Warsaw University of Technology

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„Source-term analysis for PHÉBUS FPT-1 with MELCOR 2.2 and 2.1” – Experience and Outcomes

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Introduction

- Revisit of the Phebus FPT-1 with MELCOR 2.2 and 2.1
- Focus on releases from the bundle:
  - Hydrogen
  - Structural materials
  - Radionuclides
- Project financed by PAA in 2018, in 2019 by WUT
- Recently, work ongoing with M2.2.18
- Papers:

P. DARNOWSKI, M. WŁOSTKOWSKI, M. STĘPIEŃ, G. NIEWIŃSKI, *STUDY OF THE MATERIAL RELEASE DURING PHÉBUS FPT-1 BUNDLE PHASE WITH MELCOR 2.2.11954,* ANNALS OF NUCLEAR ENERGY, VOL. 148, 2020, 107700, DOI: 10.1016/J.ANUCENE.2020.107700

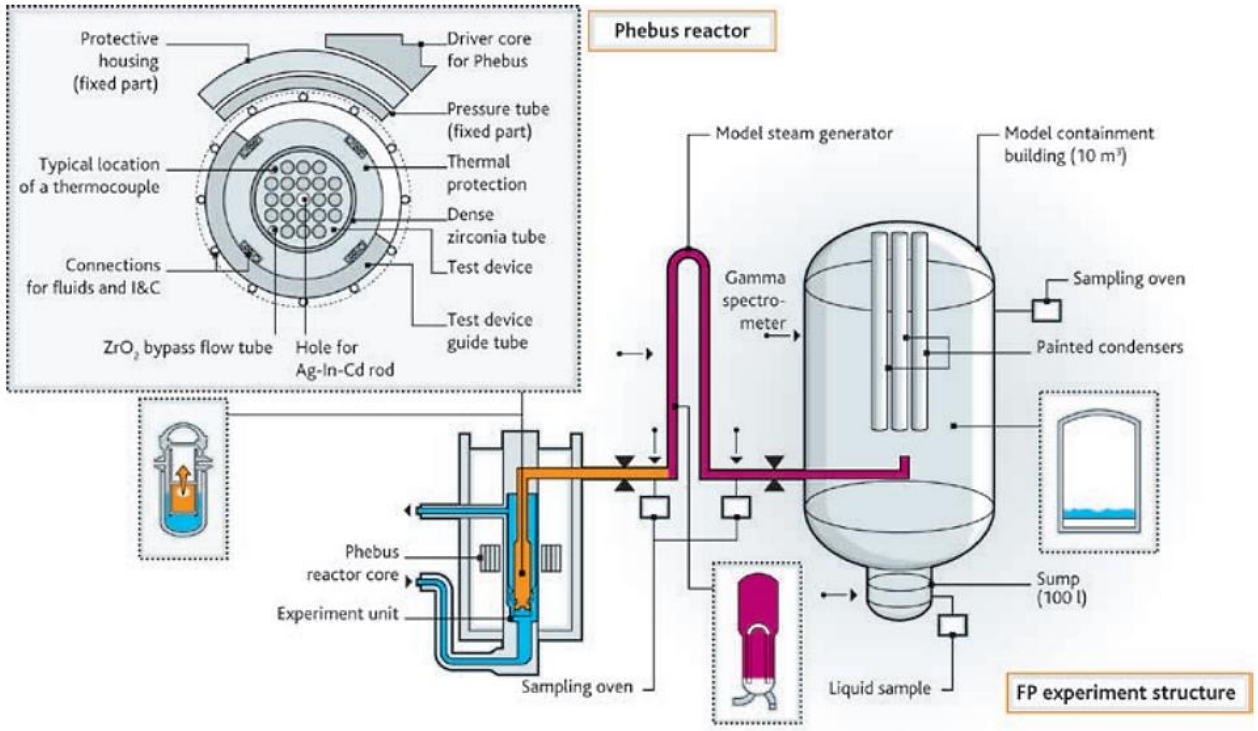
P. MAZGAJ, P. DARNOWSKI, G. NIEWIŃSKI, *UNCERTAINTY ANALYSIS OF THE HYDROGEN PRODUCTION IN THE PHEBUS FPT-1 EXPERIMENT*, NENE-2019, NENE-2019 PROCEEDINGS, PORTOROZ, SLOVENIA, 9-12.09.2019

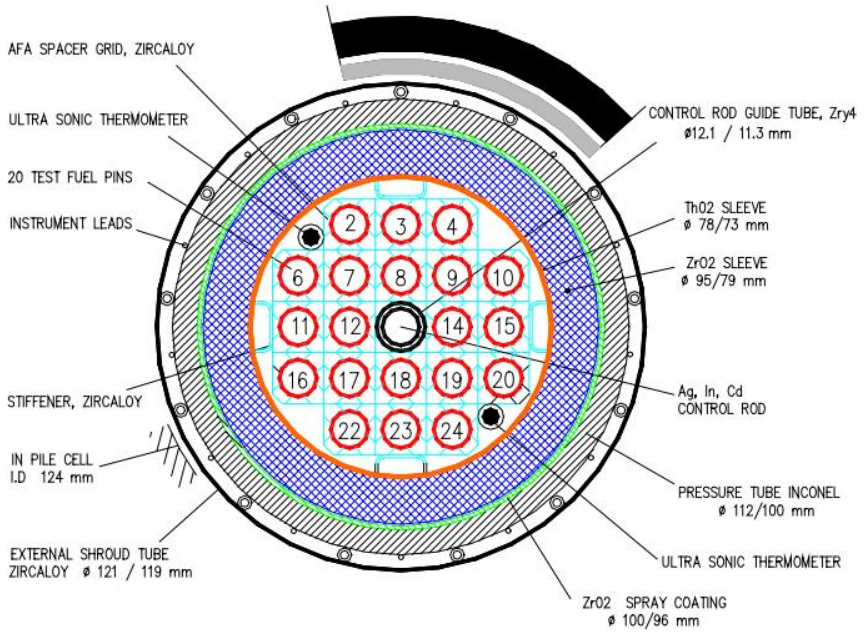
- Old results - reports in Polish:

https://www.gov.pl/attachment/2ed67789-b620-437b-b7eb-c5930bd841c3

https://www.gov.pl/attachment/64b2fefc-d115-4f26-8ff3-67010bdc246f

Phebus FPT-1



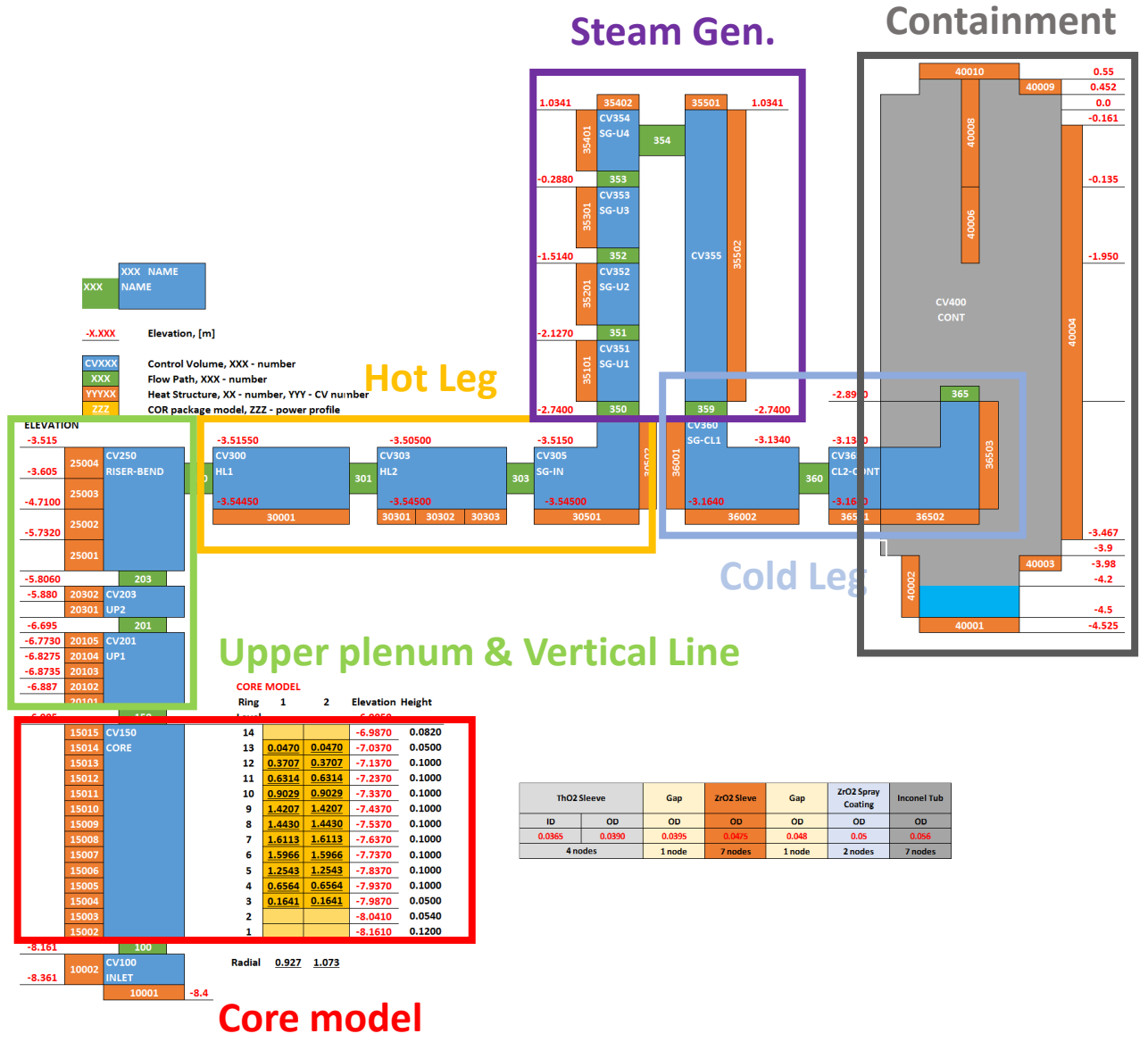


Phébus-FP test matrix.

Test	Type of fuel	Fuel degradation	Primary circuit	Containment	Date
FPT-0	Fresh fuel, 9 days pre irradiation, 1 Ag/In/Cd rod	Melt progression & FP release in steam-rich environment	FP chemistry and deposits in non condensing steam generator	Aerosol deposition, Iodine radiochemistry at pH5	December 2 1993
FPT-1	BR3 fuel ≈ 23.4 GWd/tU, 1 Ag/In/Cd rod, Re-irradiation	As FPT-0 with irradiated fuel	As FPT-0	As FPT-0	July 26 1996
FPT-2	As FPT-1, but with ≈ 31.8 GWd/tU irradiation	As FPT-1 under steam poor conditions	As FPT-1 with effect of boric acid in the steam	Evaporating sump at pH9	October 12 2000
FPT-3	As FPT-1 with B4C instead of Ag/In/Cd, 24.5 GWd/tU irradiation	As FPT-2	As FPT-0	Evaporating sump at pH5 recombiner coupons	November 18 2004
FPT-4	EDF fuel average 38 GWd/tU, no re irradiation, in the form of a debris bed	Low volatile FP and actinide release from the UO_2–ZrO_2 debris bed up to melting	Integral filters in test device, detailed post-test analyses on samples		July 22 1999

Model

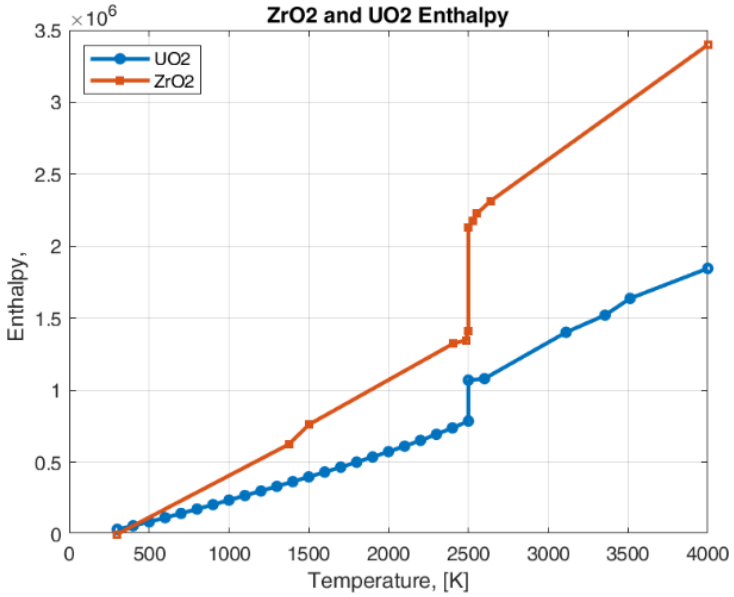
- Base: M2.2.11932
- Additional: M2.1.6342
- Based on publicly available data
  - No access to ISP-46 specification/handbooks
  - ISP-46 report and assoc. papers
  - Several papers published after ISP-46
  - SNL model descriptions in M2.1 Assessment Report.
  - Other reports
- Relatively simple model
- Single CV for core – to be updated soon 1CV->10CV

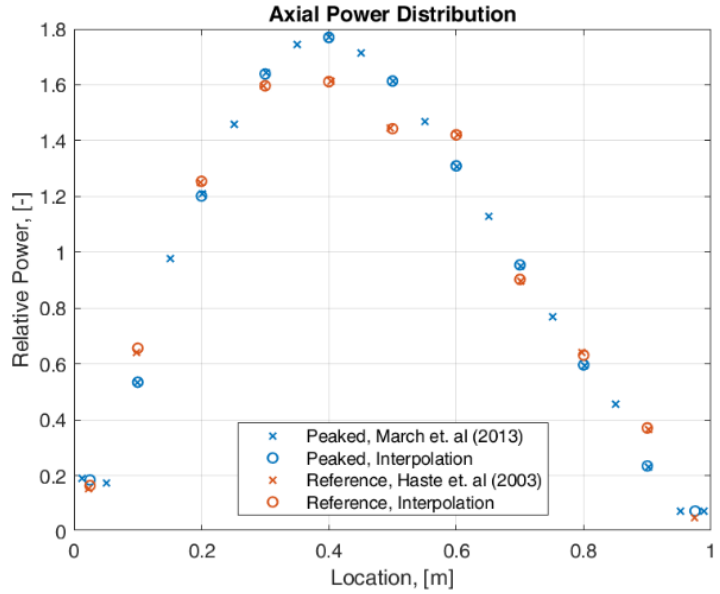


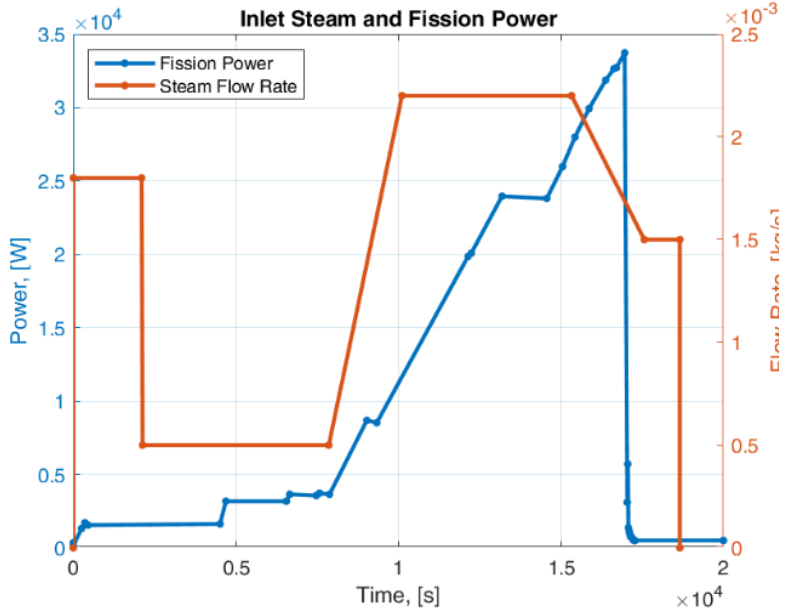
Model – some details

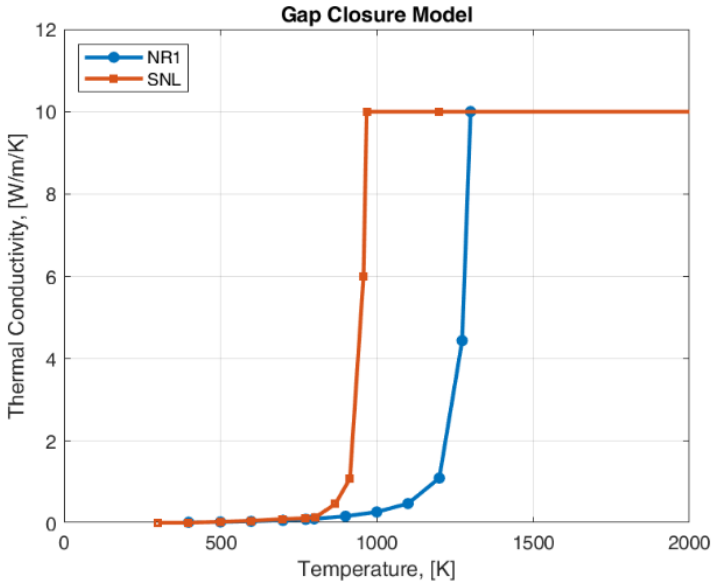
Selected modeling details:

- ZRO2-INT & UO2-INT (with MP_PRTF)
- For M2.2.11 EUT was not working properly
- Some sensitivities studied, e.g.:
  - Shroud gap closure
  - Power profile



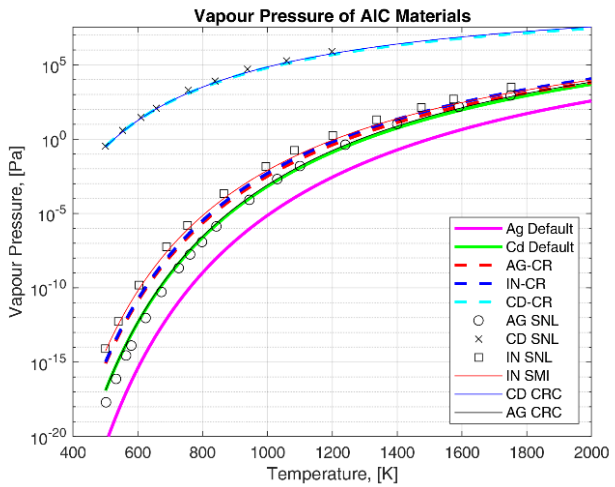






Model – inventories and releases

- Inv. from M2.1 Assessment Report
- Non usual speciation - with gap gases present
- CSM, CsI also applied but without chemical speciation model
  - All radionucl. defined with RN1_FPN card (like SOARCA)
- Ag-CR, In-CR, Cd-CR with silver model
  - SC7110,7111,7120 + COR_CR ACTDC 0.1
- Alternative as pseudo-FP (SC7103). Also for SNO2 and MO calcs.
- CORSOR-Booth, 2nd, 1st and basic - RN1_FP00 -7, -5 or -3



Number	Class	Representative	Initial mass before speciation, [g]	Mass after speciation, [g]
RN1	XE	Kr	35.49	35.49
		Xe		
RN2	CS	Rb	18.37	0.81769
		Cs		
RN3	BA	Ba	15.40	15.40
		Sr		
RN4	I2	I	1.98	0.05485
RN5	TE	Te	2.63	2.63
RN6	RU	Ru	17.29	17.29
RN7	MO	Mo	25.0	19.3925
		Tc		
RN8	CE	Pu	38.5	38.50
		Np		
		Zr		
RN9	LA	La	0.0	0.0
RN10	UO2	U	8967.0 COR package	8967.0 COR package
RN11	CD	Sb	0.23	0.23
RN12	AG	Ag	0.0	0.0
RN13	BO2	-	0	0
RN14	H2O	-	0	0
RN15	CON	-	0	0
RN16	CSI	CsI	0	3.94134
RN17	CSM	Cs2MoO4	0	21.14362
RN18	AG-CR	Ag	COR package	COR package
RN19	IN-CR	In	COR package	COR package
RN20	CD-CR	Cd	COR package	COR package
RN21	SNO2	Sn	COR package	COR package
Total mass without uranium and structural materials			154.89	154.89

SNL, 2014. MELCOR Best Practices as Applied in the State-of-the-Art Reactor Consequence Analyses (SOARCA) Project, U.S. NC Report NUREG/CR-7008, (2014).

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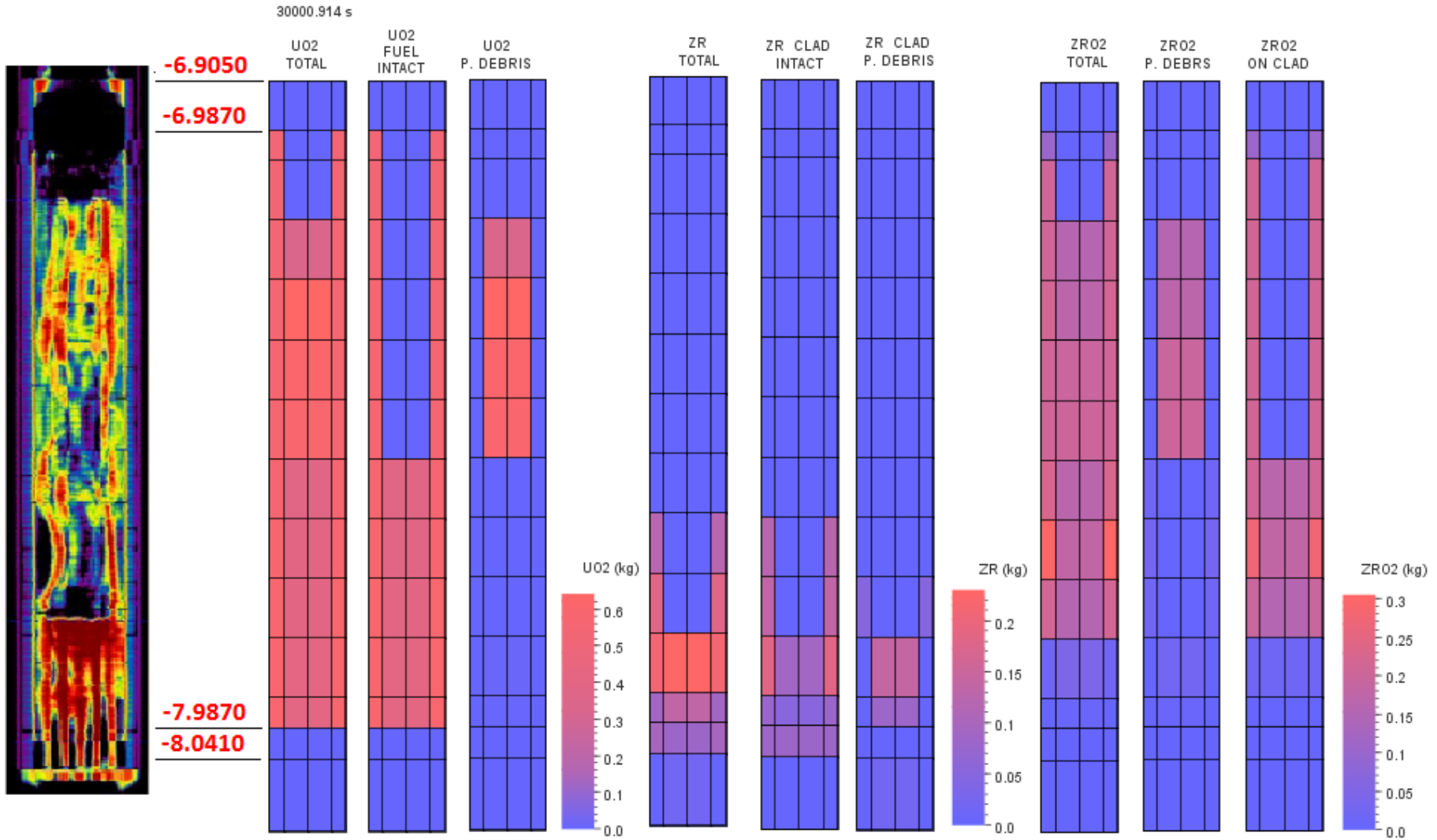
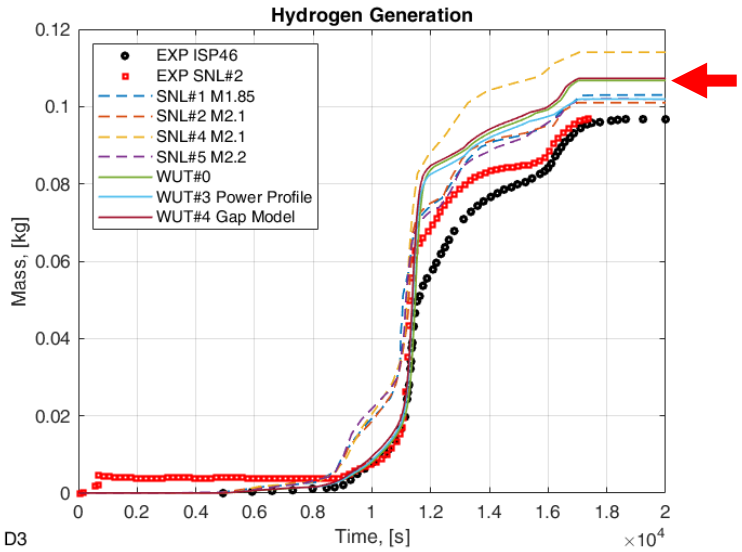
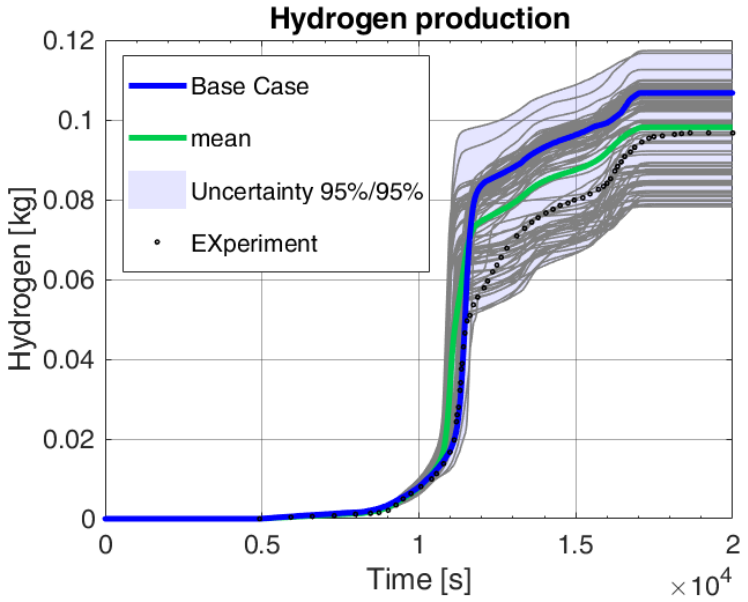
AIC equations and parameters: https://gitlab.com/darczu/x-core/-/tree/master/Modules/MaterialDatabase/VapourPressure

