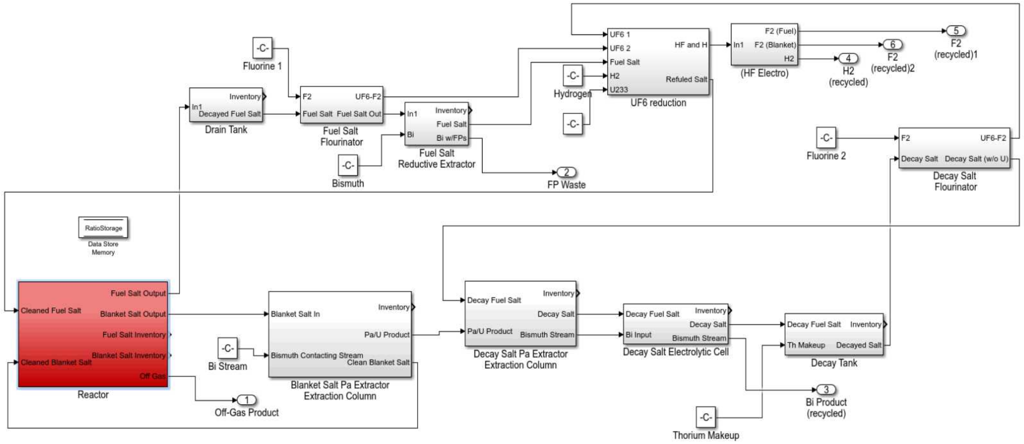
SAND2018-5585C

Developing a Molten Salt Reactor Safeguards Model



PRESENTED BY

Ben Cipiti & Nathan Shoman

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Acknowledgement

- **This work has been funded through the DOE NE MPACT (Material Protection Accounting and Control Technologies) program area.**

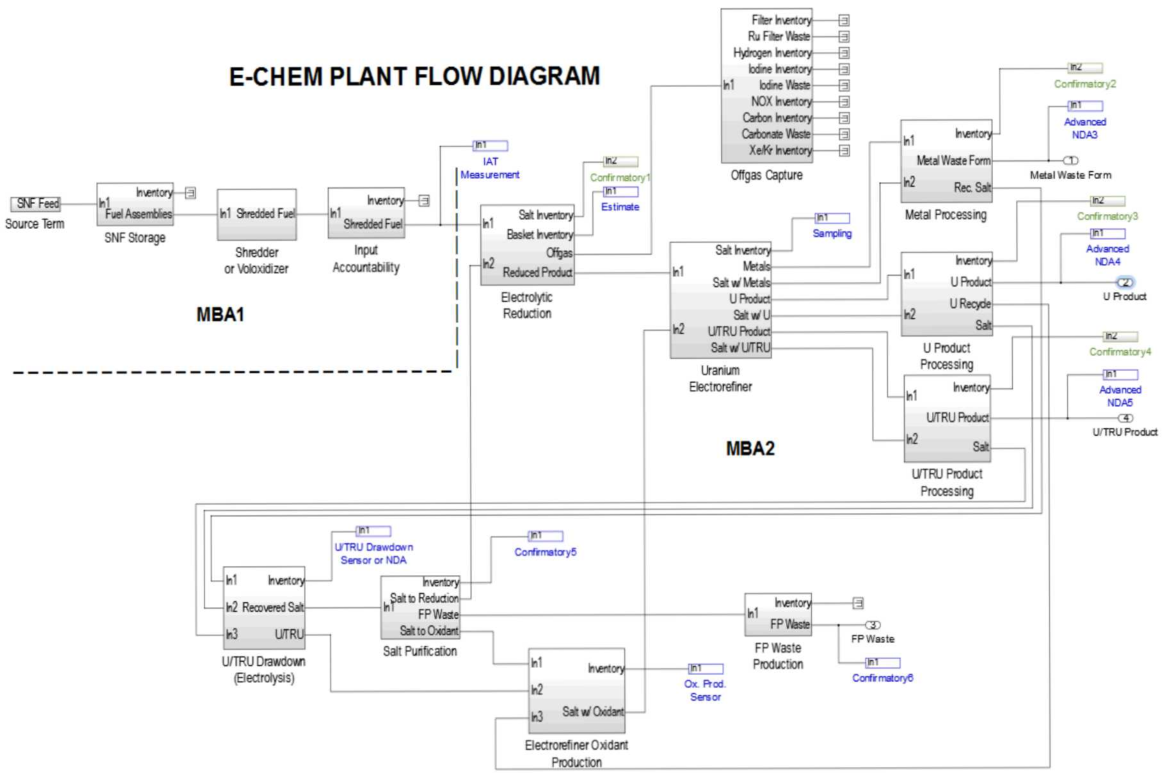
Overview

- **Renewed interest in MSRs is being driven by nuclear startups.**
- **Depending on the design, MSRs can have more safeguards challenges than a typical LWR.**
- **Part of MPACT's purpose is to help the larger DOE NE program with safeguards and security needs.**
- **An existing modeling capability was extended to examine safeguards for MSRs.**

