Non-Traditional Radioxenon Emissions from Molten Salt Reactors

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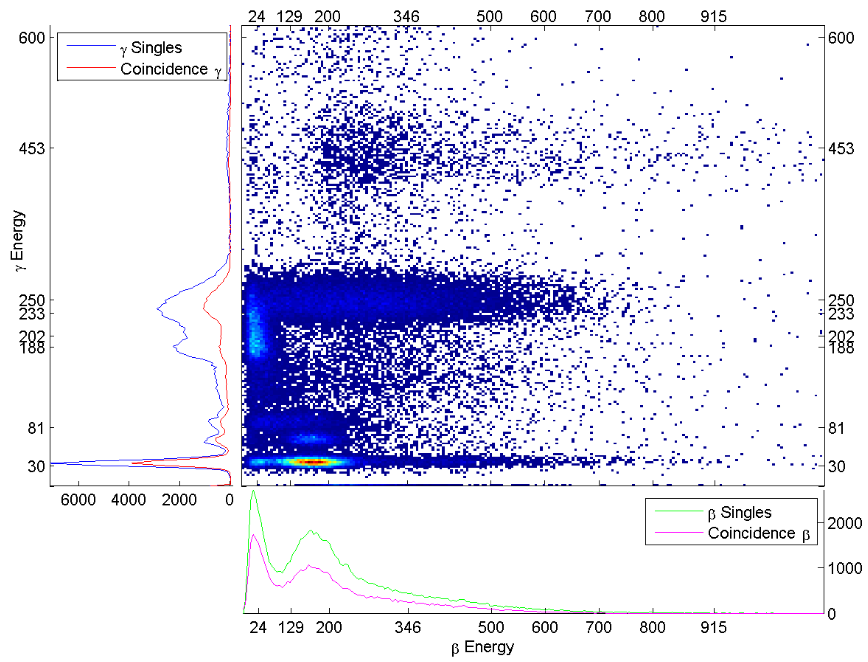
Outline

- Molten Salt Reactors (MSRs)
- Paths for Radioactive Noble Gas Production
- Signatures of Radioxenons from MSRs
- Non-Traditional Radioxenon Production via Air Activation
- Conclusions



