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Species Mass Transport Analysis of a Versatile Experimental Salt Irradiation Loop (VESIL)

Samuel Austin Walker

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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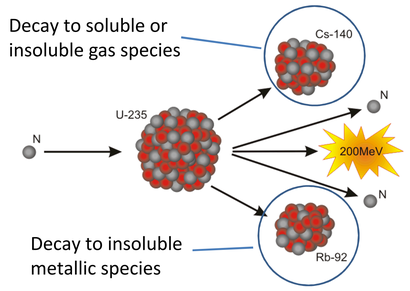
Species Mass Transport Analysis of a Versatile Experimental Salt Irradiation Loop (VESIL)

Samuel A. Walker – Rensselaer Polytechnic Institute
Contact Information: walkes4@rpi.edu
Mentor: A. Abou-Jaoude **With:** S. Bhaskar – **Nuclear Science & Technology:** Reactor Physics Design & Analysis

Motivation

- Molten Salt Reactors (MSRs) are fluid fuel nuclear reactors originally developed by Oak Ridge National Laboratory in the 1960's
- Fission products (Fig. 1) are generated directly in the coolant-fuel-salt and circulate throughout the entire primary loop

Fig. 1 - Fission Product Generation



- Insoluble fission products (Fig. 2) precipitate out of the salt and can be categorized into two groups – Noble Metals (Nb – Te) and Noble Gases (Kr & Xe)
- Understanding and controlling insoluble fission product behavior is key for safe and efficient MSR design and operation

Objectives

- Develop and couple various physics models to track insoluble fission products within the TH code CTF
- Solve Coupled PDEs - $\frac{\partial N}{\partial t} = -(\nabla \cdot Nv) + S$
- Characterize Noble Metal and Noble Gas interactions within VESIL – a dynamic fuel-salt loop proposed for irradiation in the ATR

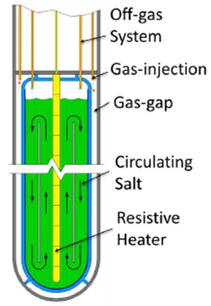
41	42	43	44	45	46	47	48	49	50	51	52	53	54
Nb	**Mo**	**Tc**	**Ru**	**Rh**	**Pd**	**Ag**	**Cd**	**In**	**Sn**	**Sb**	**Te**	**I**	**Xe**
Niobium	Molybdenur	Technetium	Ruthenium	Rhodium	Palladium	Silver	Cadmium	Indium	Tin	Antimony	Tellurium	Iodine	Xenon
92.906	95.95	(98)	101.07	102.91	106.42	107.87	112.41	114.82	118.71	121.76	127.60	126.90	131.29

Fig. 2 - Insoluble Fission Product Species – Beta Decay Chains

VESIL Design

- Natural circulation
- Choice of gas plenum or off-gas extraction system
- Choice of gas accumulation or inert gas sparging

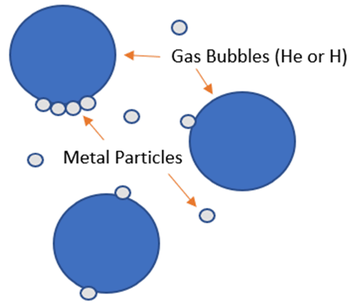
Fig. 3 – VESIL Geometry



Physical Model

- Mass transfer mechanisms: particle – wall, particle – bubble.
- Concentration gradient driven diffusion & convection model

Fig. 4 – Agglomeration Processes



Results – He Sparging: $^{132}Sn \rightarrow {}^{132}Sb \rightarrow {}^{132}Te \rightarrow {}^{132}I \rightarrow {}^{132}Xe$

Fig. 5 – He Bubbles in Loop

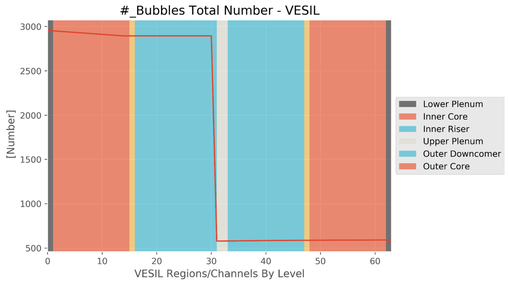


Fig. 7 – ^{132}Te on He Bubbles

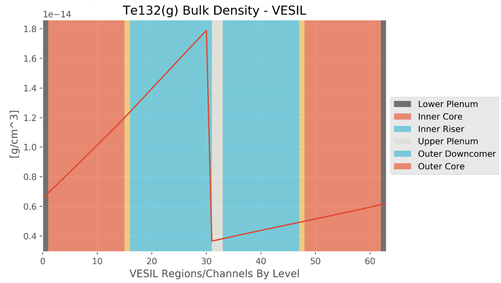


Fig. 6 – ^{132}Sb on VESIL Walls

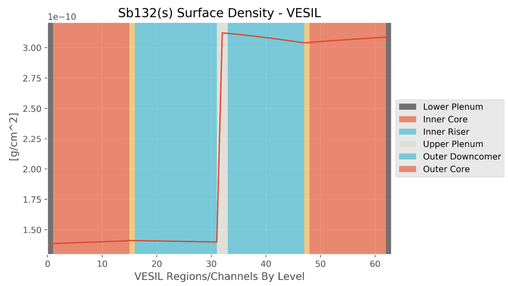
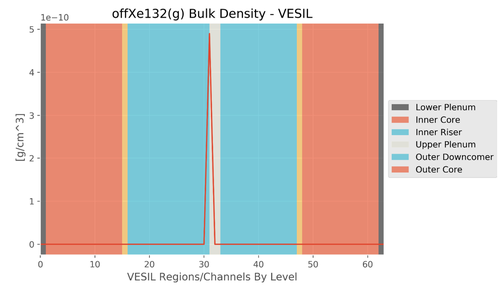


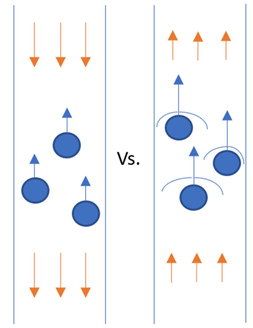
Fig. 8 – ^{132}Xe in Off Gas System



Discussion

Fig. 9 – Sparging Options

- Current sparging design uses numerous small bubbles in concurrent flow
- Other options include countercurrent flow and concurrent flow driven by larger bubbles



- Redox (Fluorine/Chlorine Potential) control can be achieved via sparging with H gas. Redox control will directly effect the speciation and solubility of some fission products (Te, Nb, etc.)

Conclusions

- Simplest VESIL design model shows gas plenum design to be adequate although source term build up is larger
- Gas sparging design model shows enhanced gas/source term mitigation as well as extraction of noble metal particles
- Additional mesh filter may be needed to collect noble metal particles before entering off gas system

References

1. Abou-Jaoude, A. Evaluation of a Versatile Experimental Salt Irradiation Loop (VESIL) inside the Advanced Test Reactor (2019)
2. Underground Bomb Shelter, Understanding Radiation (2019)

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