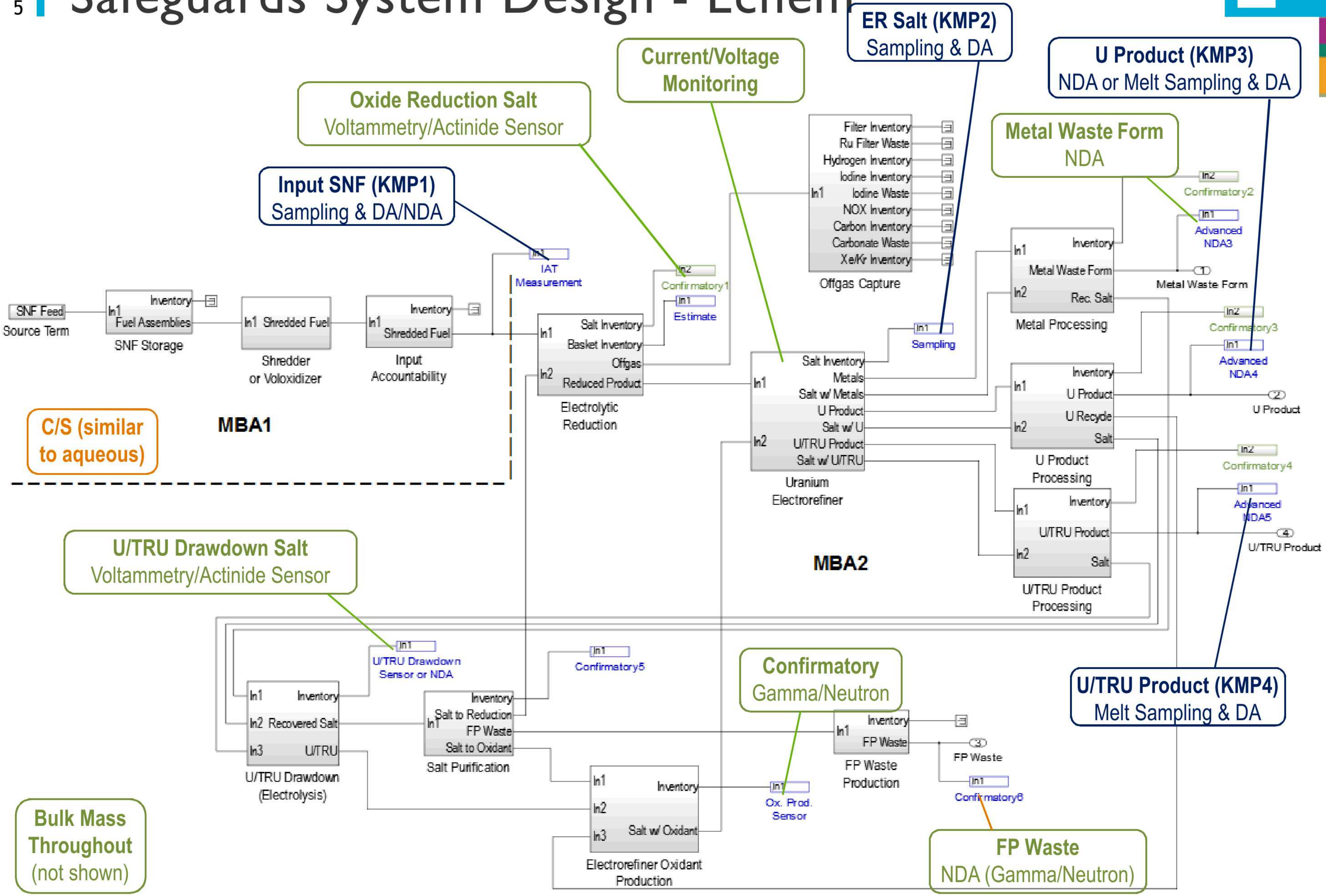
Separation and Safeguards Performance Model (SSPM) Capabilities

The SSPM is a transient mass tracking and safeguards model based in Matlab Simulink.

- Spent fuel source term library – integration with SCALE to accommodate most fuel types
- Full elemental and isotopic tracking, and bulk materials
- Customizable measurement points
- Automated calculation of MUF and error propagation in real time.
- Diversion scenario analysis
- Integration of process monitoring data



Safeguards System Design - Echem



Three Types of MSRs

- **Liquid-fueled, drop-in design, with centralized salt processing**

  Cores are designed to be self-contained for ease of installation and replacement. This design shifts some of the accountancy requirements to a centralized facility.

