

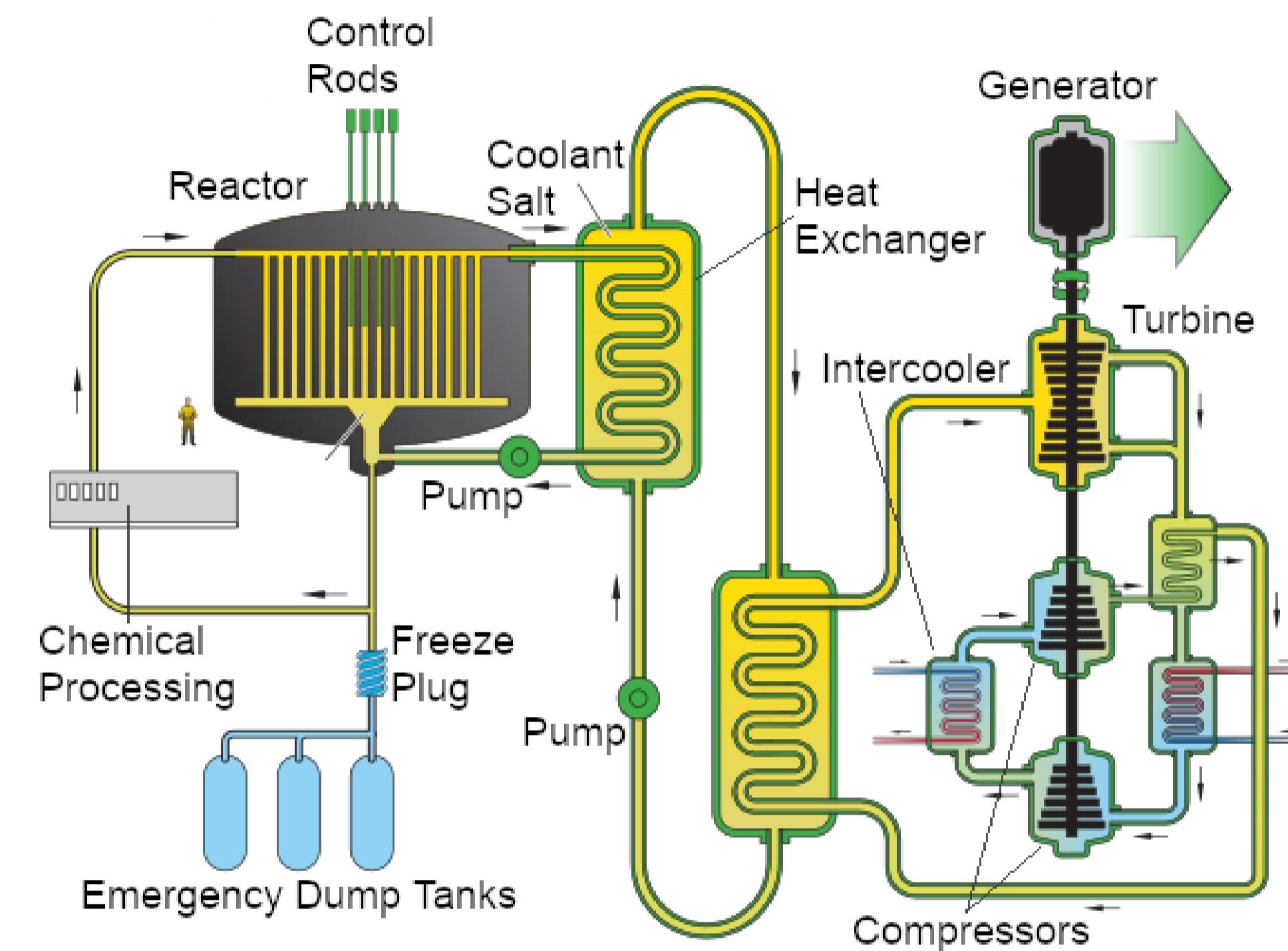


Abstract

Molten salt reactors (MSRs) utilize a molten salt mixture as the primary coolant, and some systems also have fuel dissolved in the coolant. Whilst the concept is not new, there has been renewed interest as part of the development of Generation IV reactor designs. Their unique molten design has important implications for the radionuclide signatures that could be detectable by the International Monitoring System (IMS). Short-lived gaseous and volatile radionuclides could more readily escape liquid fuels and coolants, producing emissions with a different radioxenon isotopic signature. This effect could be further enhanced by the online removal of accumulating fission products in MSR designs. This research examines these effects and discusses the potential impacts on the IMS.

