Uncertainty Quantification in Severe Accident Analyses: MUSA Insights

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MUSA

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OUTLINE

- Background
- Key Elements
- Outcomes
- Production
- What's Next

Background

https://sh1.sendinblue.com/3izxfv2tldxpfe.html?t=1685539873

MUSA

MANAGEMENT AND UNCERTAINTIES OF SEVERE ACCIDENTS

This last newsletter brings us all to the end of what's been an exciting journey to me: The Management and Uncertainties of Severe Accidents (MUSA) project. Before any further technical consideration, let me sincerely appreciate each and every piece of work you have done along these four years. No less important, my deep gratitude to all those who were instrumental in the coordination of the individual workpackages for their excellent job and their empathy. Finally, it is a must to explicitly mention the exceptional work done by the PMO, without which none of us would have reached this "coastline".

Background

The Drivers

Severe Accidents are the major contributors to NPP risk!
The "safety case" heavily relies on simulations!

How accurate are SA simulations?

Can uncertainties affect Accident Management?
Can Accident Management affect uncertainties?

Priorities for further research?

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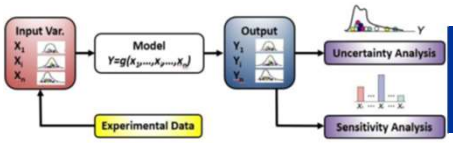
Background

The Right Timing

- **"Maturity"** of SA codes.
- Need to know SA codes **predictability.**
- **Optimization** of SA research (C/B).
- Major **computational resources!**

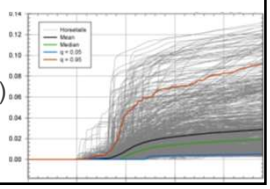
"The Age of UaSA in SA"

Background



Not the first, BUT ...

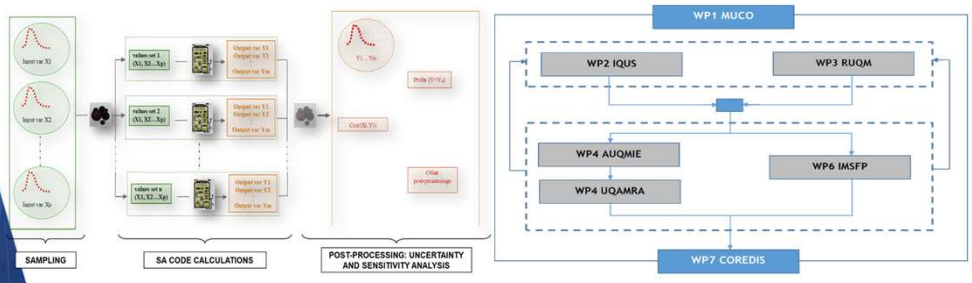
- **BEPU** was born in **Thermal-hydraulics** (USNRC: 1974-1986).
- **BEPU** was "passed to & taken forward" by OECD/CSNI.
  (NEA/CSNI/R(1994)20; NEA/CSNI/R(97)35; NEA/CSNI R(97)4; …)
- **BEPU** has since been under development.
  BEMUSE(2004-2010); PREMIUM(2012-2015); SAPIUM (2017-2019); ATRIUM (2021-)
- Pioneering work brought **BEPU into SA** (Khatib-Rahbar et al., 1989).
- And … updated 15 years later (Gauntt et al., 2005).
- Ending up in the SOARCA Study (NUREG-2254; 2022)



Key Elements

Objectives & Structure

- Management and Uncertainties of Severe Accidents).
  H2020 GA nº 847441 (625 p-m); 2019-2023.
- **Aim:** To quantify uncertainties in SA codes' predictions (AM!) (FOM: Source Term).