- **Liquid-fueled design with on-site salt processing**

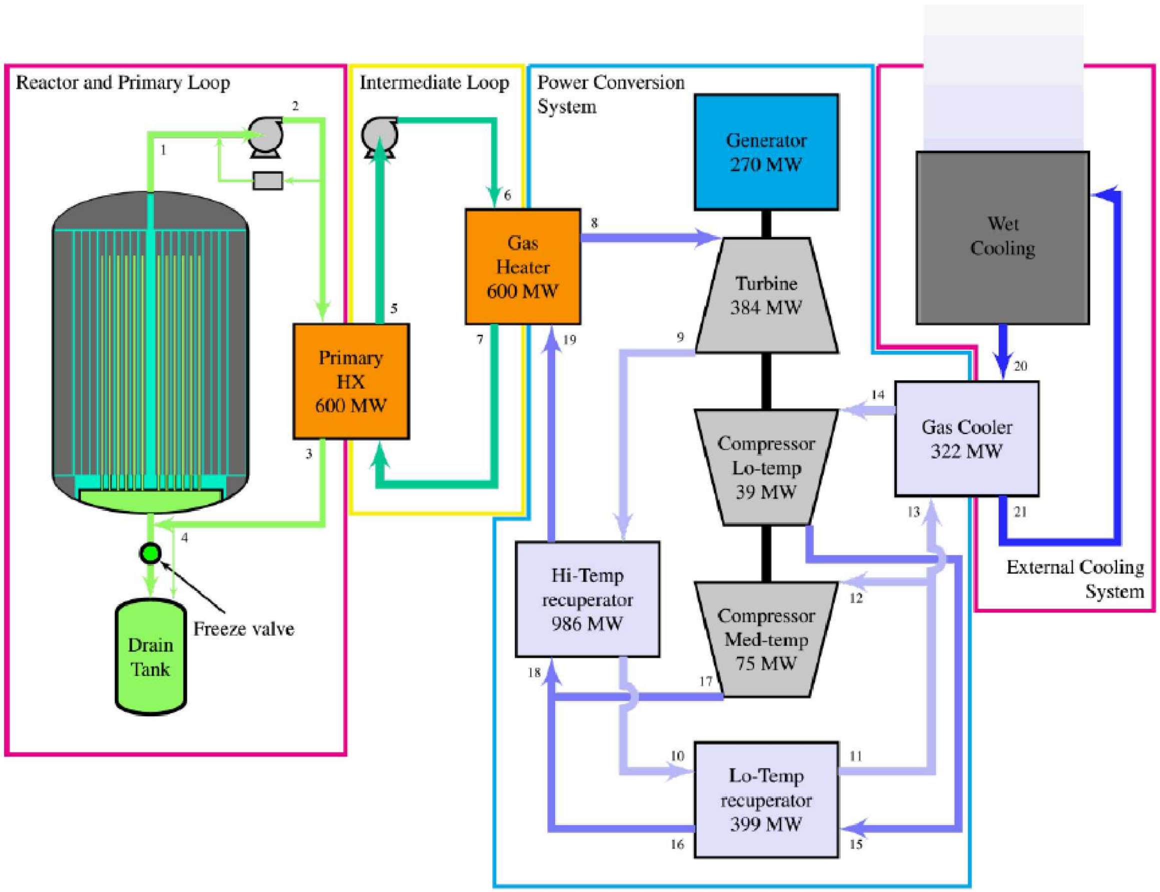
  Modeling Focus

  Salt processing on-site only removes fission products, but does not separate out actinides. Requires much less transportation of nuclear material at the expense of more accountancy challenges.

- **Solid TRISO fuel elements (either pebble bed in MS or fixed assemblies)**

  Fixed assemblies would have no greater safeguards challenge than with LWRs. Pebble beds have the added complication of accounting of pebbles (though huge numbers need to be diverted for a significant quantity).

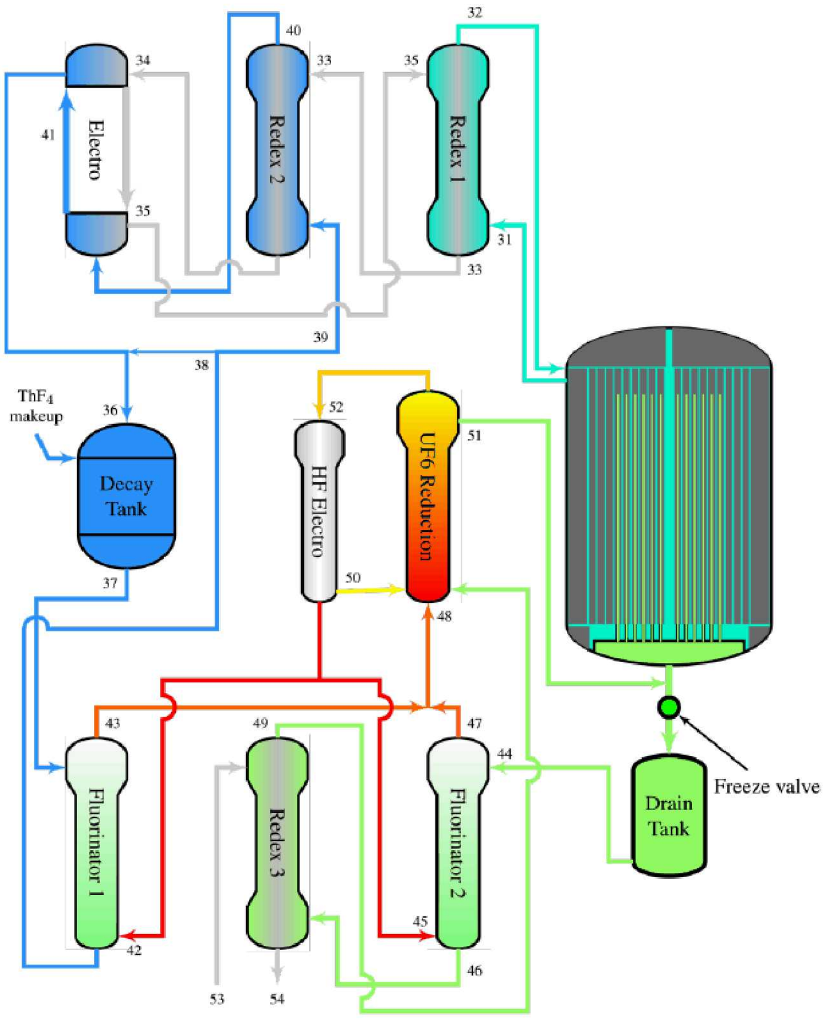
LFTR Primary Loop and Power Conversion



- Flibe based salt as primary coolant, contains fuel.
- Primary loop flow rate ~ 1700 kg/s
- Fission product gas removal is necessary since Xe-135 is a strong neutron poison. A sparging process is included on the primary loop.

Reference: A. Sowder, "Program on Technology Innovation: Technology Assessment of a Molten Salt Reactor Design: The Liquid-Fluoride Thorium Reactor (LFTR)," Electric Power Research Institute (October 2015).

