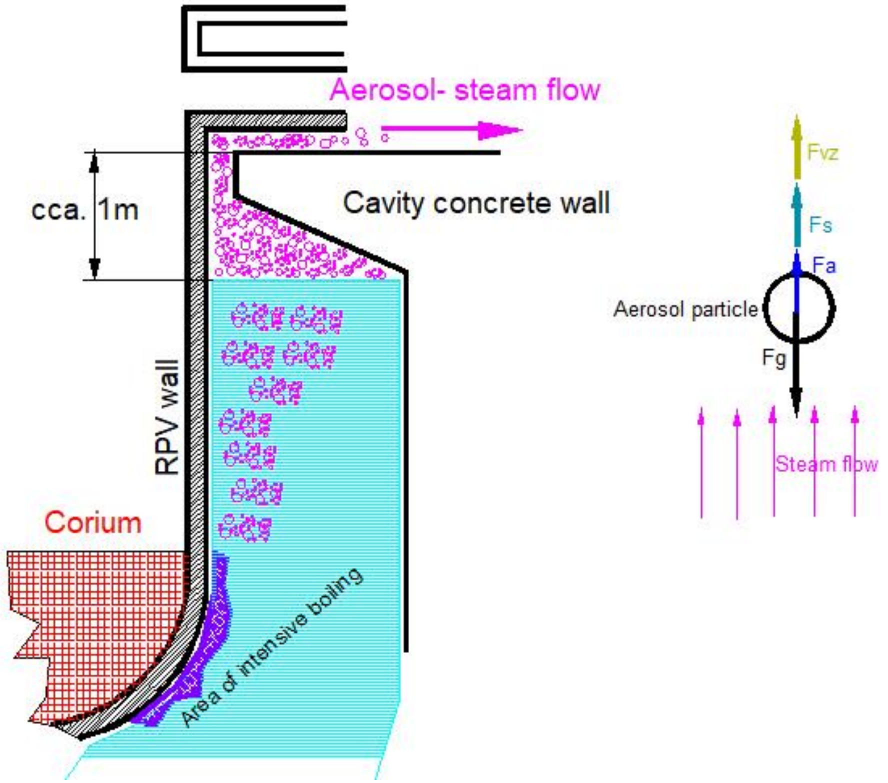
- **Possible bounding conditions in the reactor cavity**

	From		To	
Decay power in the lower head	6.00	(MW)	4.00	(MW)
Heat flux through RPV wall			1.00	(MW/m^2)
Immersion of the intense boiling area	4.00	(m)	5.00	(m)
Pressure in the containment	150.00	(kPa^{abs})	250.00	(kPa^{abs})
Temperature of the pool	saturation		saturation	
Theoretical mass flow of the produced vapor	2.70	(kg/s)	1.83	(kg/s)

Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

- **Analytical considerations for the "fog flow" from the cavity**

- $F_{N-accel.} = m.a = F_g - F_a - F_s - F_{vz}$
- $\frac{da}{dt} = \frac{d(F_g - F_{vz} - F_o)}{m.dt}$
- $F_g = m \cdot g = \frac{4}{3}\pi r^3 . \rho_w . g$
- $F_a = \frac{1}{2} w^2 . \rho_l . \xi . S = \frac{1}{2} w^2 . \rho_l . \xi . \pi . r^2$
- $F_{VZ} = \frac{4.\pi.r^3.\rho_l.g}{3}$
- $F_S = 6.\pi.\eta.r.w$