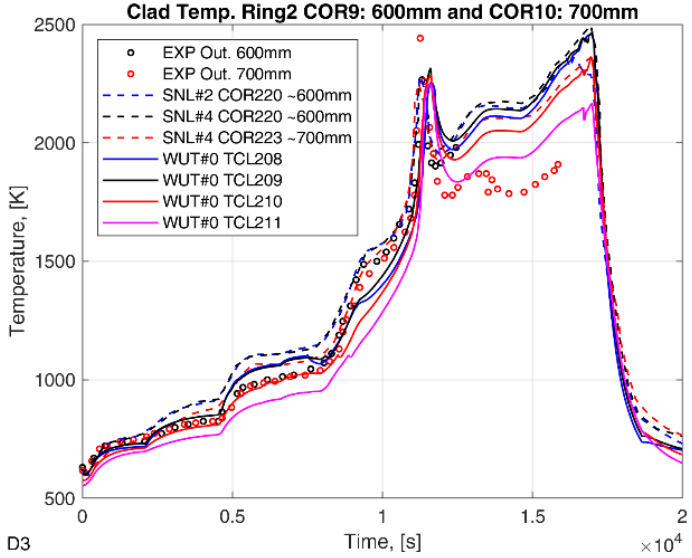
Bundle final state



Results - Hydrogen







Case	Code	Reference
SNL#1	M1.8.5	(Clément and Haste, 2003)
SNL#2	M2.1	(SNL, 2015)
SNL#3	M1.8.5	(Gauntt, 2010; SNL, 2010)
SNL#4	M2.1	(Wang et al., 2015; Wang et al., 2016)
SNL#5	M2.2.11932 M2.2.9496 M2.1	(Humphries, 2018a,b)
PS1	M1.8.5	(Birchley, 2004; Clément and Haste, 2003)

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Gauntt, R.O., 2010. Synthesis of VERCORS and Phebus data in severe accident codes and applications. Sandia National Laboratories Report (SAND2010-1633).

Wang, J., Corradini, M., Troy, W.F., Yapei, H., Wenxi, Z., Guanghui, T., Qiu, S.S., 2015. Simulation of the PHEBUS FPT-1 experiment using MELCOR and exploration of the primary core degradation mechanism. Ann. Nucl. Energy 85, 193–204.

Wang, J., Wang, C., Corradini, M.L., Haskin, T., Tian, W., Su, G., Qiu, S., 2016. PHEBUS FPT-1 simulation by using MELCOR and primary blockage model exploration. Nucl. Eng. Des. 307, 119–129. https://doi.org/10.1016/j.nucengdes.2016.06.034.

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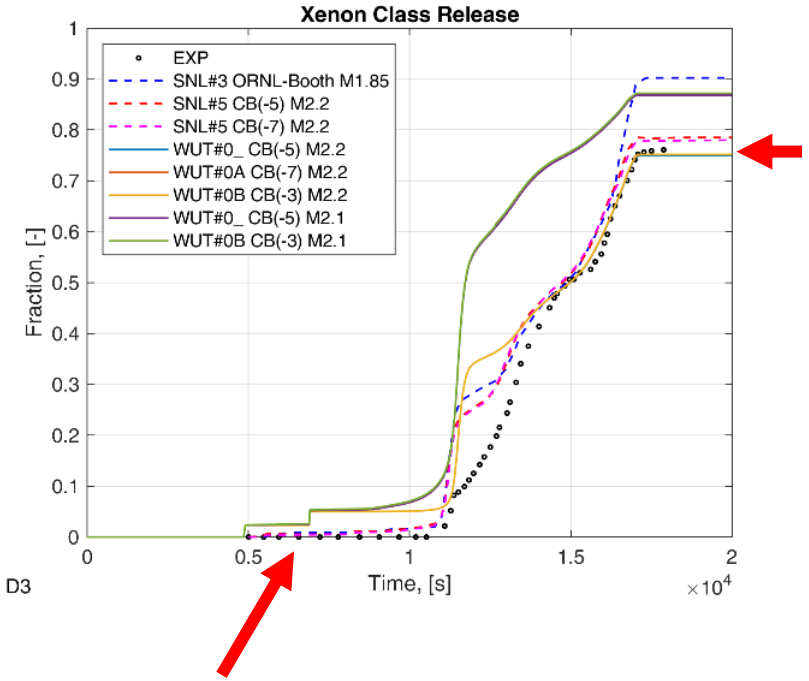
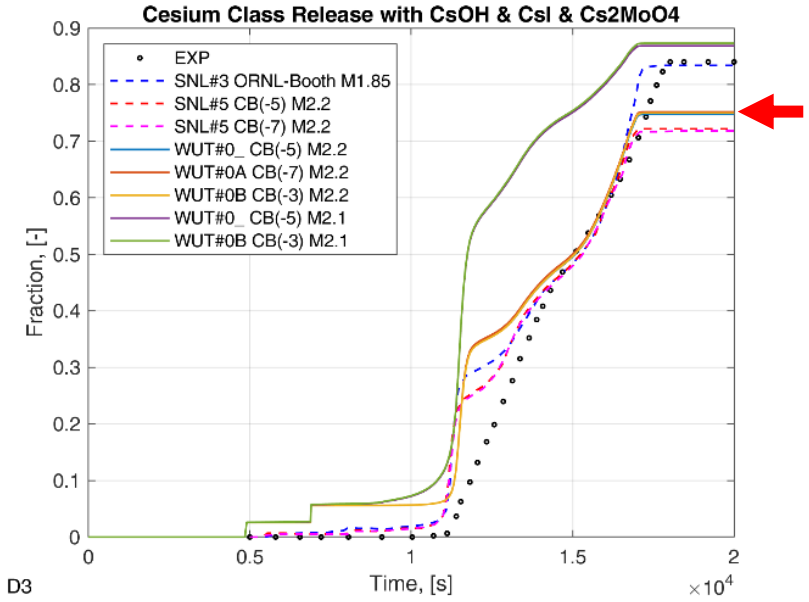
Humphries, L.L., 2018b. Quicklook overview of model changes in MELCOR 2.2: Rev 6342 to Rev 9496. Sandia Report, (SAND2017-5599)