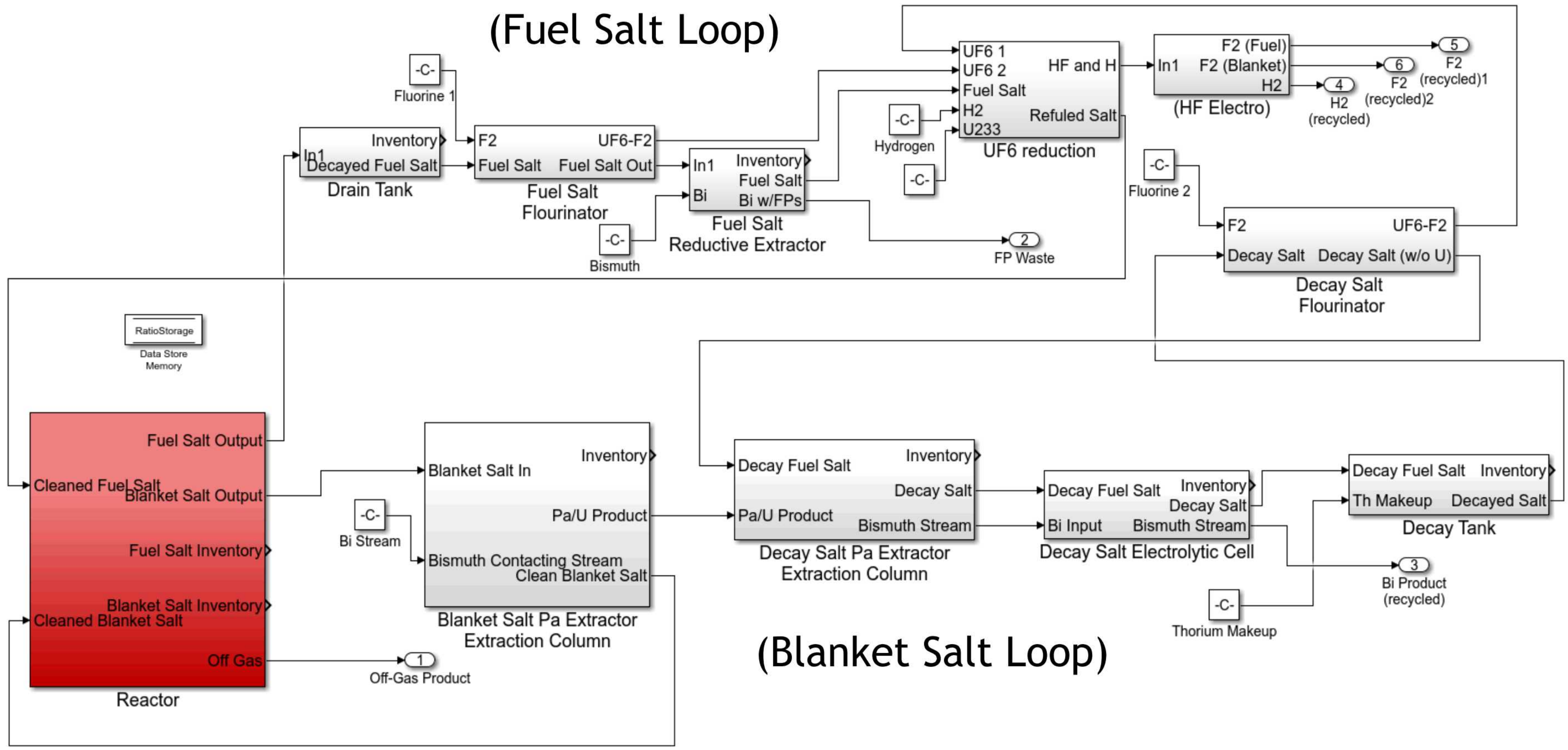
LFTR Chemical Processing System



- Mass flow rate of the fuel salt ~ 0.8 g/s.
- Mass flow rate of the blanket salt ~ 380 g/s.
- Metallic bismuth is used for the extraction processes.
- The blanket contains Th to breed $^{233}Th \rightarrow {}^{233}Pa \rightarrow {}^{233}U$. The decay tank must hold the material for about 100 days to allow time for Pa-233 to decay. The ^{233}U is transferred to the fuel salt.
- The fuel salt decays in the drain tank for about 30 days for short-lived species to decay. Then fission products are removed and ^{233}U is added.