Project Goals

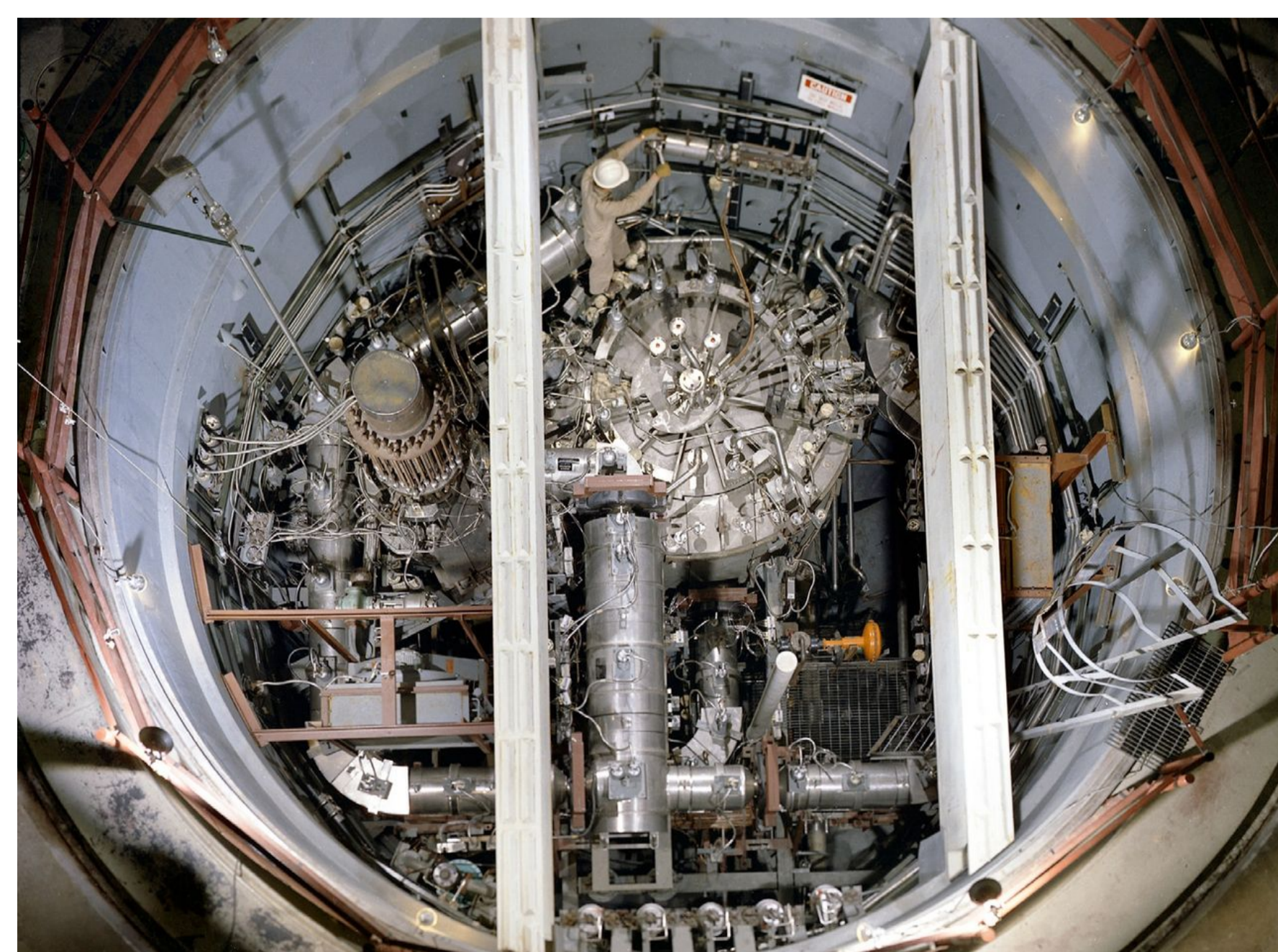
- Understanding the contribution of Molten Salt Reactors to the verification regime of the Comprehensive Nuclear-Test-Ban Treaty (CTBT)
 - Assessment of fission and activation product signatures that arise from the fuel, cooling and cover-gas components of an MSR
 - Potential signatures that would be detected by the particulate and noble gas monitoring stations of the IMS
 - Assessment of the interference of these signatures on the detection of nuclear explosive tests detected by the IMS
- Assessment of the properties of an MSR useful for other non-proliferation activities including safeguards



Generalized schematic of an MSRE.