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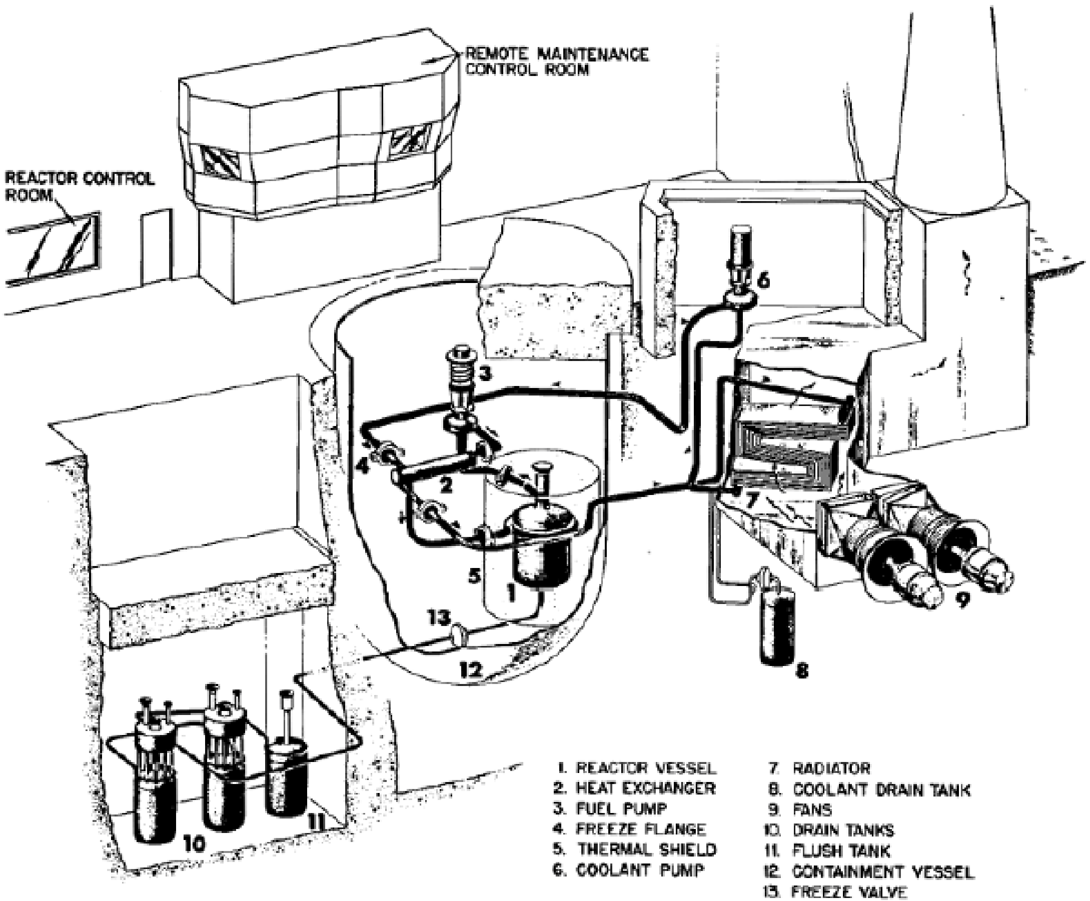
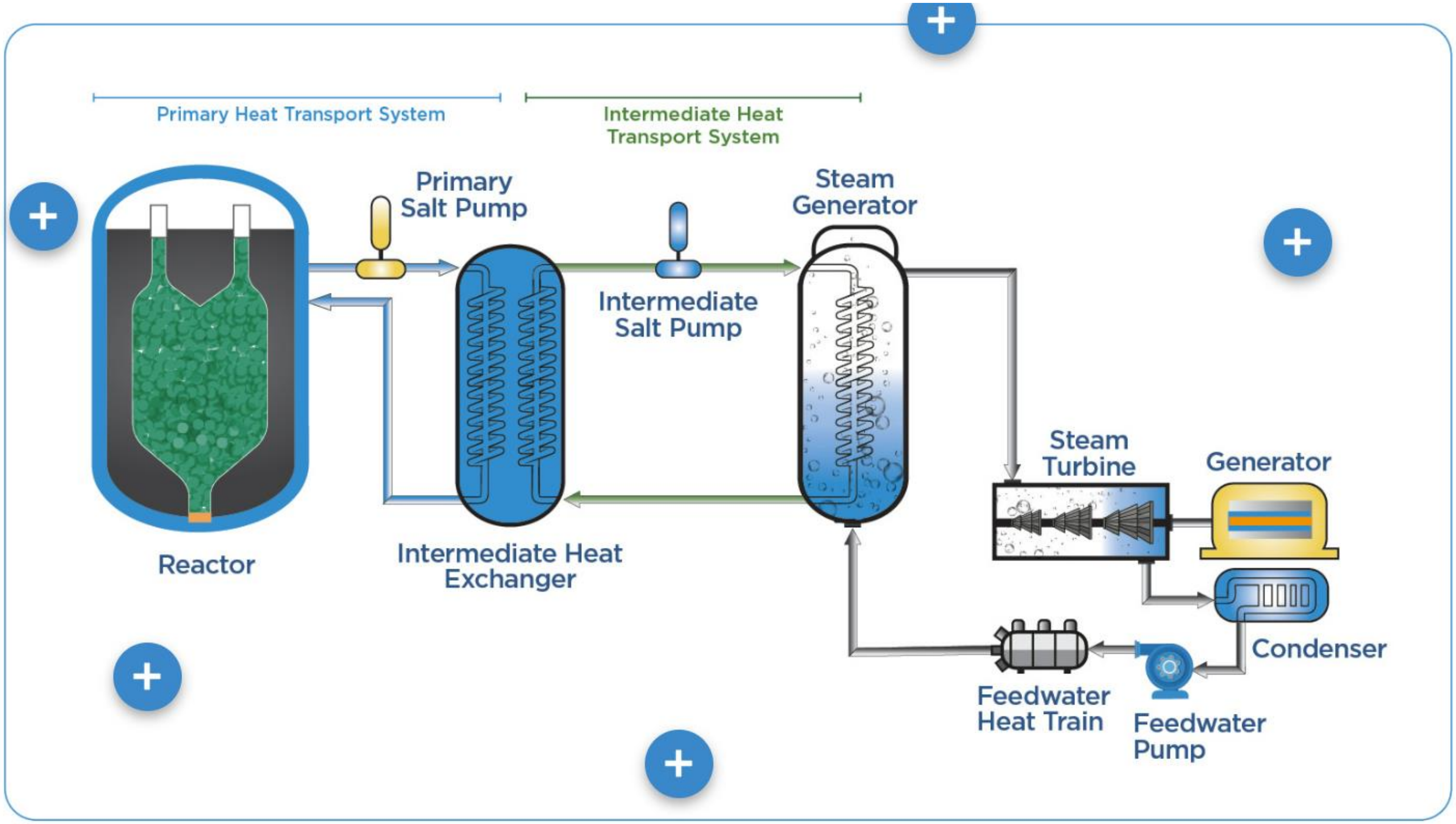
Molten Salt Reactor

