GASEOUS AND VOLATILE FISSION PRODUCT RELEASE FROM MOLTEN SALT NUCLEAR FUEL

Ian R. Scott (Moltex Energy LLP)

Nuclear reactors using molten salts of fissile isotopes as fuel continuously produce gaseous and volatile fission products. The major gaseous species are the noble gasses Xenon and Krypton while the most hazardous volatile species is iodine. Molten salt reactors typically sparge their fuel with helium which removes noble metal fission products as foams but which also strips out most volatile species which then have to be captured and safely disposed of.

It was recently discovered that nuclear reactors can be designed with molten salt fuel held in fuel assemblies very similar to those in uranium oxide or uranium metal fuelled reactors with no pumping of the molten fuel required. Fission product gasses in oxide fuel are trapped as very high pressure microbubbles in the fuel while they are released from metal fuel and accumulate to relatively high pressure in the fuel cladding. Early attempts to allow these gasses to vent into the reactor coolant in the Dounreay Experimental Fast Reactor had to be abandoned due to the high proportion of the hazardous and volatile fission product caesium which was released into the coolant.

Molten salts could in principle trap such volatile fission products much more effectively than is the case with metal fuel. It was therefore of interest to determine what the composition of the gas stream released from molten salt fuel would be and whether that composition would be consistent with simple venting of the gas into the coolant.

Methods

The chemical composition of partially burned molten salt fuel was estimated from known fission yields and was based on a molten salt of 60%NaCl/35% UC13/10% fission products (all mole%). The fuel was continually contacted with a zirconium sacrificial metal layer which maintains the fuel in a strongly reducing form which reduces its corrosive potential dramatically.

The composition of the liquid and gas phases produced was calculated using a Gibbs free energy minimisation approach and thus reflects the composition at thermodynamic equilibrium, which is considered to be a realistic assumption given the liquid form of the fuel and its high temperature. The calculations were carried out using Outotek HSC Chemistry 7 software with gas pressure set at 1 bar.

Results

The design of the fuel tube is illustrated below. Approximately ¾ of the tube is filled with molten fuel salt with the upper region left as a gas space. The gas space is divided into two regions, a lower simple tube and an upper “diving bell” apparatus that allows gas to vent but prevents coolant entering the fuel tube. That design is taken from that used for the Dounreay Experimental Fast Reactor.

The fuel salt has a surface temperature of approximately 1020°C while the walls of the upper regions of the tube are at the coolant temperature of approximately 600°C. Vapour from the molten salt therefore partially condenses on the tube walls. The flow rate of gas through the tube, with the fuel salt generating heat at 250kW/l is 1/50th of the fuel salt volume per day
giving an average gas transit time of 12 days through the lower gas region and 4 days through the upper gas region.

The composition of the gas phase produced from the hot fuel salt before and after partially condensing on the upper cooler region of the tube is shown below – note the logarithmic scale. The noble gasses dominate with a significant contribution from ZrCl₄. Of particular note are the very low levels of caesium and iodine compounds which represent respectively 0.0006% and 0.001% of the total.

There is a second mechanism whereby iodine could be released into the coolant which is by decay of Xenon isotopes released from the fuel tube before they have decayed.

The contribution of this mechanism was estimated as follows. The fuel tube was modelled as three separate reservoirs of noble gas; the fuel salt, the lower gas space and the diving bell assembly. Flow of gas between these reservoirs was equal to the rate of gas production and each reservoir was considered well mixed.

Only Cs-135 was released in larger quantities via decay of released xenon than by direct evolution and its extremely long half life and hence low radioactivity make this minimally hazardous.

This analysis allows a robust safety case for direct discharge of fission gasses from the molten salt fuel tube into the coolant to be constructed with consequent substantial simplification of the reactor system.