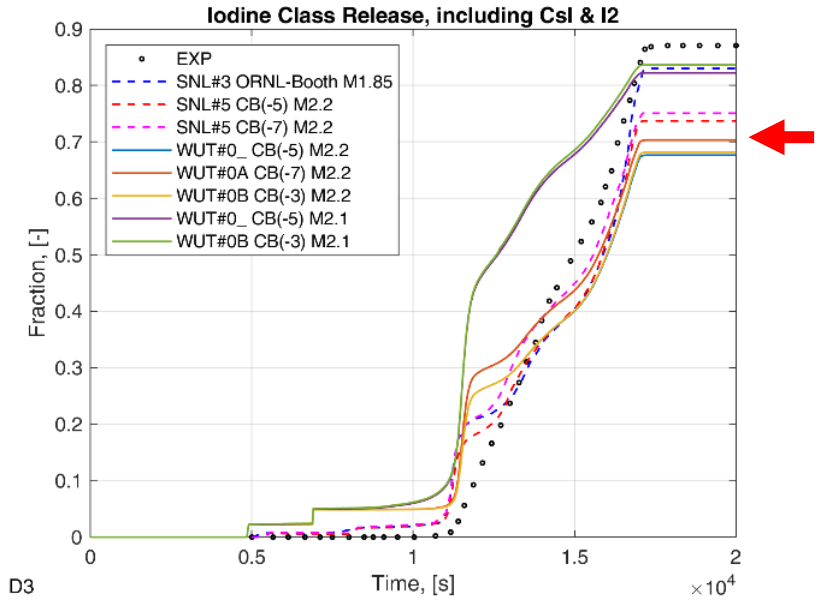
Birchley, J., 2004. Assessment of the MELCOR Code Against PHEBUS Experiment FPT-1 Performed in the Frame of ISP-46. 12th International Conference on Nuclear Engineering, 551–560. https://doi.org/10.1115/ICONE12-49267. ICONE12-49267.

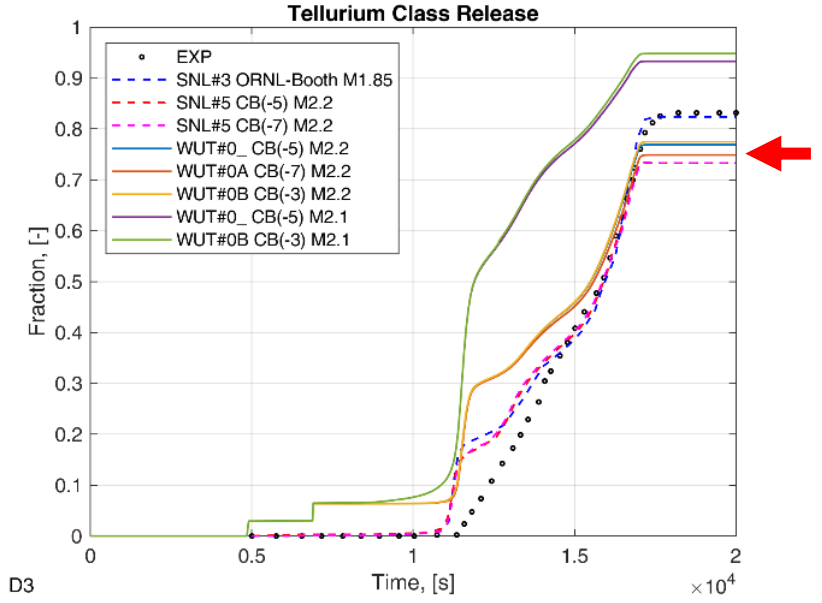
XE, I2, CS, TE

CB - CORSOR-Booth; CB(-5) 1st revision (default), CB(-3) basic version, CB(-7) second revision.









- "Steps" due to initial gap inventory

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SNL#5	M2.2.11932 M2.2.9496 M2.1	(Humphries, 2018a,b)
PS1	M1.8.5	(Birchley, 2004; Clément and Haste, 2003)

BA+RU+Sb

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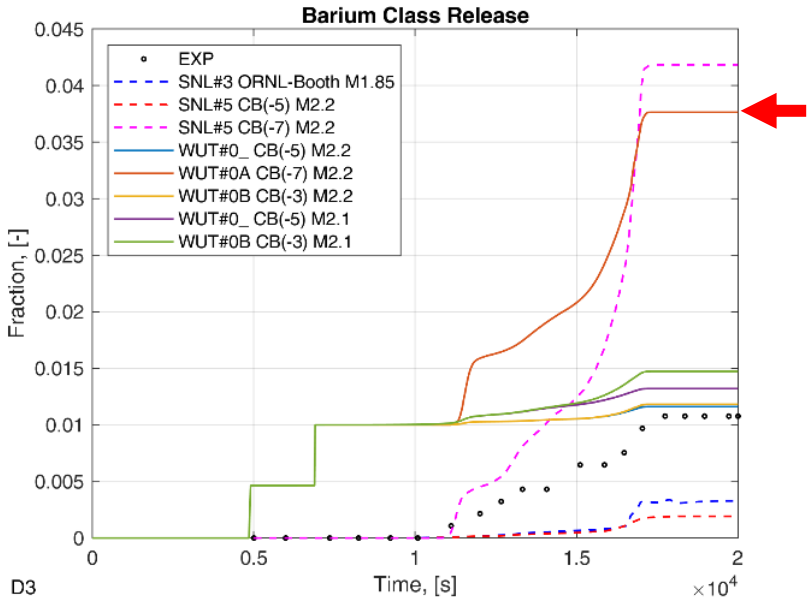