(Gen. II & III; SFPs)

Outcomes

Major «tangible» achievements

- An extensive **UP* database!**
- A vastly diverse & tested range of **methods & tools!**
- A large variety of reactor & scenarios **UQ database!**
- A "first-of-a-kind" **UQ SFP application!**
- A "still growing" dossier of **open references & more!**

* Uncertain Parameter

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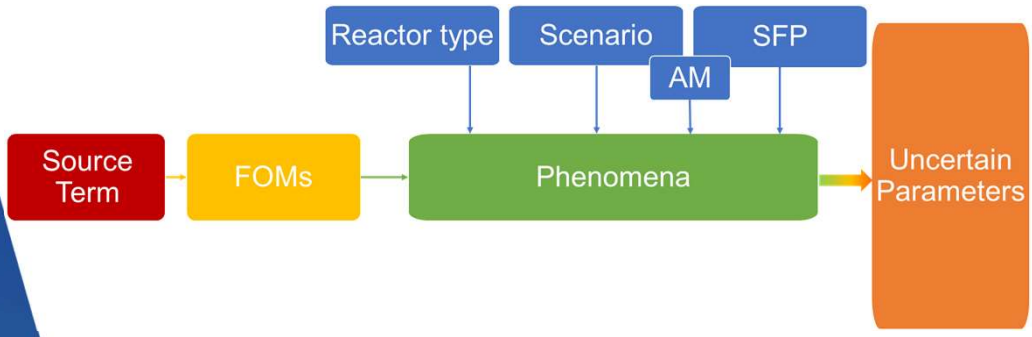
Outcomes

The UP Database



- **400 (+150) UP identified & characterized** (UB; LB; pdf).
- **"Substantiated expert judgement".**

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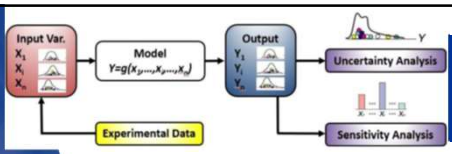
Outcomes

The UP Database

Phenomena	Uncertain Parameter	Reference value	Lower bound	Upper bound	pdf	References
Sedimentation	Gas viscosity [kg/ms]	1.0 / N/A	-5% / N/A	+5% / N/A	Uniform	Expert Judgment
	Gas temperature [K]	N/A	N/A	N/A	N/A	N/A
	Gas pressure [Pa]	1.55E+07 / N/A	-1.5% / N/A	+1.5% / N/A	Normal	Expert Judgment
	Gas mean free path	N/A	N/A	N/A	N/A	N/A
	Particle diameter Lower Bound [m]	0,000000011	0,00000001	0,0000002	Triangular	1986 Helton et al. "Uncertainty and Sensitivity Analysis of a Model for Multicomponent Aerosol Dynamics"; 2009 NEA/CSNI "State-of-the-Art Report on Nuclear Aerosols"
	Particle diameter Upper Bound [m]	0,000199	0,000005	0,00002	Triangular	1986 Helton et al. "Uncertainty and Sensitivity Analysis of a Model for Multicomponent Aerosol Dynamics"; 2009 NEA/CSNI "State-of-the-Art Report on Nuclear Aerosols"
	Slip factor (default = 1.257)	1,257	1,14	1,28	Triangular	1990 D. J. Rader. "Momentum slip correction factor for small particles in nine common gases"; MELCOR Default; Expert judgment (pdf)

Outcomes



Methods & Tools

UQ Tool	SA Code
DAKOTA/Python scripts	MELCOR2.2
DAKOTA	MELCOR2.2
DAKOTA /SNAP	MELCOR2.2
DAKOTA/SNAP, MATLAB script	MELCOR2.2
DAKOTA/SNAP	MELCOR2.2
DAKOTA	MELCOR1.8.6
DAKOTA, Python, ass. packages	MAAP5.05

UQ Tool	SA Code
SUNSET	ASTEC2.2b
SUNSET	ASTEC2.2b
SUNSET	ASTEC2.2b

UQ Tool	SA Code
SUSA4.2	AC^2
SUSA4.0	MELCOR2.2
SUSA4.2	RELAP/SCDAP

UQ Tool	SA Code
Python Tools	MELCOR 2.2
Python in-house Tool	MELCOR 2.2
Scripts	MELCOR2.2

UQ Tool	SA Code
RAVEN	MELCOR2.2
URANIE	ASTEC2.1

- **Diversity in codes and tools** (strength/weakness).
- **Convergence in key choices … to come!**