- There is a world-wide push to develop the next generation of nuclear reactor technology.
- Molten salt reactors are one of the advanced reactor designs that are receiving a lot of attention.
- The first molten salt reactor was developed by Oak Ridge National Laboratory and went critical in 1965.
- Many variations on molten salt reactor designs.
  - Liquid core with fuel mixed with coolant
  - Solid core with molten salt as the coolant

Molten Salt Research Experiment (ORNL, 1965)

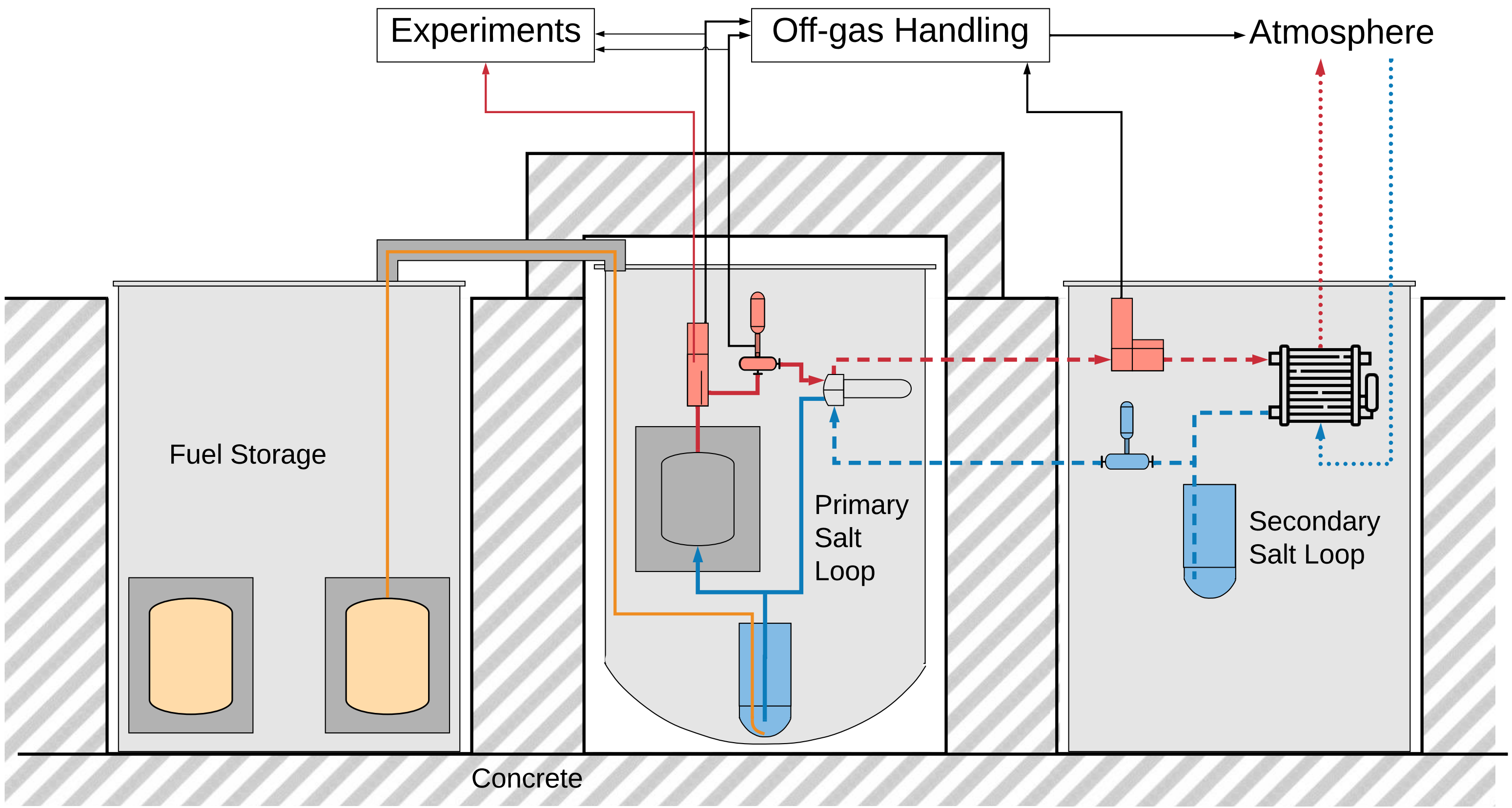


KAIROS Power Reactor



https://kairospower.com/technology/

NEXTRA Research Reactor



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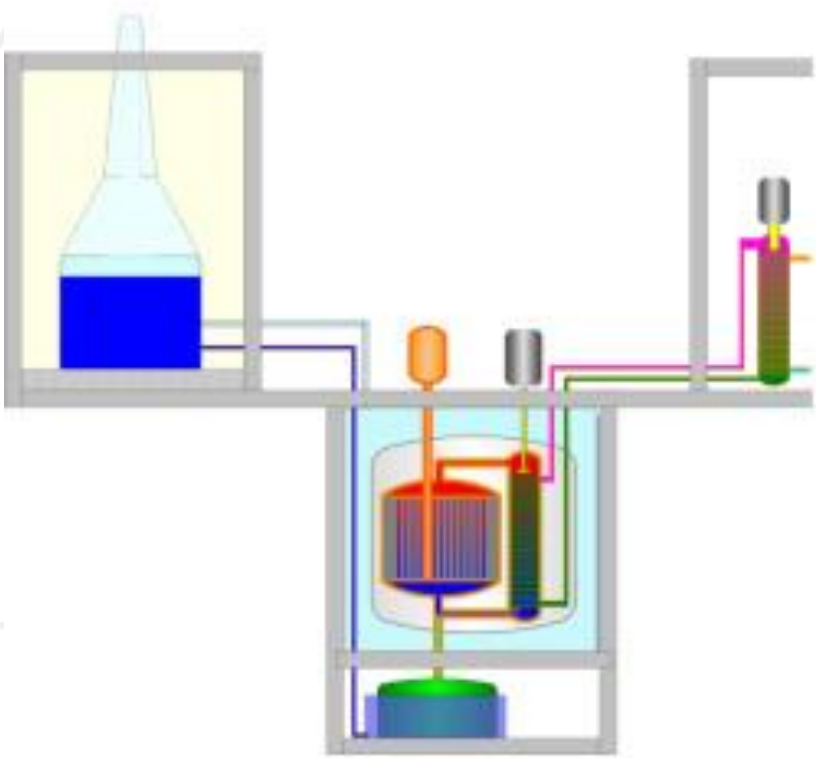
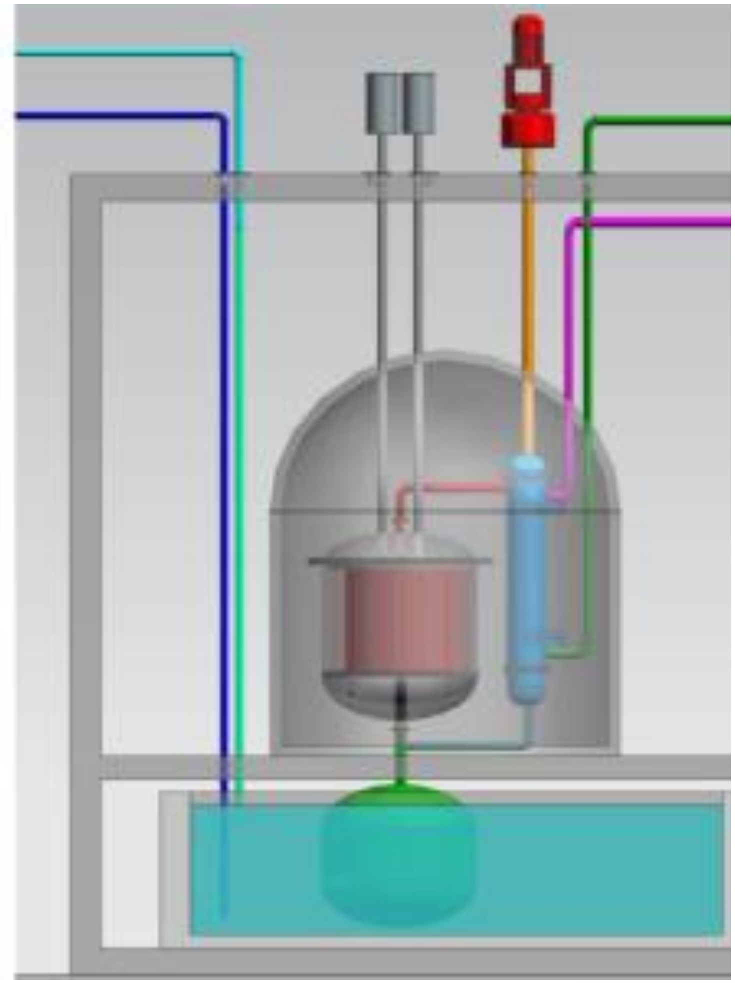
China's TMSR-LF (400 MW_{th})