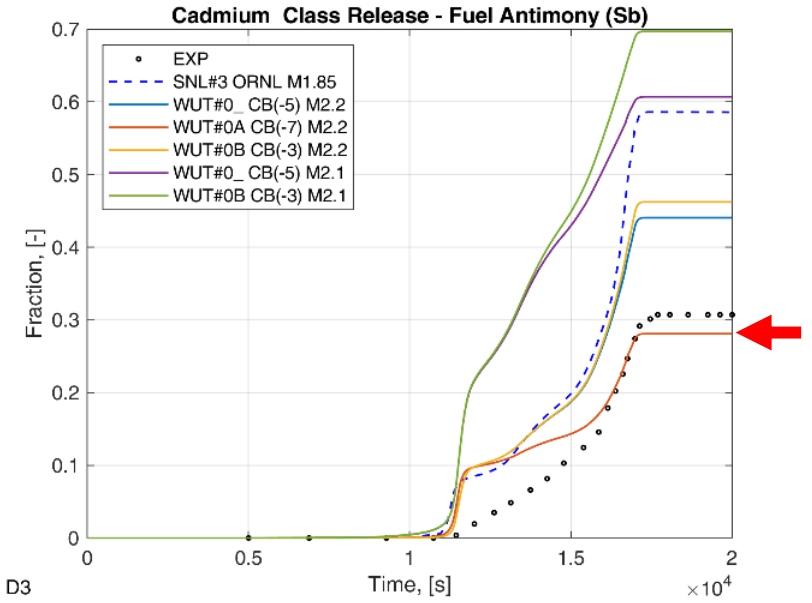

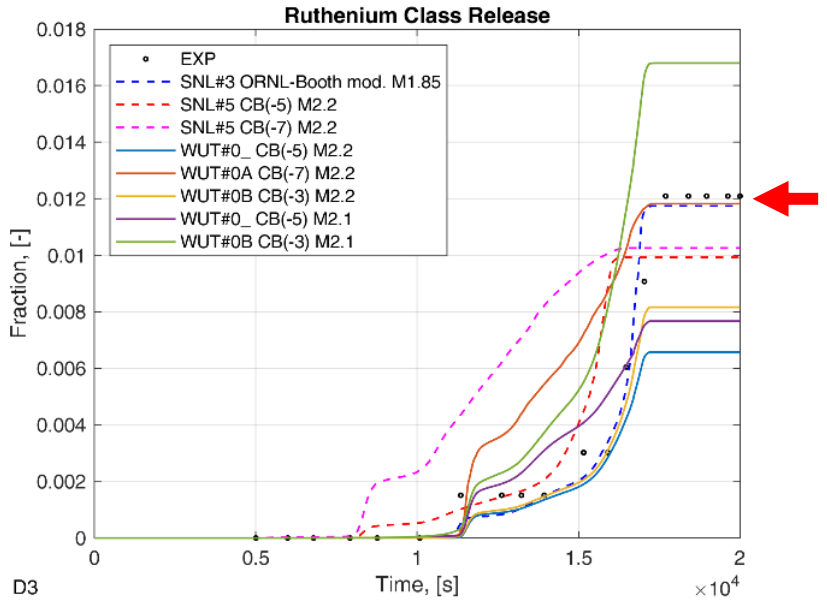

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SNL#5	M2.2.11932 M2.2.9496 M2.1	(Humphries, 2018a,b)
PS1	M1.8.5	(Birchley, 2004; Clément and Haste, 2003)

Molybdenum

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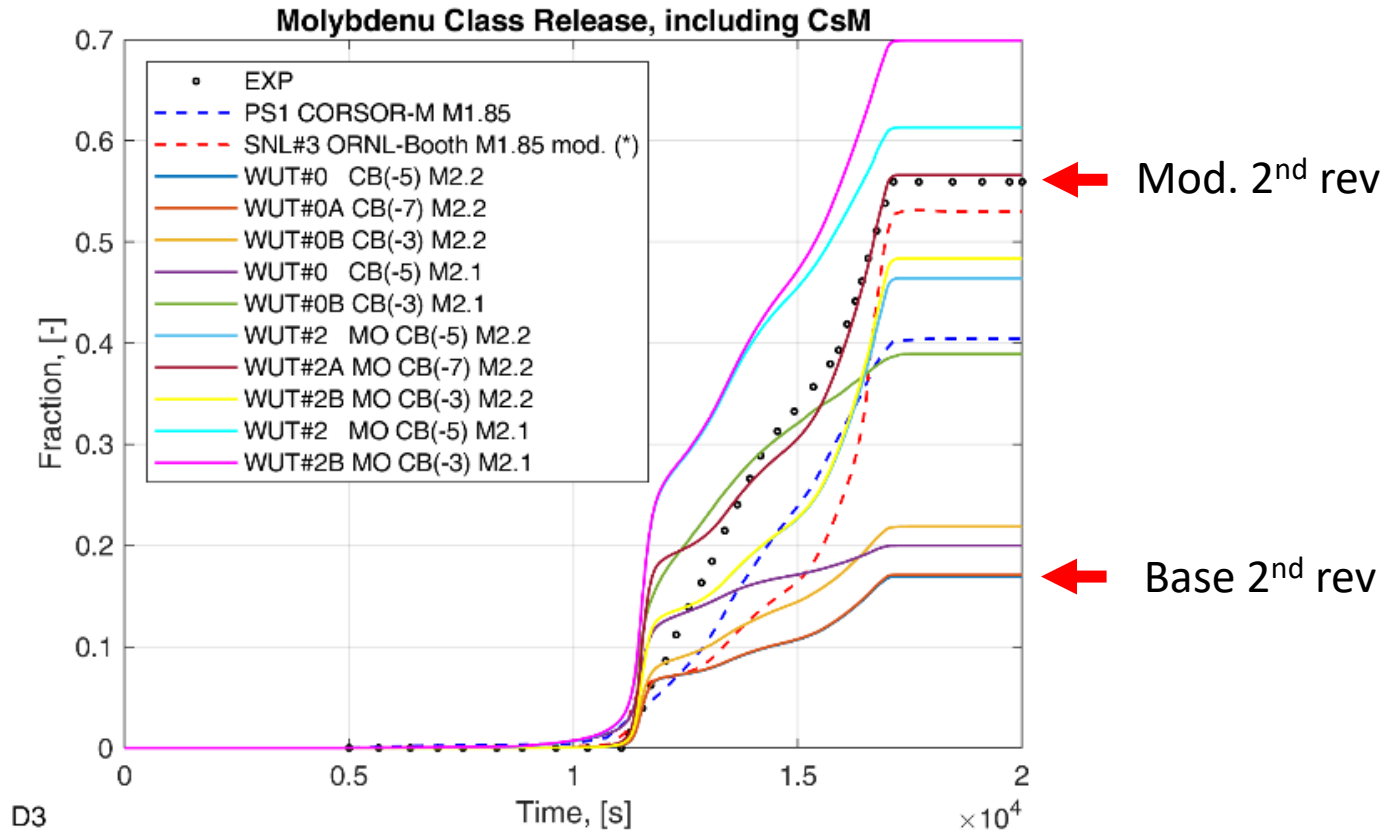

Mod. 2nd rev

Base 2nd rev

Gauntt, R.O., 2010. Synthesis of VERCORS and Phebus data in severe accident codes and applications. Sandia National Laboratories Report (SAND2010-1633).

Defining the Mo vapor pressure to be that of Cs_2MoO_4 produced significantly improved predictions of Mo release rate observed in the FPT-1 test, as will be shown in the next section of this report.

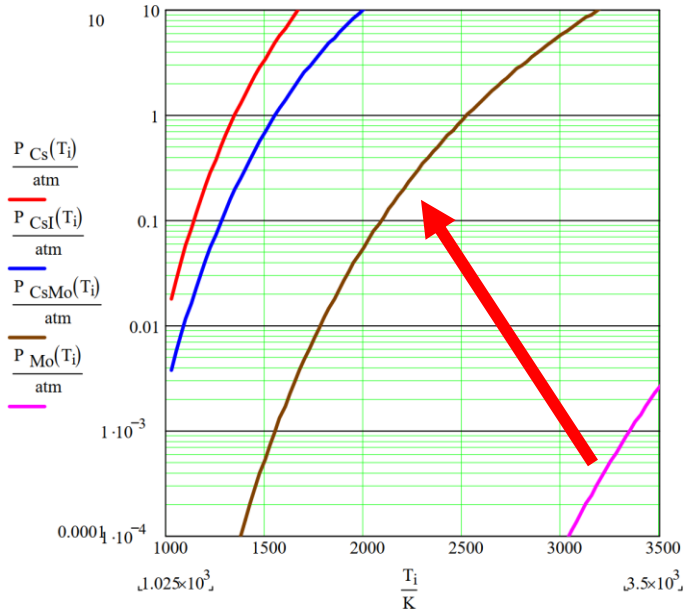

Figure 4. Vapor pressures of selected species.