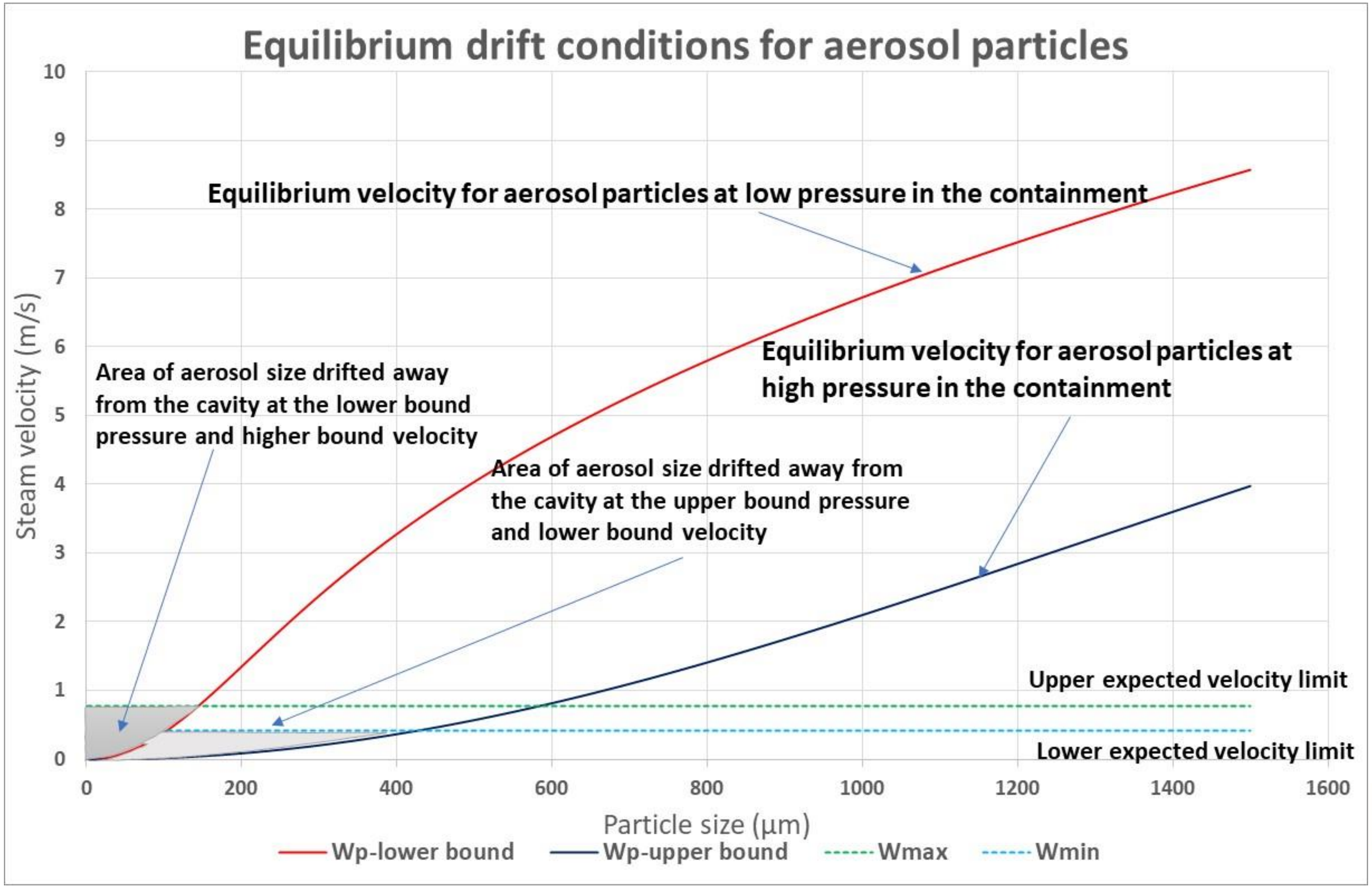


14th Meeting of the European MELCOR and MACCS User Group (EMUG)