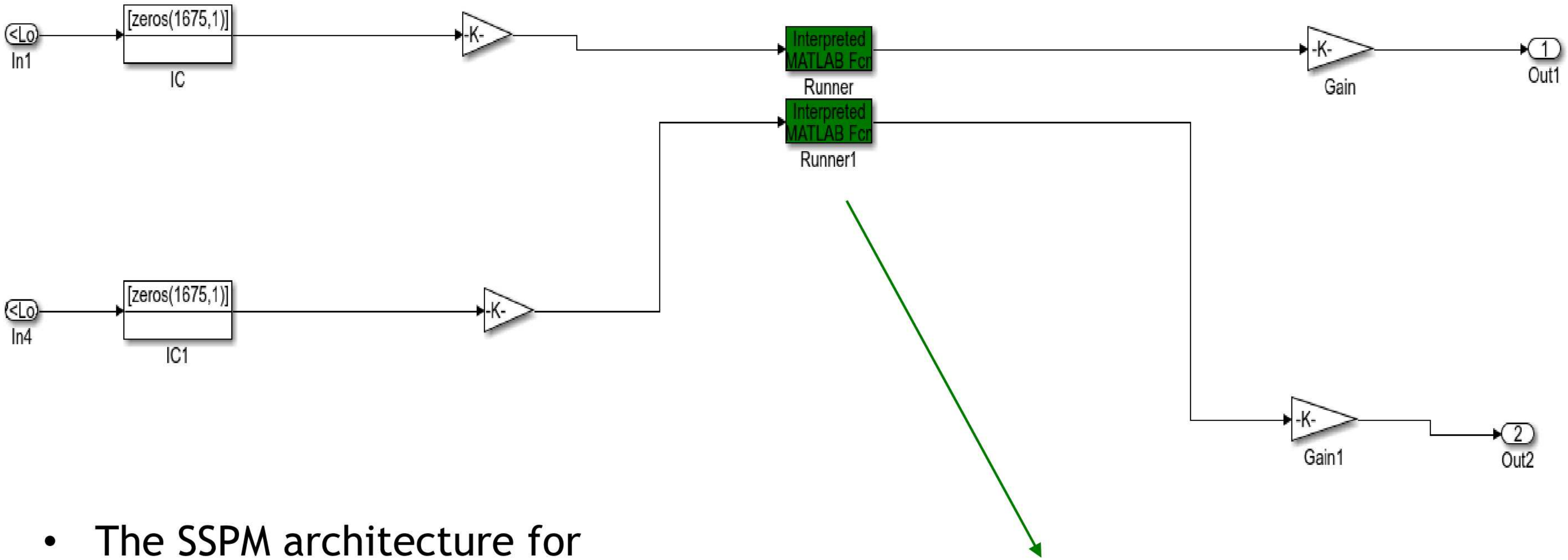
Reference: A. Sowder, “Program on Technology Innovation: Technology Assessment of a Molten Salt Reactor Design: The Liquid-Fluoride Thorium Reactor (LFTR),” Electric Power Research Institute (October 2015).

MSR Safeguards Model



Reference: A. Sowder, “Program on Technology Innovation: Technology Assessment of a Molten Salt Reactor Design: The Liquid-Fluoride Thorium Reactor (LFTR),” Electric Power Research Institute (October 2015).

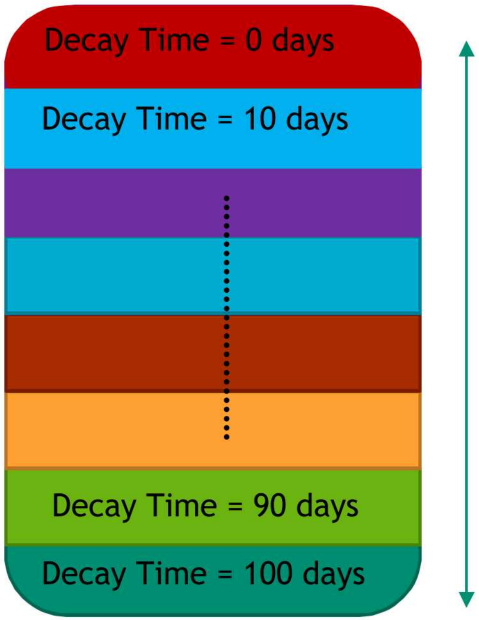
Reactor Block



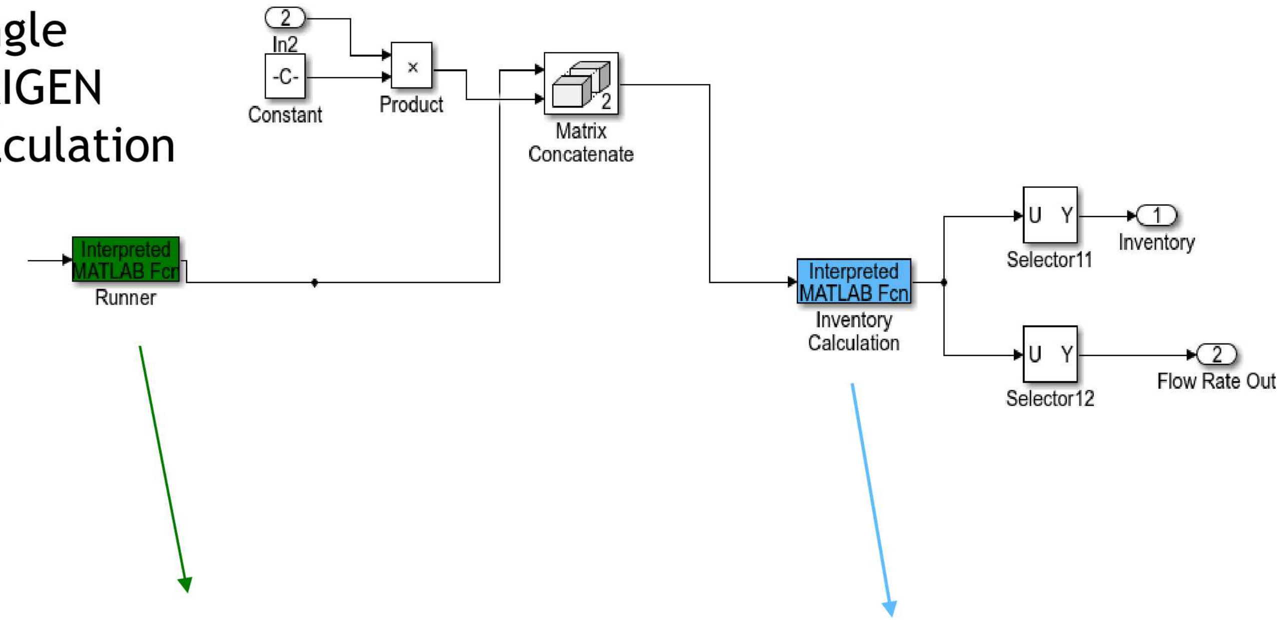
- The SSPM architecture for reprocessing tracks total elemental quantities as a function of time, and calculates isotopic ratios for each element group based on mixing.
- For the MSR model, the architecture was changed to track full isotopic mass flow rates.