Case	Code	Reference
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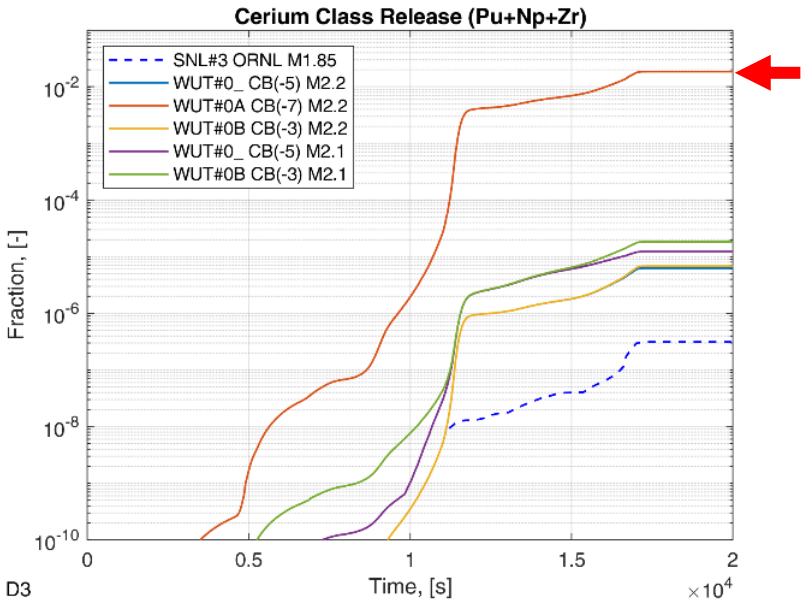
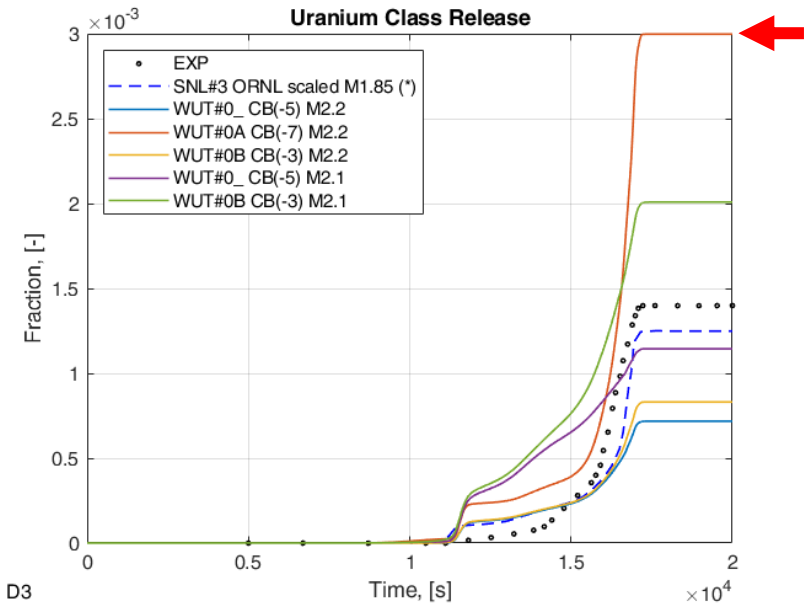
SNL#5	M2.2.11932 M2.2.9496 M2.1	(Humphries, 2018a,b)
PS1	M1.8.5	(Birchley, 2004; Clément and Haste, 2003)

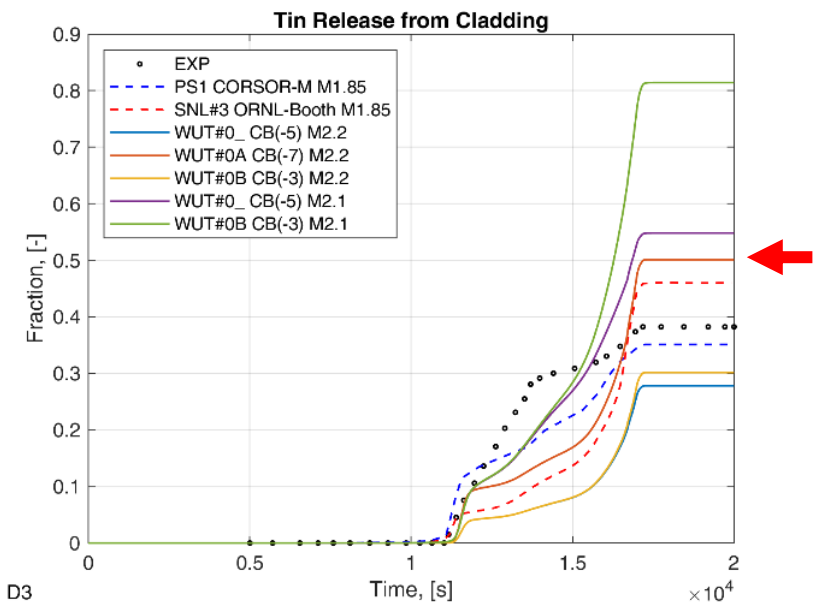
- Assuming all Cs-> CsMoO4, only about 20-30% MO class release (!)
- 20.17 g of elemental Mo and 15.86 g of elemental Cs. can bind ~5.7g Mo
- Alternative modeling: MO – Molybdenum (non-CSM) release parameters equal to CSM

CE+U+SNO2

CB - CORSOR-Booth; CB(-5) 1st revision (default), CB(-3) basic version, CB(-7) second revision.







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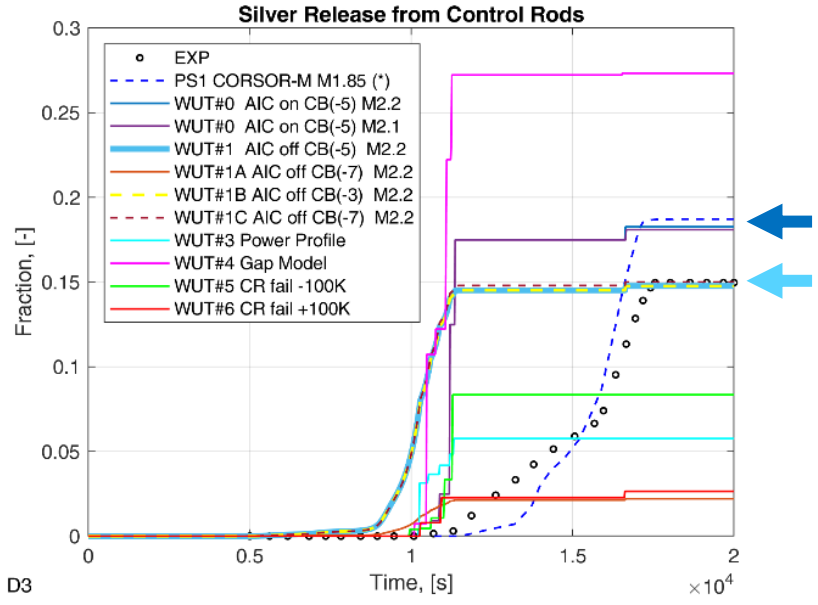
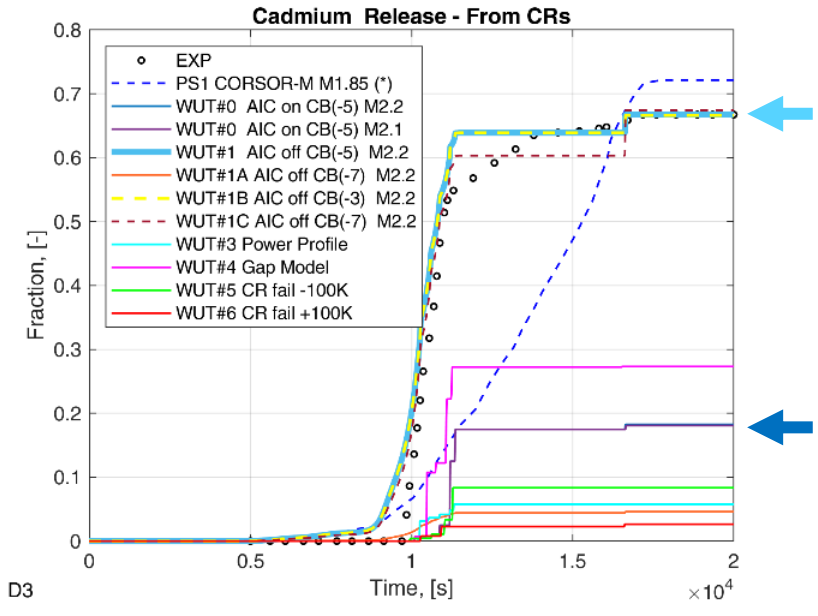
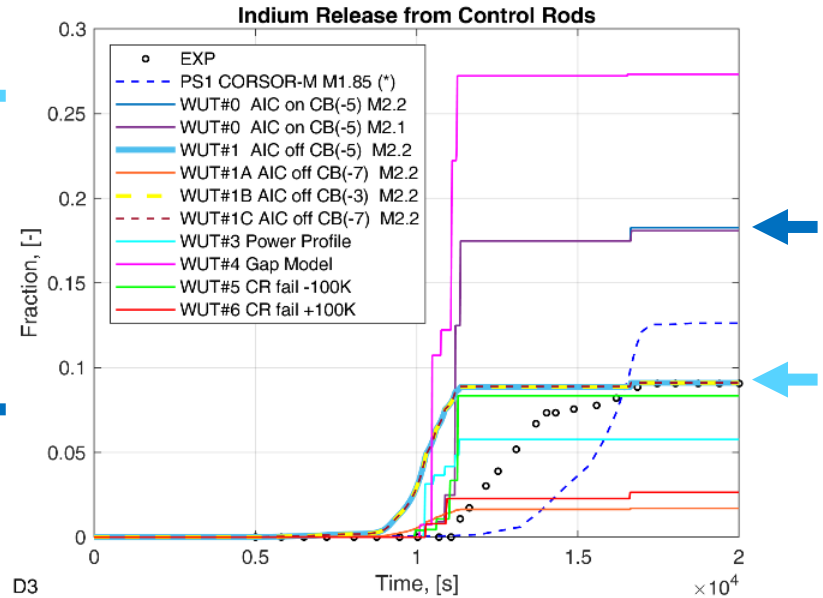
PS1	M1.8.5	(Birchley, 2004; Clément and Haste, 2003)

AIC

CB - CORSOR-Booth; CB(-5) 1st revision (default), CB(-3) basic version, CB(-7) second revision.