NUCLEAR RESEARCH INSTITUTE

Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

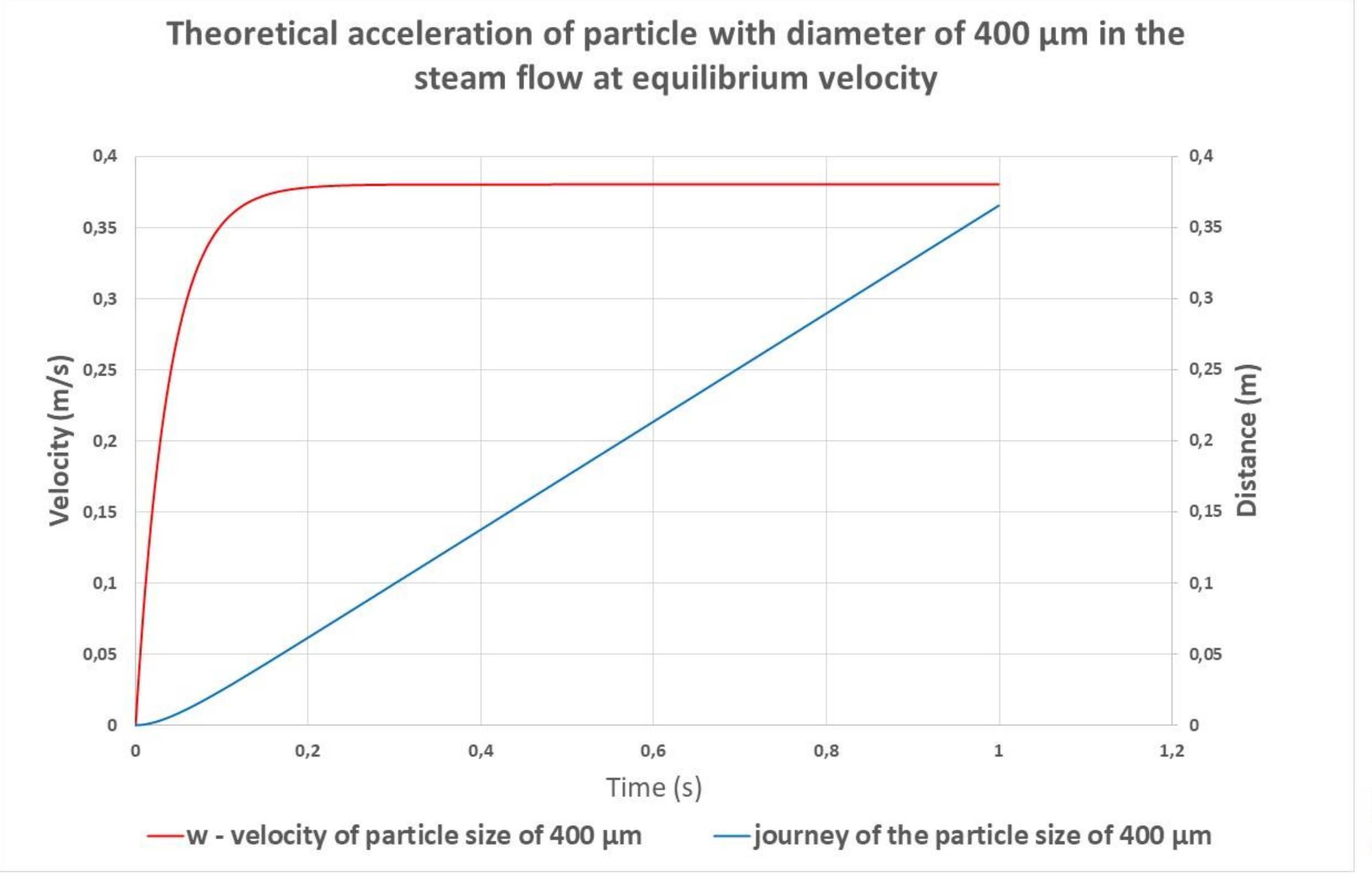
- **Combination of expected bounding conditions (steam flow, friction, densities) and postulated equations**



UJV Group
TECHNOLOGY | INNOVATION | PEOPLE

Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

- **Acceleration of theoretical maximal size particle**



Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

- **Expected “fog” flow from the cavity**
  - Aerosol particles of size up to 400 µm
  - The “fog” mass flow is to be proportional to steam density and vapor velocity. Considering previous works of the author

(*J. Baláž and R. Říha, “The project FI-IM3/181” Research and Development of the Mathematical Modell of distribution of Radionuclides in the Containment of VVER440”, Description of the Mathematical Modell of the LEAKBOX Computation Code, VUJE ČR, Dukovany, Czech Republic (2008)*),

it may be derived that maximal aerosol flow from the cavity will be ***up to 10%*** of the steam mass flow from the cavity.

Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

- **Radionuclide resuspension from the cavity**
  - Penetration of radionuclide compounds to the steam at operational conditions is known from BWRs (about 1/1000)
  - Another clue may be found in the appendix of "*Blumberg M. and Clifford P., U.S. Nuclear Regulatory Commission, Draft Regulatory Guide DG-1389, "Alternative Radiological Source Terms for Evaluation Design Basis Accidents at Nuclear Power Reactors", USA (2022)*", and is regarding of the iodine penetration to secondary steam during SGTR accident in the steam generators (1/100)
  - However, the significant portion of the resuspension of radionuclides from the cavity is given by portion of released aerosol particles, because concentration of radionuclide compounds in such particles released from the pool should correspond to concentration of corresponding compounds in the pool.

$$C_{steam}.m_{steam\ portion} + C_{aerosol}.m_{aerosol\ portion} = 0{,}01\ \ .90\% + 1.0\ \ .10\% = 0.11$$

Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

- **Introduction of the resuspension model**

  - Using procedure RN1_AS of the MELCOR 2.2 RN package
  - Definition of positive sources of the radionuclides in the steam generator box and negative sources in the reactor cavity pool
  - Definition introduced for each aerosol class $\dot{m}_{"x"} = \dot{m}_l . C_{"x"} . 0.1$

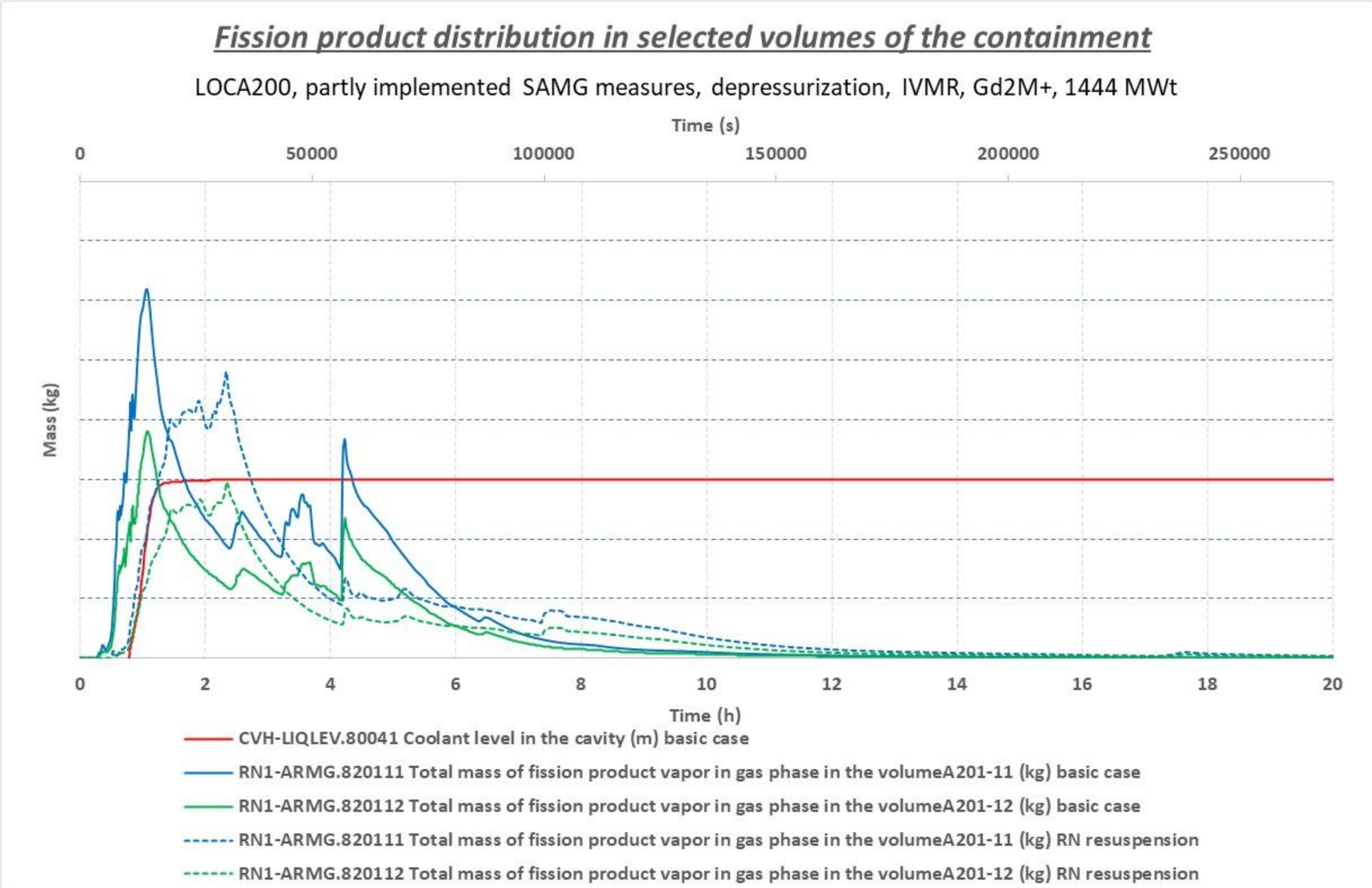
```
RN1_input
RN1_VS 117 !NSTR VOLUME PHASE CLASS FRACTION MASS TF/CF INTERP
  1 'CV82011' GAS 'CS' 0.8865   1.00  'CF' 'Mfr2011CS'  RATE
  2 'CV82011' GAS 'BA' 1.0      1.00  'CF' 'Mfr2011BA'  RATE
  3 'CV82011' GAS 'I2' 1.00     1.00  'CF' 'Mfr2011I2'  RATE
  4 'CV82011' GAS 'TE' 0.8886   1.00  'CF' 'Mfr2011TE'  RATE
  5 'CV82011' GAS 'RU' 1.0      1.00  'CF' 'Mfr2011RU'  RATE
  6 'CV82011' GAS 'MO' 1.0      1.00  'CF' 'Mfr2011MO'  RATE
  7 'CV82011' GAS 'CE' 1.0      1.00  'CF' 'Mfr2011CE'  RATE
  8 'CV82011' GAS 'LA' 1.0      1.00  'CF' 'Mfr2011LA'  RATE
  9 'CV82011' GAS 'UO2'0.8815   1.00  'CF' 'Mfr2011UO2' RATE
 10 'CV82011' GAS 'CD' 1.0      1.00  'CF' 'Mfr2011CD'  RATE
 11 'CV82011' GAS 'AG' 1.00     1.00  'CF' 'Mfr2011AG'  RATE
 12 'CV82011' GAS 'CSI'1.00     1.00  'CF' 'Mfr2011CSI' RATE
 13 'CV82011' GAS 'CSM'1.00     1.00  'CF' 'Mfr2011CSM' RATE
```