Runner: Writes isotopic masses from the process model to **ORIGEN** or **TRITON** template and executes. Output is then passed back to model. Two calculations are performed, one for blanket salt and one for fuel salt.

Decay and Drain Tank Calculation



Single ORIGEN calculation



Decay of materials in tank simulated and stored in “slices” to approximate continuous change in input material.

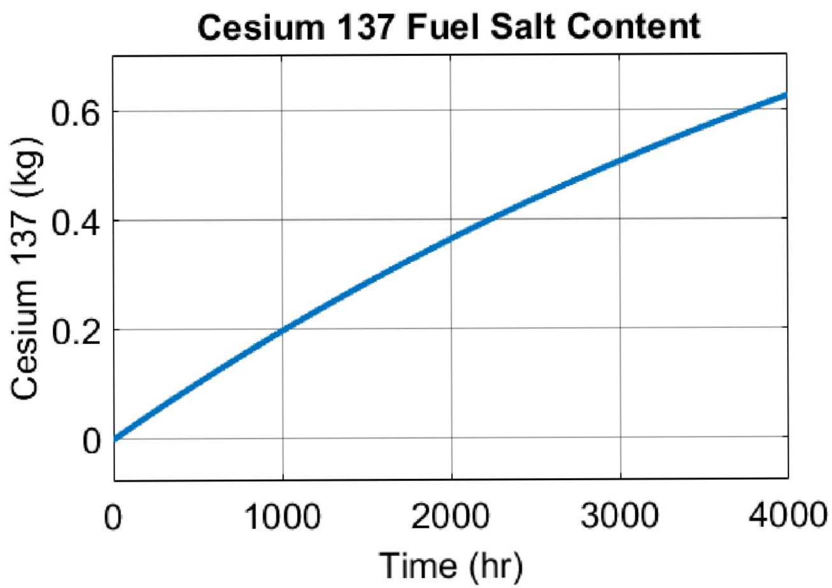
Runner: Writes isotopic masses to **ORIGEN** decay template and executes. Output is passed to inventory calculation module.

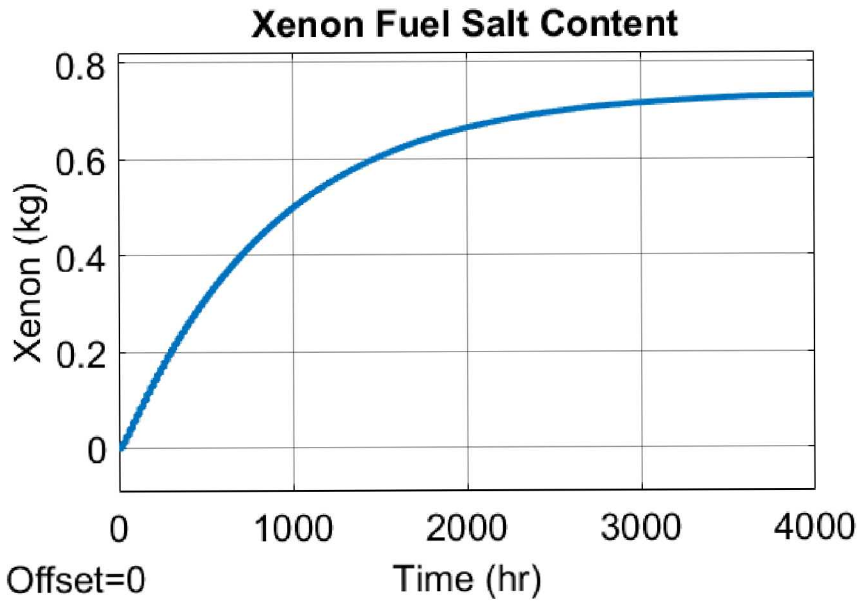
Inventory Calculation: Stores **ORIGEN** output to calculate inventory for subsequent calls. Calculates inventory and output.