Molten Salt Reactor

An MSR is a nuclear reactor that utilizes a liquid salt in the primary fuel loop as the coolant instead of water. Liquid salt allows the reactor to be operated at lower pressures with the possibility of utilizing thorium as a fuel source (to breed ^{233}U). MSRs can be operated with either solid fuel, much like a light water reactor (LWR), or with the fuel directly dissolved in the molten salt. In the second operation scheme, chemical processing and fuel additions can occur with the reactor online, eliminating the need for downtime for refueling and reducing waste.



Inside the MSRE.

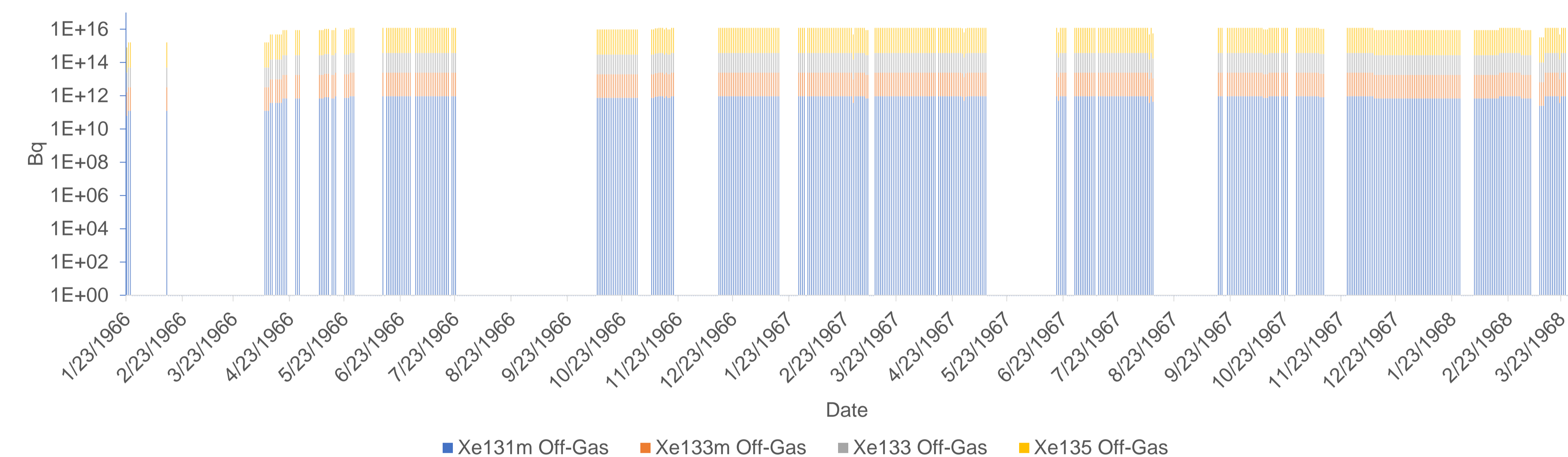
Molten Salt Reactor Experiment (MSRE)

The MSRE was an experimental MSR operated at Oak Ridge National Laboratory (ORNL) from 1965 to 1969. Extensive samples of the salt and pump gas were taken during the ^{235}U and ^{233}U campaigns [1]. Data from this experiment can be used to estimate fission yields for isotopes of interest to the IMS. In particular, the radioxenon isotopes can be estimated from ORNL calculations of ^{135}Xe . The computed generation rate from all sources was 6.4% per fission during the ^{235}U campaign. This results in a total of 5.44×10^{19} atoms of ^{135}Xe created per hour at 7.5Mw. Xenon is highly insoluble and was easily entrained in bubbles in the fuel salt. Computed values for the percentage of xenon absorbed into fuel salt voids range from 83-98%. The primary fuel loop of the MSRE consisted of the reactor, pump-bowl, and heat exchanger. The primary mechanism that stripped the xenon from the fuel salt in the pump-bowl was a toroidal spray ring which forced salt through small holes at high velocity. The efficiency of xenon stripping from all mechanisms was estimated from observational data to be between 50-100% [2].

References: [1] Compere, E., et al. (1975). Fission Product Behavior in the Molten Salt Reactor Experiment, ORNL
 [2] Kedl, R. and A. Houtzeel (1967). Development of a model for computing Xe^{135} migration in the MSRE, ORNL
 [3] US Department of Energy Nuclear Energy Research Advisory Committee - http://www.ne.doe.gov/genIV/documents/gen_iv_roadmap.pdf

Radioxenon calculations

Generation rates of the other xenon isotopes can be estimated by incorporating this information with thermal fission yields for ^{235}U . Using conservative values for the entrainment percentage and stripping efficiency of 83% and 50%, the activity for each nuclide can be calculated as a function of reactor power. Then an estimate of radioxenon in the off-gas can be built using a rough timetable of MSRE reactor power during the U-235 runs.