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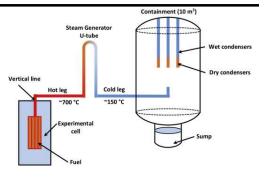
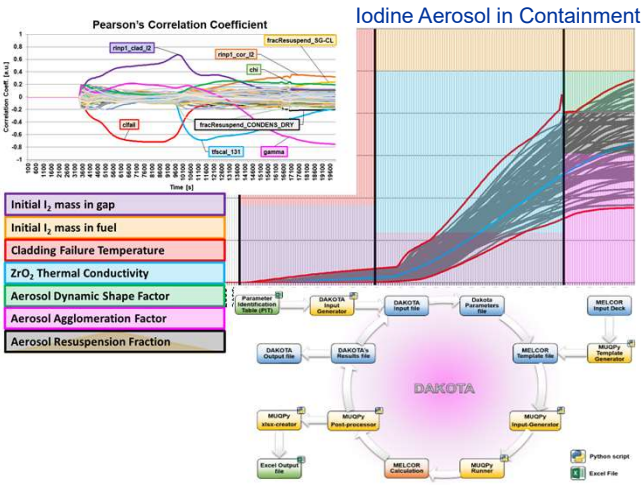
Outcomes



The Coupling & Training

PHEBUS-FPT1 modeling



Iodine Aerosol in Containment

(Bocanegra & Herranz, 2022)

Outcomes

In-Reactor Applications

#	Partner	NPP	Scenario(s)	SAM
1	BelV	PWR-1000	LBLOCA	
2	CIEMAT/UNIPI	PWR (Surry)	SBO	
3	CNPRI	HPR-1000	LBLOCA	
4	ENEA	PWR-900	SBO	
5	ENSO	PWR 4-Loops	LT-SBO at Low P	
6	EPRI	PWR (Surry)	ELAP w/o SAM ELAP+SAM	AC restored at RPV failure
7	GRS	KONVOI	MBLOCA+SBO	
8	IRSN	PWR-900	SBO+Loss of aux. FW	Sump flooding, CFVS
9	KAERI	APR-1400	C-SGTR by SBO	
10	KIT/Framatome	KONVOI	MBLOCA w/o SAM MBLOCA+SBO MBLOCA+SAM	CFVS
11	PSI	PWR-1100	SBO+SGTR	SG re-flooding
12	SNERDI	CAP-1400	LOCA+SBO	
13	TRACTEBEL	PWR-1000	SBO	Cavity flooding+CFVS

Outcomes

In-Reactor Applications

#	Partner	NP
1	BelV	PWR-
2	CIEMAT/UNIPI	PWR (
3	CNPRI	HPR-
4	ENEA	PWR
5	ENSO	PWR 4-
6	EPRI	PWR (
7	GRS	KON
8	IRSN	PWR
9	KAERI	APR-
10	KIT/Framatome	KON
11	PSI	PWR-
12	SNERDI	CAP-1400
13	TRACTEBEL	PWR-1000

#	SA Code	U&S Tool	#UPs	#FoM	#Calcs. for UQ
1	MELCOR	URANIE			
2	MELCOR	DAKOTA	24	3	93
3	ASTEC	SUNSET	5	8	100
4	MELCOR	DAKOTA	8	1	130
5	RELAP/SCDAP	IUA2.0	19	26	124
6	MAAP	Python	232	12	500
7	AC2	SUSA	81	10	100
8	ASTEC	SUNSET, Python	43	12	100
9	MELCOR	DAKOTA	6	4	300
10	ASTEC	KATUSA	18	6	900 (300*3)
11	MELCOR	DAKOTA, Python	17	2	100
12	MAAP	DAKOTA			
13	MELCOR	Python	15	6	111

LOCA+SBO

SBO

Cavity flooding+CFVS

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Outcomes

In-Reactor Applications

#	Partner	NP
1	BelV	PWR-
2	CIEMAT/UNIPI	PWR (
3	CNPRI	HPR-
4	ENEA	PWR
5	ENSO	PWR 4-
10	KIT/Framatome	KON
11	PSI	PWR-
12	SNERDI	CAP-1400
13	TRACTEBEL	PWR-1000