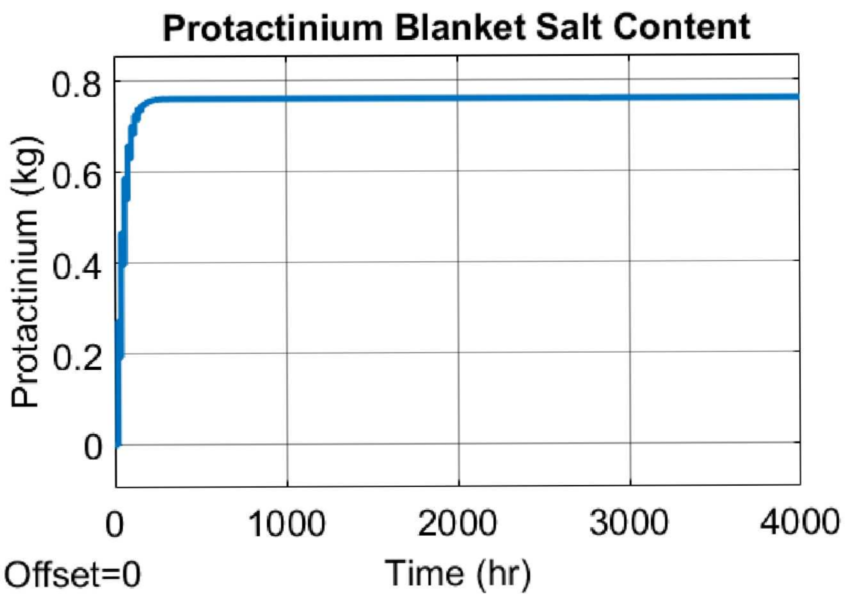
Isotopic Tracking with Time

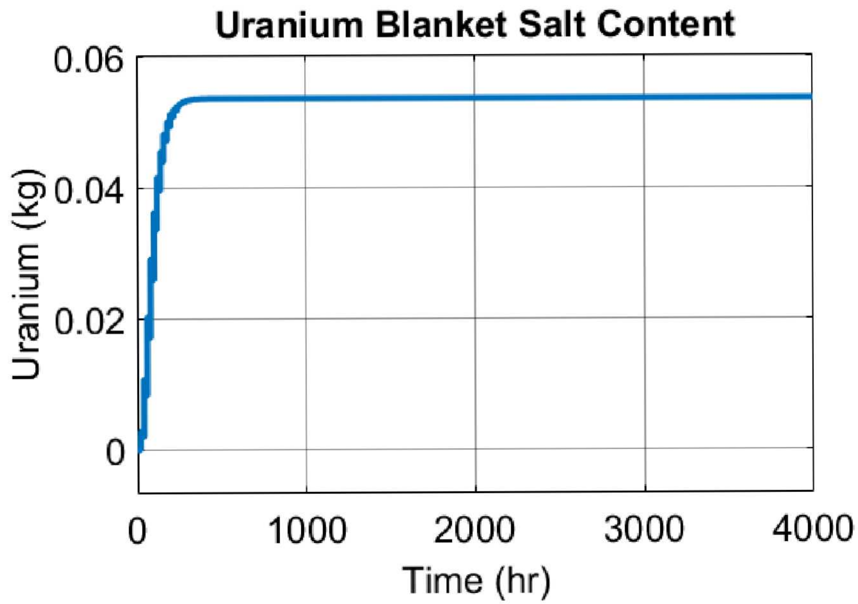
Time (h)	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360
'he4'	0.000313	0.000619	0.000917	0.001209	0.001493	0.001771	0.002043	0.002308	0.002567	0.00282	0.003067	0.003309	0.003545	0.003775	0.004001	0.004221	0.004436	0.004646
'se80'	8.67E-05	0.000173	0.000259	0.000345	0.000431	0.000516	0.000601	0.000686	0.00077	0.000854	0.000938	0.001022	0.001106	0.001188	0.001271	0.001354	0.001436	0.001517
'br81'	0.000134	0.000272	0.000409	0.000545	0.000681	0.000817	0.000952	0.001087	0.001221	0.001355	0.001489	0.001621	0.001754	0.001886	0.002018	0.002149	0.00228	0.00241
'kr85'	0.000163	0.000375	0.000583	0.000786	0.000985	0.001179	0.001369	0.001553	0.001734	0.001911	0.002083	0.002251	0.002415	0.002575	0.002731	0.002883	0.003033	0.003178
'kr86'	0.001132	0.002239	0.003319	0.004374	0.005404	0.006411	0.007395	0.008355	0.009293	0.010204	0.011102	0.011972	0.012821	0.013651	0.014462	0.015253	0.016035	0.016797
'sr90'	0.00282	0.00564	0.008449	0.011252	0.014043	0.016824	0.019594	0.022355	0.025106	0.027847	0.030578	0.033299	0.03602	0.038731	0.041432	0.044123	0.046804	0.049476
'y91'	0.00121	0.003554	0.006138	0.008752	0.011341	0.013903	0.016434	0.018936	0.021398	0.023829	0.026231	0.028603	0.030936	0.033238	0.03551	0.037753	0.039965	0.042148
'zr94'	0.002908	0.005872	0.008827	0.011771	0.014701	0.017621	0.020532	0.023442	0.026343	0.029233	0.032114	0.034984	0.037845	0.040695	0.043536	0.046366	0.049187	0.051998
'nb95'	1.21E-05	4.86E-05	0.000109	0.000191	0.000296	0.000423	0.00057	0.000737	0.000923	0.001128	0.001351	0.001592	0.001849	0.002123	0.002412	0.002717	0.003036	0.003369
'mo98'	0.002352	0.004697	0.007035	0.009364	0.011689	0.014001	0.016304	0.018606	0.020899	0.023181	0.025454	0.027726	0.029989	0.032241	0.034484	0.036726	0.038959	0.041181
'mo99'	0.002031	0.003671	0.004995	0.006063	0.006925	0.007621	0.008183	0.008636	0.009002	0.009296	0.009534	0.009727	0.009882	0.010007	0.010107	0.010187	0.010256	0.010306
'mo100'	0.002068	0.004127	0.006179	0.008225	0.010263	0.012296	0.014319	0.016343	0.018356	0.020359	0.022353	0.024346	0.02633	0.028313	0.030287	0.03225	0.034214	0.036167
'ru101'	0.001436	0.002917	0.004393	0.005865	0.007331	0.008792	0.010251	0.011706	0.013151	0.014597	0.016032	0.017467	0.018892	0.020318	0.021733	0.023148	0.024554	0.025959
'pd105'	2.32E-05	0.000108	0.000239	0.0004	0.000578	0.000768	0.000965	0.001167	0.001371	0.001576	0.001782	0.001988	0.002193	0.002399	0.002604	0.002808	0.003012	0.003215
'sn126'	0.000131	0.000262	0.000393	0.000523	0.000652	0.000781	0.00091	0.001038	0.001166	0.001293	0.00142	0.001546	0.001672	0.001797	0.001923	0.002048	0.002172	0.002296
'te132'	0.002663	0.004878	0.006721	0.008253	0.009527	0.010589	0.011465	0.012202	0.01281	0.013318	0.013736	0.014085	0.014374	0.014613	0.014812	0.014981	0.015121	0.01524
'i129'	0.000489	0.001266	0.002056	0.002846	0.003637	0.004426	0.005215	0.006005	0.006794	0.007583	0.008371	0.009158	0.009946	0.010737	0.011525	0.012312	0.013099	0.013887
'i131'	0.001451	0.003066	0.004696	0.006295	0.007834	0.009299	0.010679	0.011975	0.01319	0.014326	0.015383	0.016359	0.017276	0.018123	0.01891	0.019638	0.020315	0.020943
'xe132'	0.000276	0.001008	0.0021	0.003479	0.005088	0.006877	0.008805	0.010835	0.012948	0.015119	0.017318	0.019547	0.021775	0.024003	0.026221	0.02843	0.030608	0.032767
'xe133'	0.000866	0.002846	0.005209	0.007601	0.009864	0.011931	0.013783	0.015419	0.016861	0.018128	0.019238	0.020212	0.021059	0.0218	0.022452	0.023017	0.023514	0.023942