14th Meeting of the European MELCOR and MACCS User Group (EMUG)

NUCLEAR RESEARCH INSTITUTE

Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

- **Results of the resuspension model**
  - Concentration radionuclide increase in the SG BOX is not so significant
  - However, the settlement of the radionuclides is delayed substantially



UJV Group
TECHNOLOGY | INNOVATION | PEOPLE

Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

- **The source term increase**

Class	"Cs"	"Ba"	"I"	"Te"	"Ru"	"Mo"	"Ce"	"La"	"UO2"	"CD"	"AG"	"CsI"	"Cs2MoO4"
Increase of release (%)	59,00	34,18	3,20	136,34	40,00	-15,49	-0,77	2,45	2,62	-15,57	54,61	43,83	39,13

Modelling of the resuspension of radionuclides from the reactor cavity during IVMR:

- **Discussion of the results/ Conclusion**
- **The resuspension of RN compounds from the cavity is possible to model via introducing procedure RN1_VS of radionuclide sources. The dedicated procedure is seemed be too simple**
  - Ratio between radioactive and nonradioactive portion of the compounds in each class is required as a constant
  - There is no way how to influence distribution of aerosol size particles handed over to MAEROS procedure of RN package
- **The quantification of the source of radionuclides is based on analytical considerations, which were never been experimentally or CFD verified.**
- **Moreover, estimation of up to 10% of steam flow neglects existing dependences on steam velocity and density.**
- **On the other hand, pilot results of the radionuclide resuspension from the cavity during IVMR indicates very high importance of the issue and the necessity to address it accordingly**
- **It is strongly recommended to carry out CFD study, which would allow introduce simple algebraic dependences for the fog flow from the cavity, the intensity of the boiling and submerge of the heat transfer area.**
- **The above-mentioned study could also verify aerosol particle size distribution and to provide the basement for introduction of particle size distribution in the future.**

Recent experience with the MELCOR 2.2:

- **Encountered issues:**
  - Deactivation of heat structures of the containment followed of calculation failure
  - Logic error in support structures (followed of calculation termination)

Recent experience with the MELCOR 2.2:

Deactivation of heat structures of the containment followed of calculation failure:

```
CYCLE= 4172270 T= 4.751096E+04 DT(CVH)= 1.508800E-02 CPU= 4.749341E+05
CYCLE= 4172280 T= 4.751111E+04 DT(CVH)= 1.516600E-02 CPU= 4.749352E+05
CYCLE= 4172290 T= 4.751127E+04 DT(CVH)= 1.520100E-02 CPU= 4.749364E+05
CYCLE= 4172300 T= 4.751142E+04 DT(CVH)= 1.513400E-02 CPU= 4.749375E+05
/SMESSAGE/  TIME= 4.75115E+04 CYCLE= 4172309
 HSOFF: HEAT STRUCTURE BEING DEACTIVATED
 HEAT STRUCTURE NUMBER: *****, NAME: HS82011101
/SMESSAGE/  TIME= 4.75115E+04 CYCLE= 4172309
 HSOFF: HEAT STRUCTURE BEING DEACTIVATED
 HEAT STRUCTURE NUMBER: *****, NAME: HS82011103
/SMESSAGE/  TIME= 4.75115E+04 CYCLE= 4172309
 HSOFF: HEAT STRUCTURE BEING DEACTIVATED
 HEAT STRUCTURE NUMBER: *****, NAME: HS82011104
/SMESSAGE/  TIME= 4.75115E+04 CYCLE= 4172309
 HSOFF: HEAT STRUCTURE BEING DEACTIVATED
 HEAT STRUCTURE NUMBER: *****, NAME: HS82011501
CYCLE= 4172310 T= 4.751154E+04 DT(INC)= 2.511700E-30 CPU= 4.749390E+05
CYCLE= 4172320 T= 4.751154E+04 DT(INC)= 2.511400E-28 CPU= 4.749402E+05
CYCLE= 4172330 T= 4.751154E+04 DT(INC)= 2.511100E-26 CPU= 4.749413E+05
```

- Each KTMT heat structure name is compiled as HS8xxxyy, and heat structure number is compiled as 8xxxyy, where xxx is the room number and yy is number of HS within the room.
- There are 35 Heat structures in the reactor from HS4001 to HS4035

Recent experience with the MELCOR 2.2:

Logic error in support structures (followed of calculation termination):

```
 Attempted cycle advancement was unsuccessful - DT reduced to = 8.5693E-03
Diagnostic Message  Time= 4.2021E+03 Dt= 3.0000E-02 Cycle= 682124 (CVH)
 Attempted cycle advancement was unsuccessful - DT reduced to = 1.2880E-02
Diagnostic Message  Time= 4.2028E+03 Dt= 3.0000E-02 Cycle= 682150 (CVH)
 Attempted cycle advancement was unsuccessful - DT reduced to = 8.4089E-03
Diagnostic Message  Time= 4.3100E+03 Dt= 3.0000E-02 Cycle= 685728 (COR)
 LOGIC ERROR IN CORSTR
 APPARENT LOAD ON SS  IN CELL IA=17 IR= 8 WHICH DOESN'T EXIST
Calculation terminated by: SUPPORT MODEL LOGIC ERROR
```

Ring 8				
FU	CN	CL	SS	NS
0	0	0	0.00	6.30
0	0	0	0.00	10.31
0	0	0	0.00	7.47
0	0	0	0.00	7.47
0	0	0	0.00	7.47
0	0	0	0.00	7.47
0	0	0	0.00	7.47
0	0	0	0.00	7.47
0	0	0	0.00	7.47
0	0	0	0.00	7.47
0	0	0	0.00	8.23
0	0	0	27.18	17.24
0	0	0	0.00	1.65
0	0	0	0.00	1.05
0	0	0	0.00	1.01
0	0	0	0.00	1.06
0	0	0	1.08	0.39
0	0	0	0.00	0.00
0	0	0	0.00	0.00

Thank you for your attention

UJV Group

TECHNOLOGY | INNOVATION | PEOPLE

Hlavní 130 Rez, 250 68 Husinec
Czech Republic
+420 266 173 427
+420 798 330 423