https://doi.org/10.1016/B978-0-08-101126-3.00017-8

Many Other Companies Developing MSRs

- Terrestrial Energy (Ontario, Canada)
- Moltex Energy (London, England)
- ThorCon Power (Florida, USA)
- TerraPower(Washington, USA)
- Flibe Energy (Alabama, USA)
- Transatomic Power Corporation (Massachusetts, USA)

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Paths for Radioactive Noble Gas Production

- Traditional fission products may be made in core then off-gas.
  - Some reactors (e.g. MSRE and NEXTRA) design have uranium integrated in the salt. Fission product gasses may be produced and then off-gas from salt.
  - Other reactor designs (e.g., KAIROS) have uranium integrated in a solid fuel. The graphite based fuel form is porous and noble gasses may transport out of the fuel into the liquid salt. Off-gas from salt could lead to fission product release.
- Non-traditional radioxenons may be produced through air activation. In contrast to light water reactors, the MSR designs do not have significant shielding (e.g., water) between the fissioning fuel and the reactor vessel. As a result, neutron leakage from the MSR reactor vessels may be up to a factor of 1,000 higher (normalized for reactor power) than what is observed in light water reactors.
- It is anticipated that activation gasses will be confined in air volume outside of reactor vessel. Releases will occur during maintenance or other activities.

