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Regulatory Perspective on VHTR Dust Safety Issue

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1. Introduction

Dust can be generated in VHTR and its impact on VHTR source term has been a long lingering safety issue(1,2). Though the design of tri-structural isotropic(TRISO) fuel is known to prevent large scale failure and fission product release even in accident scenarios, radiologically significant quantities of fission products will be present in the primary system coming from either a small fraction of failed fuel particles or intact fuel because of the diffusion in the fuel(3). The released fission products will be transported in the coolant gas, and plate out onto surfaces in the primary system. But analysis of the fission product distribution, in both normal and accident scenarios, is complicated in VHTR by the likely presence of dust. The FP-laden dust is supposed to be mobilized during the rapid depressurization accident and thus contributes to another source term mechanism. Also in all industrial plants where burnable solid compounds are treated, dust combustion becomes a significant risk and combustion of graphite dust in Chernobyl adds concerns to the dust safety issue. Thus, dust generation, interaction with fission product, transport and combustion constitutes the areas to be resolved for dust safety issue. U.S. NRC is organizing dust working group meeting since 2009 to discuss this dust safety. This paper summarizes the past experiences and current knowledge of dust in section 2 referencing the discussions of the recent 2011 dust working group meeting and suggests a domestic regulatory perspective to resolve the issue in section 3.

2. Past Experiences and Current Knowledge of Dust

This section summarizes the past experiences of dust generation and the current knowledge in assessing and modeling the dust behaviour.

2.1 Dust Generation and Characterization

Tens of kilograms of dust have been generated in previous high temperature reactors by several mechanisms, one of the most significant one being the abrasion of graphite when graphite parts move relative to each other, or relative to metal parts in the reactor. Extensive dust formation was observed in the AVR (Arbeitsgemeinschaft Versuchsreaktor), which is a German experimental reactor of the pebble bed design operated for approximately 20 yrs (1973~1988). Estimated dust inventory inside the reactor at the end of life was ~ 60 kg(4). The observed dust was strongly bound on pipe walls and it was hard to scratch the dust layer even with hammering the pipe walls. The source of the dust was mainly from the fuel handling system. But the specific chemical condition of AVR, the air and oil ingress incidents during the operation renders it difficult to extend the results to other prototypical HTR.

On the other hand, very little dust was observed in prismatic block type reactors like Fort St. Vrain (FSV) and Peach Bottom reactor. The recent observation in the Japanese 30MWt HTTR (High Temperature Engineering Test Reactor) was also came from the abraded piston rings of primary helium purification system (Fig.1), not from the core. The amount of dust from core graphite is negligible(5) and the experience shows that the rings require frequent replacement.

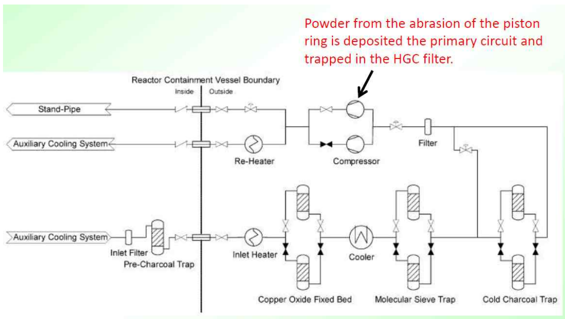

Fig. 1. Source of Dust in Japanese HTTR

So the general consensus is that the dust is generated mainly in pebble bed reactor by friction and it is not generated much in the prismatic core, even though it is difficult to estimate the quantitative amounts. Design changes of the piston ring or the fuel handling system could reduce the dust generation from this secondary systems.