Estimate of activity escaping the pump-bowl for each xenon isotope of interest during the ^{235}U MSRE campaign

Isotope	Cum. Yield	Bq s ⁻¹ MW ⁻¹	Bq d ⁻¹ at power (7.5Mw)
$^{131\text{m}}\text{Xe}$	4.05E-02	1.43E+06	9.29E+11
$^{133\text{m}}\text{Xe}$	1.89E-01	3.61E+07	2.34E+13
^{133}Xe	6.70E+00	5.35E+08	3.47E+14
^{135}Xe	6.54E+00	1.80E+10	1.17E+16

Radioxenon activity estimates in off gas as a function of MSRE reactor power.

Salt Irradiation

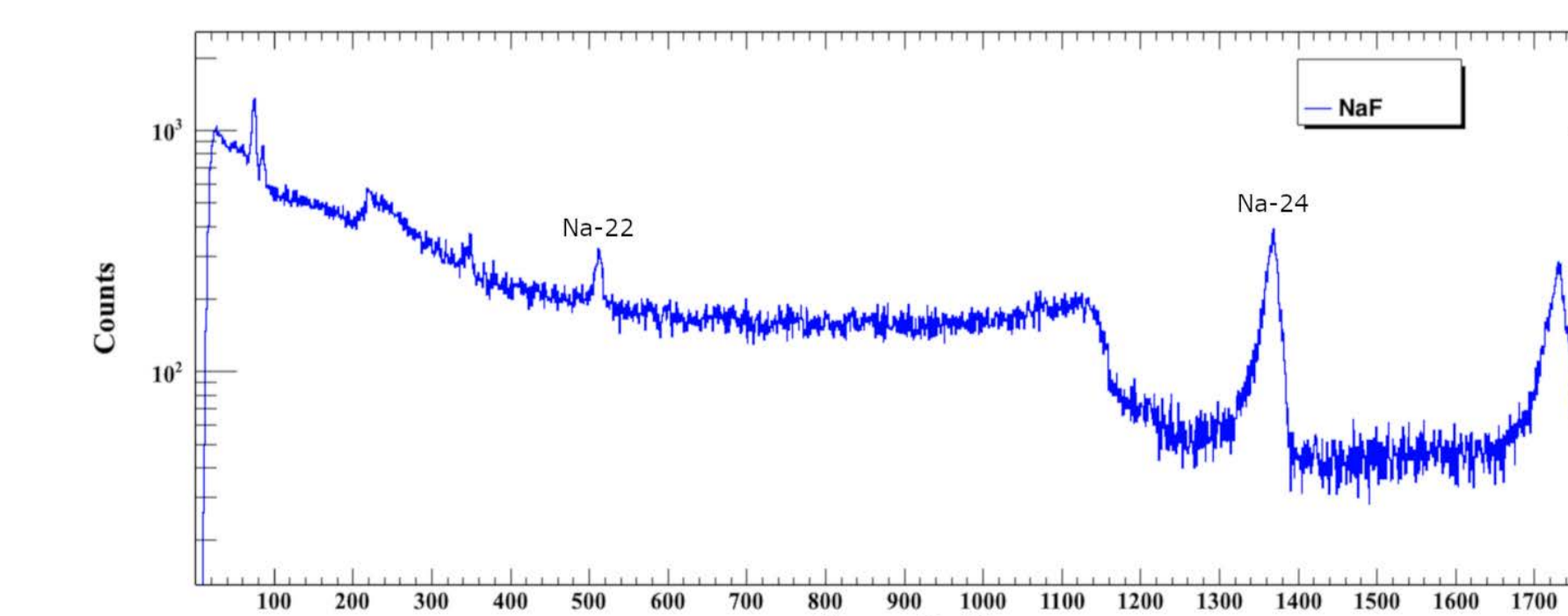
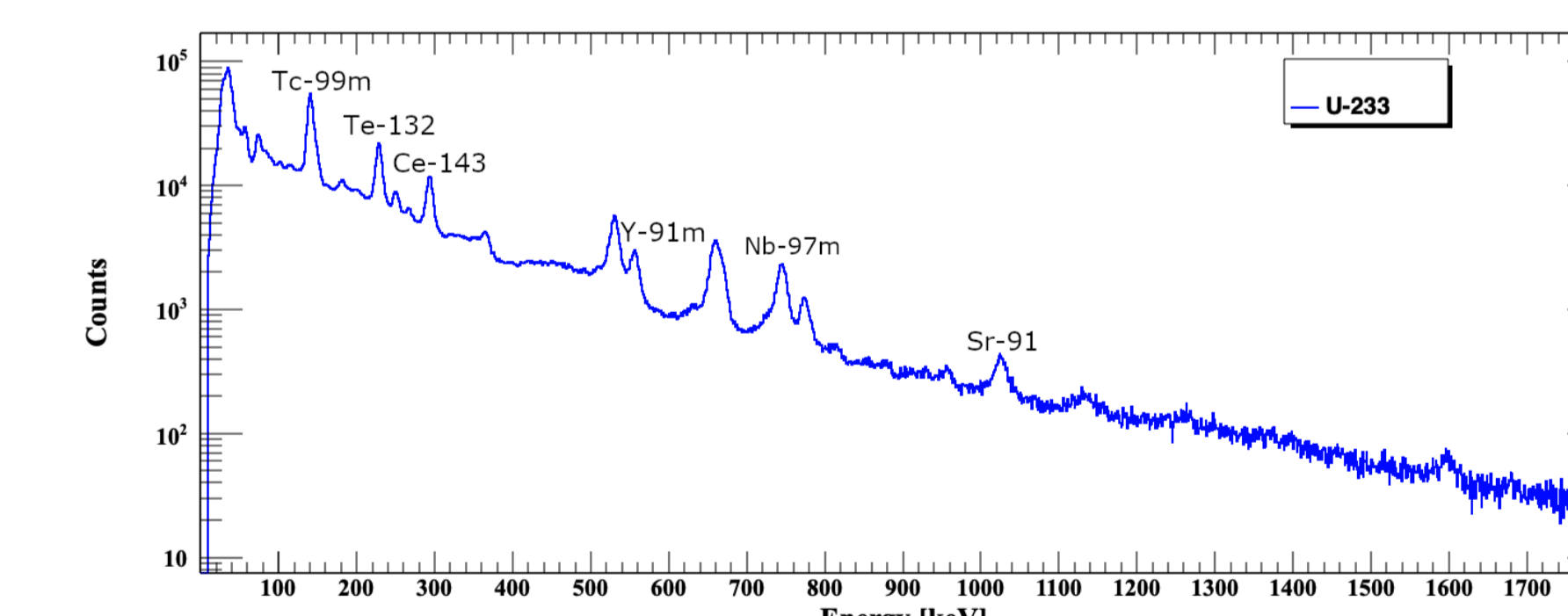
The ability for on-line processing of molten salts adds a possible pathway for radioactive releases with signatures much different than those typically seen for light-water reactors and reprocessing facilities. Additionally, the variety of fuel and coolant salts proposed for Generation IV reactor designs necessitates a broad investigation of activation product signatures. In order to study these signatures and interferences, a series of irradiation experiments are being conducted. Commonly used salts, both fluorides and chlorides, and ^{233}U are being irradiated and measured individually by gamma spectroscopy.