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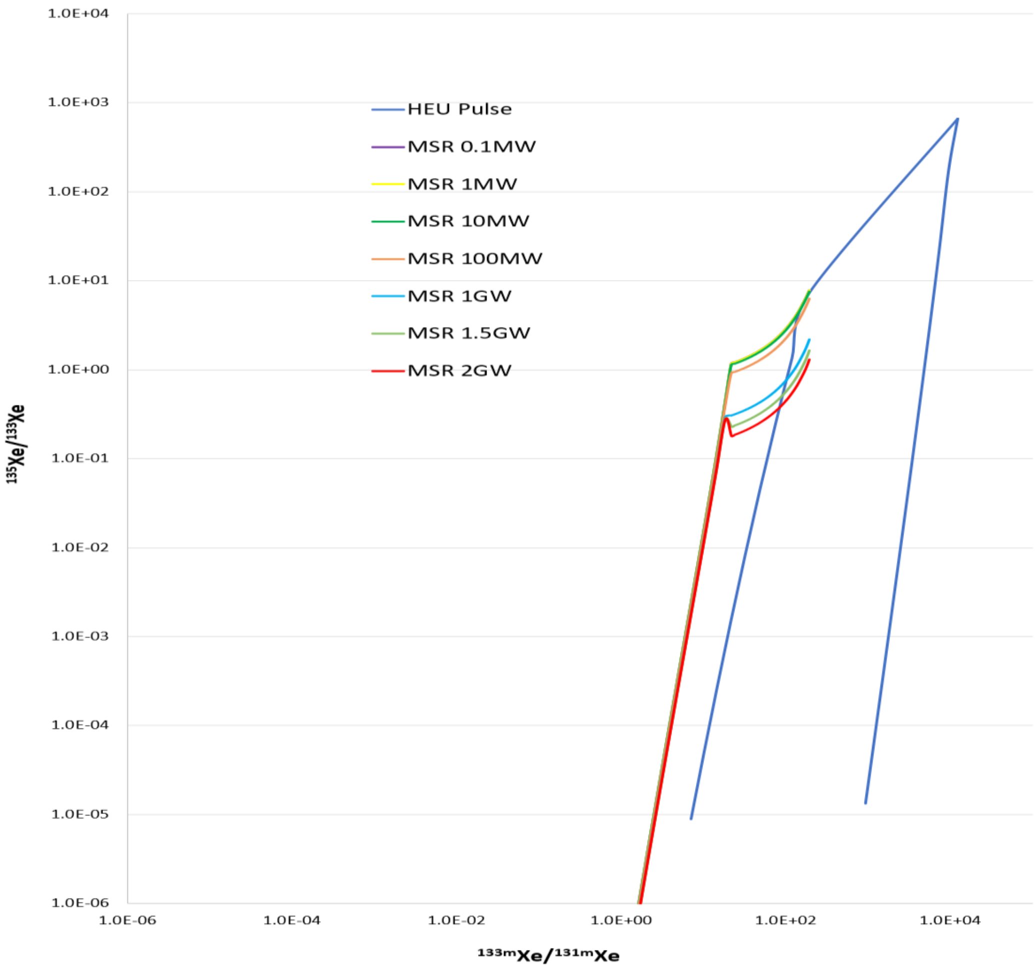
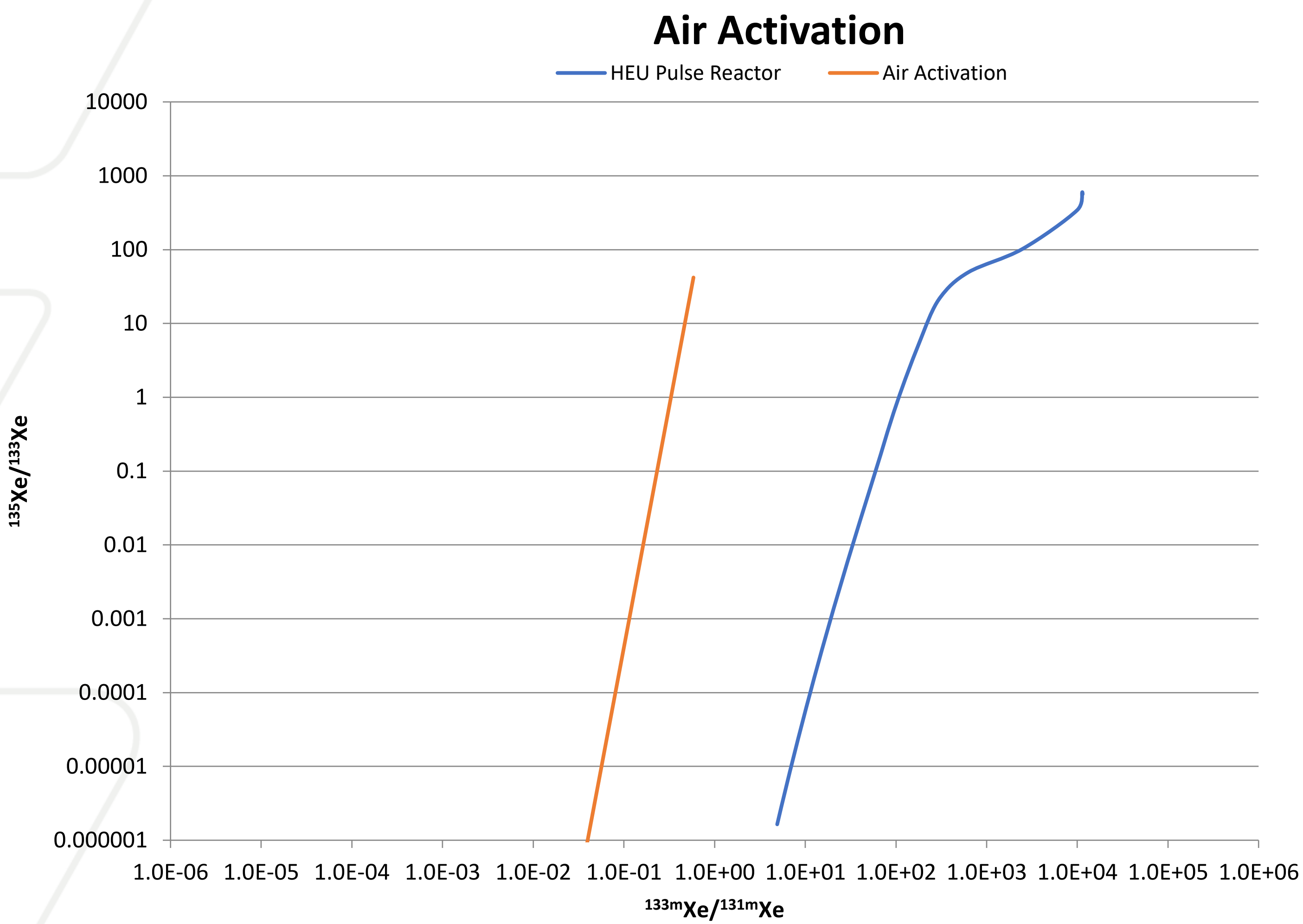
Signatures of Radioxenons from MSRs