- Silver model – with "discrete" release events
- sensitive e.g. CR failure temp. (base is 1623K) but also to others
- Manual: Code uses lowest vapour pressure and treats AIC as single material. For Ag model it leads to constant release fraction, e.g. 18% for Ag, Cd, In
- Alternative approach based on (Birchley, 2004), CORSOR-M – fitting with SC7105
- AIC as pseudo-FP - with fit for CB 1st rev.- RN1_CSC card (SC7103 for CORSOR-Booth)
- Sensitive to revision of CB, 1st rev. fit does not work for 2nd rev.

Conclusions

- For TH, H2 M2.2 and M2.1 results very similar, for RN siginificant differences
- M2.2.11 better than M2.1, but for some RN underpredicts releases
- CORSOR-Booth Revision 2 (RN1_FP00 -7) recommended
- Be careful with AIC and Mo
- Molybdenum release to be studied
  - able to reproduce with non-physical assumptions
- Silver model to be studied - AIC release
  - able to reproduce final release with pseudo-FP, kinetics not satisfactory
- Inputdeck to be refined with more recent M2.2.18 and eutectics model
- More detailed CVH, removal of non-typical chemical speciation
- More extensive uncertainty and sensitivity is planned

References

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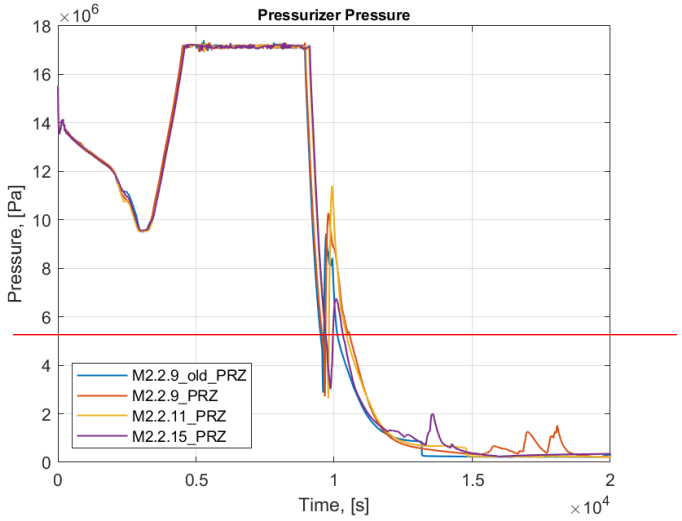
Possible code issues

- M2.2.9-2.2.15 with PWR plant model and ACC model
- SBO + some LOCA
- ACC activate, but in short time pressure increase again and injection is deactivated.
- Pressure later drops but ACC does not re-activate
- ESF-ACC-PRS and ESF-ACC-REM indicate water presence and proper pressure.
- P_activate ~ 4.9 Mpa, water ~70 m3

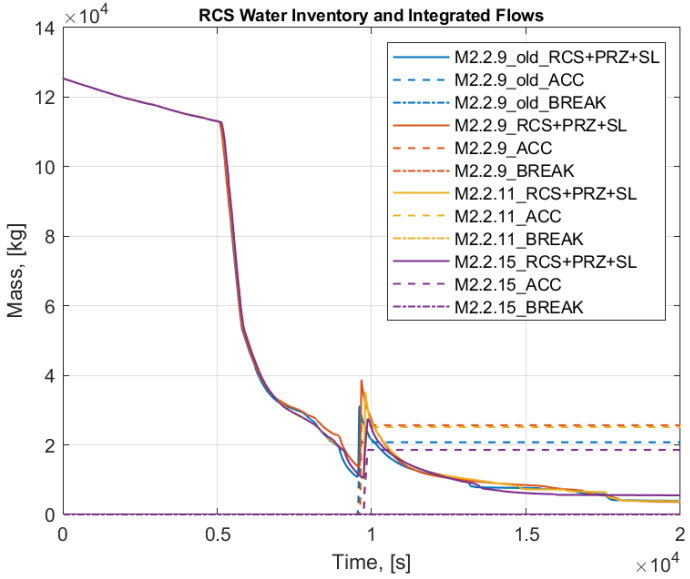


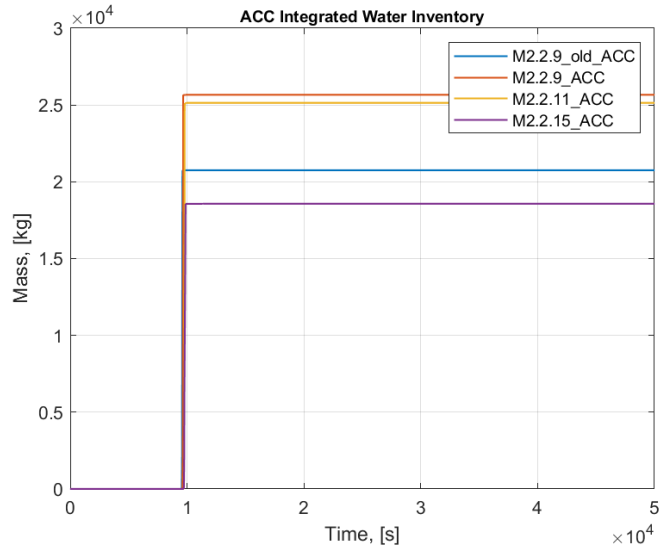
Other:

- For FPT-1 supporting plate made of zircaloy,

the material was changed to stainless steel

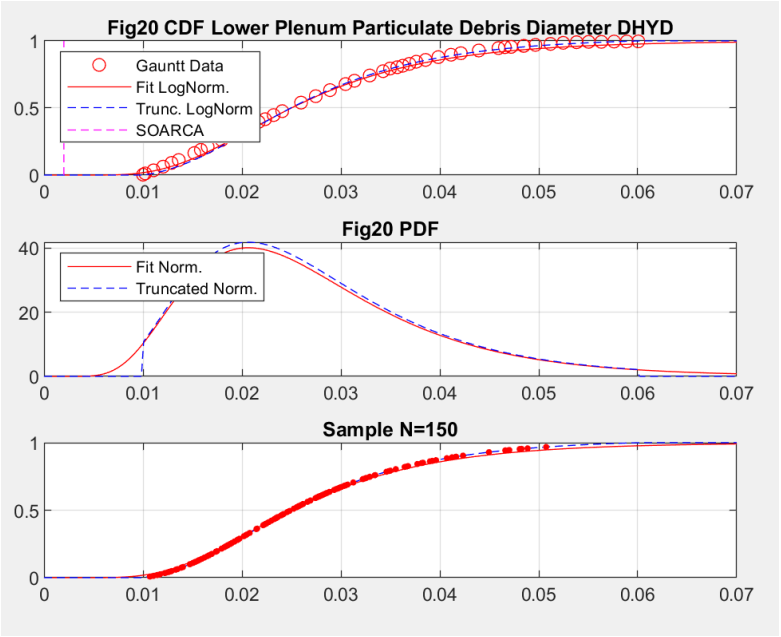
as MELCOR was not able to support the bundle





MelSUA Matlab

- Matlab tools to perform uncertanity/senstivity analysis
- MELCOR Input Variable Functionality
- PowerShell running
- MATLAB: sampling+distribution+preprocessing+postprocessing
- post-processing with EDF file or APTPLOT scripts/files processing
- Early stage of development, basic version works
- Hopefully next EMUG I will present it in more details.
- GitLab repository:
- https://gitlab.com/darczu/x-core/-/tree/master/Modules/MLC_package



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Thank you for your attention!

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