2.2 Fission Product Interaction with Dust

Radionuclides are released continuously from fuel during operation of the gas cooled reactor and it deposits, throughout the reactor coolant system, within matrix and structural graphite, on metal surfaces in the reactor coolant system and also on dust. It is presumed that dust will be promptly mobilized by depressurization events and thus radionuclides bound to the dust will be carried promptly into the containment. The main mechanisms are aerosol-dust interaction which is relatively well understood and also the vapor-dust interactions. To understand the vapor-dust interaction, we need to characterize the irradiated graphite, like permeability parameters, porosity and tortuosity. Huge amount of continuing work on water vapor absorption on graphite exists, but nearly all are not applicable to nuclear graphite or dust. To model the fission product interaction properly, therefore, we need first to characterize the irradiated nuclear graphite and then to develop the empirical data base on radionuclide vapor isotherms.

2.3 Transport of Dust

Modeling of aerosol transport in VHTR is a very challenging problem because even the nature of dust in prismatic reactor is not well characterized. The mechanisms involved are turbulent deposition, gravitational settling, thermophoresis, diffusiophoresis, bouncing, particle break-up and resuspension, just naming a few. Difficulties in modeling the phenomena could be easily understood by citing a few issues raised. For example, influence of wall roughness on turbulent deposition is not well investigated, theoretical models for resuspension exist but they cannot be reliably used in safety case of NPP. Moreover, vibration or shock should accompany the depressurization and it seems not possible theoretically to model the phenomena. Thus, developing empirical approach needs to be pursued and preferred, but still it's not clear whether laboratory level data could be extrapolated to prototype reactor.

2.4 Combustion of Dust

Consensus on the issue of dust combustion is agreed upon relatively well. The AVR data show that there are relatively few free dust in the circuit. Also the high thermal conductivity and low impurity content renders the graphite generally resistant to combustion and most tests performed(6) since '60s indicate dust in VHTR primary circuit is non-explosive, or mildly explosive in ITER tests. Thus the current knowledge shows that the dust combustion is not a significant concern for VHTR accidents.

3. Regulatory Perspective on Dust Issue

In section 2, we have summarized briefly the current knowledge base and knowledge gaps for dust safety issue. Considering the complexity of the phenomena, the limited domestic resources available for this area and the aggressive roadmap of NHDD project targeting to apply the licensing of demonstration reactor by 2017, we need to have a well organized and focused approach to handle this issue. In this section, we'd like to propose a conceptual direction to handle the issue.

Evaluating the knowledge gap for the dust phenomena, we found the following question is first to be answered by the domestic designer for VHTR licensing before filling the whole knowledge gaps. We raise a question and propose in what direction it should be handled.

1) Does the presence of dust promote FP retention or does it enhance FP release in an accident ?
   - specify the nuclear graphite to be used in domestic VHTR design.
   - search and assess the characteristics of the irradiated graphite from the available data base
   - take a dust-free case and estimate the FP release
   - take a prototype dust involving scenario and estimate the FP release
   - evaluate whether the dust-free scenario is a upper bound from the aspect of source term

2-1) In case we could estimate, even in a rough way based on the current knowledge, that the dust-free is upper bound from the source term point of view, we could get rid of the dust as a safety issue.

2-2) In case we find that the dust-free scenario is not a upper bound for FP release, it is necessary to develop a reliable PIRT for dust behavior and prioritize the safety-significant and important phenomena for VHTR licensing.

This approach is based on our engineering judgment reflecting that 1) it is not possible to answer all the issues raised for dust with the limited domestic resources and the NHDD roadmap, 2) there is high possibility that the dust retains the fission product in the circuit and it does not promptly mobilize even in a depressurization incident and 3) reasonable bounding evaluation is possible even with the current knowledge of dust. This approach needs to be discussed seriously with the designer together.

4. Conclusions

We have summarized the current knowledge and gaps for dust safety issue. Then we have proposed the regulatory perspective on how to handle the issue. Our approach is based on our engineering judgment, accepting the complexity of the phenomena and the scarcity of domestic expertise and resources. Serious discussion between the designer and the regulatory body is in need to concretize and implement the idea.

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