Matthew J. Mitchell, Coral Kazaroff, Peter Sobel, S.R. Biegalski, "Radioxenon signatures of molten salt reactors", submitted to the Journal of Radioanalytical and Nuclear Chemistry (JRNC), 2022.

Air Activation Signature



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Non-Traditional Radioxenon Production via Air Activation

- MSR reactors may range from 1 MW to 1,000 MW in thermal power.
- Many design factors affect the air activation:
  - Power
  - Material between fuel and air.
    - Graphite in some designs
    - Reactor vessel
    - Other shielding
  - Volume of air in space.

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Calculated Air Activation

- Activation was calculated utilizing T6-DEPL (KENO-VI + ORIGEN) with ORIGEN utilized for decay.
- Irradiation was conducted for 1 year to allow for asymptotic buildup of materials.
- Results were normalized to reactor power and air volume.

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Air Composition

Nitrogen	78.08%
Oxygen	20.95%
Argon	0.93%
Carbon Dioxide	0.04%
Neon	0.018%
Helium	0.00052%
Methane	0.00018%
Krypton	0.00011%
Hydrogen	0.000055%
Nitrous Oxide	0.000032%
Carbon Monoxide	0.00002%
Xenon	**0.0000087%**

https://www.chemicool.com/elements/composition-of-air.html

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	Calculated Activity Concentration (Bq m^{-3} MW^{-1})					
	No Decay	12 hours of decay	1 day of decay	7 days of decay	30 days of decay	1 year of decay
^{41}Ar	5.39E+09	5.67E+07	5.98E+05	-	-	-
^{14}C	3.03E+08	3.03E+08	3.03E+08	3.03E+08	3.03E+08	3.03E+08
^{37}Ar	1.40E+08	1.39E+08	1.38E+08	1.22E+08	7.76E+07	1.03E+05
^{3}H	1.66E+07	1.66E+07	1.66E+07	1.66E+07	1.64E+07	1.56E+07
^{83m}Kr	2.46E+06	2.60E+04	2.76E+02	3.30E-08	2.74E-08	1.86E-09
^{16}N	2.11E+06	-	-	-	-	-
^{37}S	3.81E+05	-	-	-	-	-
^{19}O	1.67E+05	4.33E-12	5.89E-30	2.07E-46	3.30E-62	6.90E-78
^{85m}Kr	1.67E+05	2.60E+04	4.06E+03	8.56E-07	3.71E-22	8.09E-39
^{81m}Kr	1.50E+05	-	1.71E-12	5.65E-22	3.53E-37	4.18E-53
^{13}N	1.19E+05	-	-	-	-	-
^{125}Xe	3.65E+04	2.23E+04	1.36E+04	3.70E+01	5.45E-09	-
^{125}I	3.57E+04	3.57E+04	3.55E+04	3.32E+04	2.54E+04	5.10E+02
^{79}Kr	2.96E+04	2.34E+04	1.84E+04	1.07E+03	1.94E-02	4.73E-18
^{133}Xe	2.32E+04	2.19E+04	2.06E+04	9.75E+03	4.75E+02	9.65E-13
^{39}Ar	1.19E+04	1.19E+04	1.19E+04	1.19E+04	1.19E+04	1.18E+04
^{35}S	7.53E+03	7.50E+03	7.46E+03	7.12E+03	5.94E+03	4.18E+02
^{85}Kr	4.51E+03	4.51E+03	4.51E+03	4.50E+03	4.49E+03	4.23E+03
^{131m}Xe	1.35E+03	1.32E+03	1.28E+03	8.99E+02	2.34E+02	7.10E-07
^{129m}Xe	1.04E+03	9.97E+02	9.60E+02	6.01E+02	9.97E+01	4.39E-10
^{127}Xe	7.88E+02	7.81E+02	7.73E+02	6.90E+02	4.45E+02	7.56E-01
Total	5.85E+09	5.15E+08	4.58E+08	4.42E+08	3.97E+08	3.19E+08