Coolant salts	Fuel salts
$\text{UCl}_3\text{-NaCl}$ Modern Chloride MSR	$(\text{U/Pu})\text{Cl}_3\text{-NaCl}$ Modern Chloride MSR
$\text{NaBF}_4\text{-NaF}$ LFTR Design	$\text{LiF-BF}_2\text{-(Th/U)F}_4$ (FLiBe) MSRE, LFTR, IMSR, and MOSART Designs
NaF-BF_2 ThorCon Design	$\text{NaF-BF}_2\text{-(Th/U)F}_4$ ThorCon Design
KF-ZrF IMSR Design	NaF-RbF-UF_4 IMSR Designs
LiF-KF-NaF (FLiNaK) TAP Design	LiF-(U/Pu/La)F_4 TAP Design

Example fuel and coolant salts in various MSR designs.

Safeguards

Significant design differences with MSRs complicate the policy and safeguards currently implemented for light water reactors. In particular, discrete "item" accounting is not possible. Liquid fuel constituents means the inventory is constantly changing due to fission and transmutation. This coupled with online chemical (re)processing further complicates accurate fissile material accountability.



Measurements of irradiated ^{233}U using a cadmium zinc telluride (CZT) detector and irradiated NaCl using a silicon drift detector (SSD) in support of MSR safeguards research.