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12	MAAP	DAKOTA			
13	MELCOR	Python	15	6	111

- **DB in technology/scenarios/UQ approaches/ …** (strength/weakness)**.**
- **Preliminary insights into AMgmt.**
- **Cross-comparison might "substantiate" some options!**

LOCA+SBO		
SBO	Cavity flooding+CFVS	

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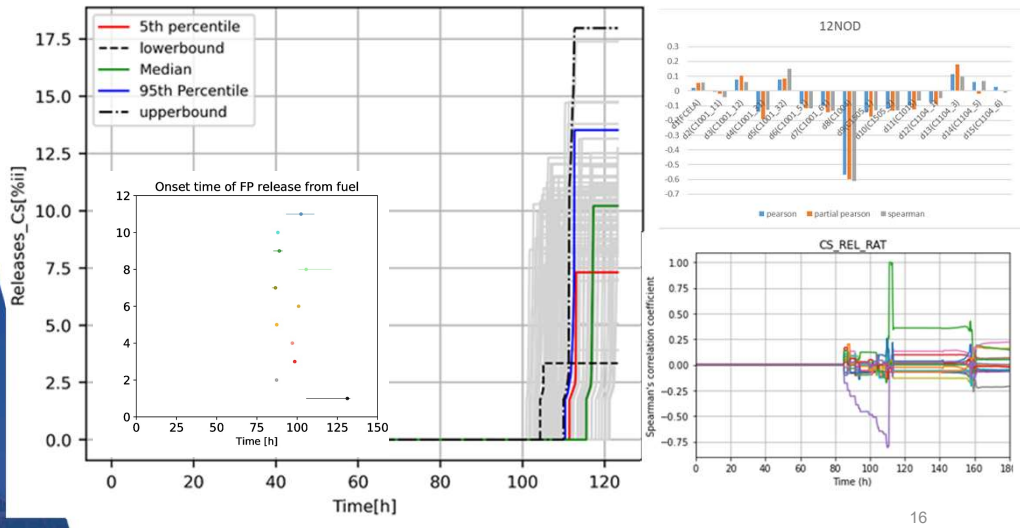
Outcomes

In-SFP Applications



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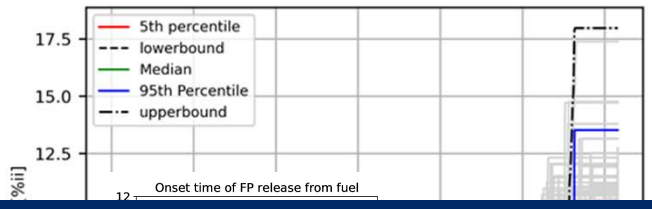
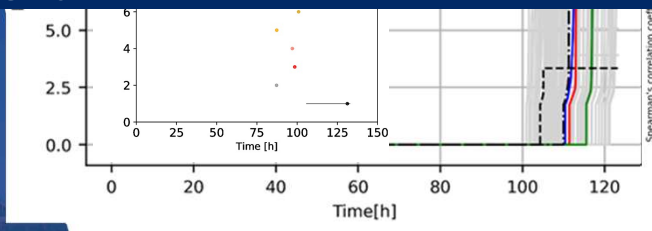
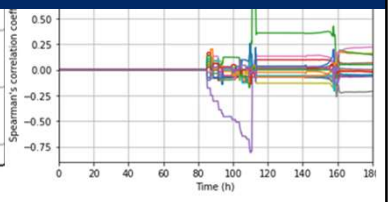
Outcomes

In-SFP Applications



- **Onset of fuel melting (1%)**
- **Specific, highly conditioned** (FOMs; termination; phenomena; BCs; codes; …) scenario.