'xe134'	0.003552	0.007387	0.011129	0.014792	0.018366	0.021863	0.025272	0.028602	0.031854	0.035039	0.038144	0.041182	0.044151	0.047052	0.049884	0.052648	0.055344	0.057981
'xe135'	0.000375	0.000416	0.00042	0.000421	0.000421	0.000421	0.000421	0.000421	0.000421	0.000421	0.000421	0.00042	0.00042	0.00042	0.00042	0.00042	0.00042	0.00042
'xe136'	0.00613	0.013369	0.02058	0.027642	0.034538	0.041277	0.04786	0.054287	0.060567	0.0667	0.072687	0.078538	0.084252	0.089828	0.095278	0.100581	0.105758	0.110837
'cs137'	0.004272	0.008544	0.012802	0.017048	0.021274	0.02549	0.029686	0.033872	0.038048	0.042204	0.046351	0.050477	0.054593	0.05869	0.062776	0.066853	0.070909	0.074956
'ba138'	0.003582	0.007351	0.011106	0.014843	0.018571	0.022289	0.025996	0.029684	0.033362	0.03703	0.040688	0.044336	0.047964	0.051582	0.05519	0.058788	0.062376	0.065944
'ba140'	0.004056	0.00792	0.011594	0.015102	0.01844	0.021619	0.024649	0.027529	0.030269	0.03288	0.035372	0.037743	0.040005	0.042158	0.044201	0.046154	0.048008	0.049782
'la139'	0.003629	0.007677	0.011705	0.015721	0.019728	0.023715	0.027692	0.031659	0.035606	0.039543	0.04347	0.047377	0.051274	0.055161	0.059038	0.062895	0.066742	0.07058
'ce141'	0.002965	0.007063	0.011107	0.015063	0.01894	0.022728	0.026435	0.030073	0.033631	0.037109	0.040518	0.043856	0.047125	0.050325	0.053454	0.056514	0.059514	0.062444
'ce142'	0.003859	0.008235	0.012593	0.016938	0.021274	0.02559	0.029896	0.034191	0.038467	0.042733	0.046979	0.051215	0.055441	0.059647	0.063843	0.068029	0.072196	0.076352
'ce144'	0.003149	0.006282	0.009397	0.012499	0.015579	0.018649	0.021698	0.024728	0.027748	0.030748	0.033729	0.036699	0.039649	0.042589	0.045509	0.04842	0.05131	0.054181
'pr143'	0.000692	0.002442	0.004823	0.007562	0.010485	0.013475	0.016456	0.019386	0.022236	0.024997	0.027658	0.030209	0.03266	0.035002	0.037245	0.039387	0.04143	0.043383
'nd145'	0.00141	0.003629	0.005918	0.008205	0.010483	0.012755	0.015018	0.01727	0.019513	0.021756	0.023988	0.026211	0.028424	0.030626	0.032829	0.035022	0.037204	0.039377
'nd146'	0.001671	0.003415	0.005154	0.006887	0.008615	0.010342	0.012056	0.01377	0.015475	0.017179	0.018873	0.020568	0.022252	0.023937	0.025611	0.027285	0.02895	0.030614
'pm147'	2.96E-05	0.000118	0.000262	0.000457	0.000701	0.000991	0.001323	0.001695	0.002103	0.002547	0.003024	0.003531	0.004066	0.004629	0.005216	0.005826	0.006458	0.00711
'sm151'	4.45E-05	0.000155	0.000303	0.000471	0.00065	0.000833	0.001017	0.0012	0.001378	0.001553	0.001725	0.001891	0.002054	0.002212	0.002366	0.002515	0.002661	0.002802
'u233'	53.16151	53.14686	53.13662	53.12665	53.11668	53.10671	53.09675	53.08678	53.07681	53.06685	53.05688	53.04691	53.03695	53.02698	53.01701	53.00704	52.99708	52.98711
'u234'	0.01288	0.025698	0.038465	0.051183	0.063851	0.076469	0.089038	0.101506	0.113965	0.126424	0.138783	0.151142	0.163401	0.175661	0.18782	0.19998	0.21204	0.2241
'u235'	4.13E-06	1.67E-05	3.76E-05	6.68E-05	0.000104	0.00015	0.000204	0.000265	0.000335	0.000412	0.000497	0.00059	0.000691	0.000799	0.000915	0.001038	0.001169	0.001306

Initial Results









MSR Model Next Steps

- Work with ORNL to ensure consistent results. The model can be setup to work with ORIGEN or TRITON, or just use pre-generated data sets.
- Ultimately we need a better 2D depletion and transport model.
- Develop a safeguards approach—add measurements to the model and determine the appropriate approach for setting up a material balance.
- Examine the alternative MSR designs.