China's TMSR-LF Extrapolation (500 MW and 100 m³ of air volume)						
	Activity (Bq)					
	No cooling	12 hours of decay	1 day of decay	7 days of decay	30 days of decay	1 year of decay
^{41}Ar	2.16E+14	2.27E+12	2.39E+10	-	-	-
^{14}C	1.21E+13	1.21E+13	1.21E+13	1.21E+13	1.21E+13	1.21E+13
^{37}Ar	5.61E+12	5.55E+12	5.50E+12	4.89E+12	3.10E+12	4.11E+09
^{3}H	6.62E+11	6.62E+11	6.62E+11	6.62E+11	6.57E+11	6.25E+11
^{83m}Kr	9.83E+10	1.04E+09	1.11E+07	1.32E-03	1.09E-03	7.42E-05
^{16}N	8.44E+10	-	-	-	-	-
^{37}S	1.52E+10	-	-	-	-	-
^{19}O	6.68E+09	1.73E-07	2.36E-25	8.28E-42	1.32E-57	2.76E-73
^{85m}Kr	6.68E+09	1.04E+09	1.62E+08	3.42E-02	1.48E-17	3.24E-34
^{81m}Kr	5.98E+09	-	6.84E-08	2.26E-17	1.41E-32	1.67E-48
^{13}N	4.74E+09	-	-	-	-	-
^{125}Xe	**1.46E+09**	**8.92E+08**	**5.45E+08**	**1.48E+06**	**2.18E-04**	-
^{125}I	1.43E+09	1.43E+09	1.42E+09	1.33E+09	1.01E+09	2.04E+07
^{79}Kr	1.19E+09	9.35E+08	7.37E+08	4.27E+07	7.74E+02	1.89E-13
^{133}Xe	9.29E+08	8.76E+08	8.23E+08	3.90E+08	1.90E+07	3.86E-08
^{39}Ar	4.74E+08	4.74E+08	4.74E+08	4.74E+08	4.74E+08	4.73E+08
^{35}S	3.01E+08	3.00E+08	2.99E+08	2.85E+08	2.38E+08	1.67E+07
^{85}Kr	1.81E+08	1.81E+08	1.81E+08	1.80E+08	1.79E+08	1.69E+08
^{131m}Xe	5.39E+07	5.26E+07	5.11E+07	3.59E+07	9.35E+06	2.84E-02
^{129m}Xe	4.15E+07	3.99E+07	3.84E+07	2.40E+07	3.99E+06	1.76E-05
^{127}Xe	3.15E+07	3.12E+07	3.09E+07	2.76E+07	1.78E+07	3.02E+04
Total	2.34E+14	2.06E+13	1.83E+13	1.77E+13	1.59E+13	1.28E+13

Conclusion

- Air activation within MSRs leads to production of non-traditional radioxenon.
- Larger commercial scale MSRs could produce activities detectable within the International Monitoring System.
- International monitoring efforts should be prepared for non-traditional radioxenon isotopes within samples.
- The international monitoring community may also note potential release of ^{37}Ar and ^{3}H.

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