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Outcomes

Major «intangible» achievements

- **A journey from an uneven to an “even” community:**
  “Diffusion driven by expertise & knowledge forward/backward gradients”.
- **A “grown” community in an “unexplored world”**
  “Team work” proved to be resourceful when working out of the comfort zone.
- **An “empowered community” ready to give the best**
  Self-criticism, stamina to keep fighting, and an open mind to look ahead.

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NUGENIA 2019 Forum
FISA 2019
EUROSAFE 2021 Forum
SNETP 2021 Forum
NESTet Conference 2021
FISA 2022
SNETP Coordinators Hub Day
SNETP 2023 Forum

Production

MUSA C&D Numbers

General presentations at Conferences and meetings	20
Main Communication Events	8
Technical Presentations at Conferences	17
joint	7
planned	+3 + **ERMSAR**
Articles on scientific journals	8 (+)
joint	4
planned	+2
Forecasts	10 – 25 ind. papers

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Production

MUSA C&D Numbers

- "The EC MUSA Project on Management and Uncertainty of Severe Accidents: Main Pillars and Status", Energies, 2021, 14, 4473
- "UQ for a SA sequence in a SFP in the frame of the H-2020 project MUSA: first outcomes", Annals of Nuclear Energy, 188, 2023. ISSN 0306-4549, https://doi.org/10.1016/j.anucene.2023.109796.
- "Status of the Uncertainty Quantification for Severe Accident Sequences of different NPP designs in the frame of the H-2020 project MUSA", Annals of Nuclear Energy, 188, 2023. ISSN 0306-4549, doi.org/10.1016/j.anucene.2023.109796.
- "Main outcomes of the Phebus FPT1 uncertainty and sensitivity analysis in the EU-MUSA project", submitted to NED/ANE.

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Production

Education & Training

- **3 learning modules** (MSc students & to generic audience:

1. **Analysis of SA from the Early Days to the Next Future** (CIEMAT) – on web
2. **Methodologies for uncertainty assessment in SA** (UNIPI) – on web
3. **ST Uncertainties in Fukushima-like scenarios** (CIEMAT) – on web

Module 1

Module 2

Module 3

- **A Specific lecture in the SAP Course Technical Programme**

What's Next

Challenges Ahead

- **The UP database optimization** (filling; extension; restrc.).
- **A systematic consolidation of UaSA application in SA.** (#UP; nodding; FOMs; …) – **Innovation.**
- **A "balanced" use of expert judgement.**
- **Further attention to accident management** (forward/reverse effect).
- **Show-cases for innovative technologies** (ST-ATFs; LW-SMRs)

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What's Next

INNOMUSA: General Goals

- To **exploit the achievements** made in **MUSA.**
- To **consolidate a systematic methodology.**
- To **focus on AM*:** Effect of U on AM & Effect of AM on U.
- To **address innovation Ntech.:** NT-ATFs; LW-SMR

*** Decision making efficiency and effectiveness**

What's Next

INNOMUSA: Outlook

- **The Community is ready** (skills & tools).
- **The MUSA DBs are available** and "optimizable".
- **A final key step still ahead, though: INNOMUSA.**
- **Efficient articulation indispensable.**
- **Major focus: Accident Management*.**
- **Final outcome: a systematic & proved Methodology**
  (showcases for eATFs & SMRs included)

* Decision making efficiency and effectiveness

What's Next

INNOMUSA: A Project on the making

& (UNIPI;LGI)

Dissemination

METHOD
(KIT; GRS)

- Uncertainty DB
  (approach?; qualification; extensión; …)
- UA Approach
  (MC, Wilks, others, …;
  FOMs; parameters;
  bifurcations; outliers; bias; crashes; …)
- Data analysis (SA)
  ("Best suite"; physical consistency; …)
- Noding/ Phasing / Noise / Nmrcs

EDUCATION & TRAINING (ENEN+)

APPLON
(ENEA; JRC)

- Water-cooled reactors
  (Gen-II & Gen-III; AMgmt)
- LW-SMRs
  (Av. Designs; SASPAM)
- Amgmt*
- Short-term ATFs (shc)
- Spent fuel pools (shc)

Communication

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Thank you for your attention!

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MUSA has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847441.

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