

OFF-GAS FOR MOLTEN SALT REACTORS – RADIONUCLIDE CONFINEMENT

J. MCFARLANE
Oak Ridge National Laboratory
Oak Ridge, United States Of America
Email: mcfarlanej@ornl.gov

H. ANDREWS
Oak Ridge National Laboratory
Oak Ridge, United States Of America

Z. KITZHABE
Oak Ridge National Laboratory
Oak Ridge, United States Of America

D. OREA
Oak Ridge National Laboratory
Oak Ridge, United States Of America

K. ROBB
Oak Ridge National Laboratory
Oak Ridge, United States Of America

Abstract

The off-gas or cover-gas system comprises a crucial part of a molten salt reactor (MSR) design. The basic requirements regarding the gas head space that is in contact with a fuel salt are well understood. While a molten salt is an excellent solvent or trapping medium for activation and fission products, not all of the generated species stay in the salt. Noble gases have low solubility and the longer lived Xe and Kr isotopes will readily escape the salt into the pump bowl headspace or other spaces where the gas and liquid phase are in direct contact. The solubility of tritium, either present as an activation product in fluoride salts or as a ternary fission product remains are an area of active investigation.

Aerosols can be generated, either from vaporization and condensation or semi-volatile species or from mists arising from the turbulence of actively pumped fluid. These latter particulates will carry a complete inventory of radionuclides, nominally at the same relative concentration as in the fuel salt. Aerosols can also be generated when the salt is actively sparged to remove noble gases, done to reduce the concentration of Xe-135 poison. These bubbles can serve as sites for nucleation and growth of a disperse phase in the salt that will collect salt components of low solubility, such as noble metal particles, fission gases, and residue from corrosion and erosion of the surfaces of reactor materials.

The chemistry of salt components is established by the chemical potential of a dominant redox couple, e.g., U(III)/U(IV), which will be influenced by burnup and measures for active redox control. The salt is a dynamic multiphase system, with gradients in temperature, component concentration, and with varying irradiation environment. However, because it is so hot, attainment of chemical thermodynamic equilibrium can be assumed within defined volume elements. In the off-gas system, however; temperature can drop

from being several hundred degrees in proximity to the core to cryogenic – the latter for noble gas capture. Speciation as calculated by chemical thermodynamics will only serve to establish an initial condition. Processes such as aerosol transport, condensation of volatiles, radiative decay, revolatilization, and radiation damage need to be understood.

The advanced reactor technology program supported by the United States Department of Energy (US-DOE-NE) has made important strides in understanding the chemistry, physics, and engineering of an MSR. Unlike off-gas systems associated with used nuclear fuel recycling, MSR off-gas systems must operate continuously, thus requiring redundancy for performance during maintenance. Radionuclides with short-half lives will dominate requirements for handling decay heat and confinement for regulatory purposes. Unlike used fuel recycling, many of the fission products of concern will stay in the salt, iodine being the best example. Should an off-normal event occur, much of the volatile fission product inventory will have already been removed during prior operation. For instance, a salt spill even followed by freezing in place will trap most of the inventory of radionuclides, reducing the risk of release. Pressurization or hydrogen explosions, issues related to light water reactor severe accidents, will not occur. However, failure of an MSR off-gas system will itself be a serious occurrence and one that must be mitigated through system design.

These scenarios demonstrate the importance of tracking the inventory of radionuclides in an MSR off-gas. As the chemistry of these isotopes is dependent on their elemental abundance, traditional tracking using gamma spectroscopy must be supplemented by other means. Laser induced breakdown spectroscopy (LIBS) has been shown to track elemental concentrations in the gas phase to ppm levels. LIBS can also be used to analyze aerosols on line, giving the composition of the salt, including O and H impurities. Molecular analysis achieved using Raman spectroscopy can be especially useful in the case of determining the concentration of homonuclear diatomics such as H₂ and I₂. Raman is also sensitive to isotopic abundance. Mass spectrometry is complementary to both these methods and is particularly sensitive to alkali halides and acidic gases. These methods have strengths and weaknesses and so a multiplexed approach to measurement is recommended.

The US DOE-NE has funded several studies on gas transport and aerosol formation in molten salts, spectroscopic studies and quantitative analysis. Recently we tested multiple sensors in a large-scale pumped chloride salt loop (160 kg of NaCl-KCl-MgCl₂). Early results will be summarized at the workshop and detailed analyses are ongoing. The success of these tests indicate that a combination of sensors have the capability, sensitivity, and responsiveness to track changes in loop operation. We have also shown that testing in large-scale loops are important test beds can provide data needed for the design of integrated off-gas systems for MSRs.

This work was funded by the United States Department of Energy, Office of Nuclear Energy, Advanced Reactor Technology, Molten Salt Reactor Campaign.