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AEROSOL ISSUES IN FAST REACTOR

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ABSTRACT

Aerosols are the principle carrier of radioactivity to the public domain in case of nuclear accidents. They also pose an inhalation health hazard, if it exceeds the allowable limit. In this paper aerosol issues pertaining to Fast Reactor Safety are presented.

INTRODUCTION

The Fast Reactors occupies 2nd stage in Nuclear Program schedule, envisaged by eminent scientist Dr. Homi Bhabha. It uses un-moderated neutron for sustaining chain reaction and produce power by using compact core fuelled with fissile material like ^{239}Pu. It also used to breed a fertile material ^{232}Th to a fissile material ^{233}U, which will be used as a fuel for the 3rd stage Nuclear Program. Since the power density is more for fast reactor, sodium is used as a coolant for the removal of heat generated during fission. The most common design of fast reactor is the 'pool-type'. This consists of a compact core, surrounded by a neutron shield, immersed in a pool of liquid sodium contained in a double walled vessel with a hemispherical bottom and sealed by a roof. An Argon-filled space above the sodium pool accommodates changes in the total volume of coolant due to changes in operating temperature. Pumps contained within the vessel circulate the sodium coolant through the core and heat from the core is removed. The sodium coolant is circulated through intermediate heat exchangers, which are also contained within the vessel. The intermediate heat exchangers are coupled to a secondary, external, and sodium cooling circuit. The secondary sodium takes away the heat from the primary circuit and exchanges heat with a water circuit to produce steam to drive turbine generator sets to produce electricity.

During the normal operation of the reactor, there will be a balance between the heat generated in the core to the heat removed by the coolant. When the heat balance is lost due to some initiating events and subsequent failure in the removal of such heat results in Core Disruptive Accidents (CDA). In the unlikely event of CDA, the sodium slug may impact the reactor roof top plug, causing damage. This provides a pathway for the escape of radioactive material (fission products and fuel material) and sodium into the containment. Fuel and fission product vapors will condense and form aerosols. In addition, sodium burning will give rise to various compounds of sodium aerosols.

Further, even during the normal operation of the reactor, the hot circulating sodium in the secondary loop may get in contact with atmosphere through cracks and burns to give aerosols which are classified as (i) Pool fire – sodium rapidly flows down to form a pool in the lowest part of the space, (ii) spray fires – the leakage flow is dispersed into small droplets and burn along the trajectories, and (iii) the column fire – this is due to the presence of leak jackets in which, sodium flows down to form a column generating droplets. During normal operation of the reactor, the evaporation of sodium from the pool surface to the cover gas at lower temperature, results in the suspension of sodium aerosol in the cover gas, which ultimately get deposited on the cooler region in the cover gas space.

Thus safety analysis of fast reactor deals with the formation of aerosols in the reactor environment and the release of such aerosols to atmosphere, since the aerosols are the principle carriers of radioactivity to public domain. The environmental source term is the quantity of radioactive material released into the environment after the CDA, which in turn depends on the quantity of aerosols remains suspended inside the Reactor Containment Building (RCB) and the quantity of aerosols leaked from the RCB. In this paper, various aerosol issues related to the fast reactor safety are described in detail.

AEROSOL ISSUES

1 Initial Size distribution

The initial size distribution of sodium compound aerosol is an important factor to be applied to HAARM code to predict the suspended mass concentration of aerosols as a function of time, inside the RCB. Also initial size distribution of sodium compound aerosols at different ignition temperature of sodium and for different relative humidity is useful for the realistic prediction of suspended mass concentration inside the RCB.

2 Gamma effect in aerosol deposition

In the case of CDA, RCB is bottled-up with large amount of sodium compound aerosols and aerosols of fuel and fission products. It should be noted here that the radiation dose inside the RCB, after CDA is extremely high (in the order of tens kGy). So it is very important to evaluate the suspended sodium compound aerosol mass concentration in the presence of gamma field.

3 Chemical composition of sodium compound aerosols

Sodium forms various compounds when contacted with atmosphere viz. sodium monoxide, sodium peroxide, sodium hydroxide, sodium carbonate and sodium-bi-carbonate depending upon the oxygen, moisture and carbon-dioxide available at the environment. Out of various compounds of sodium, sodium hydroxide is highly corrosive. This gets converted to carbonate when it reacts with carbon dioxide available in the atmosphere. Hence quantification of hydroxide and carbonate, over a period of time starting from the ignition, is helpful to mitigate the damages caused by hydroxide.

4 Co-agglomeration of sodium aerosols with other aerosols

In the bottled-up condition of RCB, sodium aerosols agglomerate with aerosols of fuel and fission products resulting dendritic structures. Since mass of sodium aerosols are high, the mass deposition pattern of aerosols inside the RCB follows that of sodium. The fractal dimension of co-agglomerated aerosols (Sodium with other fission/fuel aerosols) and their deposition pattern in a confined environment are to be studied.

5 Aerosol Retention Factor in sodium pool

Retention Factor (RF) quantifies the release of fuel or fission products from sodium to environment. RF can be expressed as

$$RF = (m_x/Na)_{\text{in pool}} / (m_x/Na)_{\text{in aerosol}}$$

Where m denoted the mass and x stands for the elements (U, C_s, I, S. By finding the values of RF for a fission product, the amount of fission product released to RCB may be estimated for a given pool volume.

6 Scavenging of iodine in sodium aerosols

The sodium oxide aerosols react with moisture present in the atmosphere become sodium hydroxide and their size grows as they absorb moisture. During that time, Iodine or any volatile fission products, generated in the form of vapour, get diffused into the porous sodium compound aerosol. As the Sodium compound aerosol settles, the fission product vapors also get settled, thus reducing the concentration of Iodine or any volatile fission products. The scavenging of Iodine in the sodium compound will be studied.

7 Aerosol dispersion in environment

The sodium oxide aerosol dispersion and the consequent ground level concentration are to be studied in a local distance range for safety analysis. The ground level mass concentration of sodium oxide aerosols is calculated using Gaussian Plume Model (GPM) for conservative estimates.

8 Aerosol dispersion in large vessel

Since the volume of RCB for the fast reactor is of the order 10^4 m^3. Hence a study on the spatial variation of aerosol mass/number concentration in a large vessel is a useful tool to estimate the release rate and subsequent ground deposition of aerosols if it is leaked.

9 Aerosol size and concentration in cover gas

The calculation of heat transfer to top shield in the argon cover gas would be accurate if we take in to account the presence of sodium aerosol in the cover gas. Hence the experiments on heat and mass transfer across a cover gas system together with the simultaneous measurements of sodium aerosol characteristics are necessary for the validation of theoretical models of the cover gas environment. The aerosol characteristics would give necessary inputs for the design of Argon cover gas filter system.

3.0 SUMMARY

Experimental results obtained will be used for the realistic estimate of the environmental source term for CDA case. This will help in arriving at a realistic boundary dose value, which will become necessary if more than one reactor is housed in a site. Thus aerosol study occupies a major part in the Safety Analysis of Fast Reactor.