Long-term Prediction of Emissivity of Structural Materials for High Temperature Reactor Systems

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ABSTRACT

The Reactor Pressure Vessel (RPV) and the internal components rely partially on radiation from their outer surface for cooling. In the event of an unexpected high temperature excursion, the dependence on radiation for the expulsion of heat from the system becomes all the more important because of the fourth power temperature dependence of radiated heat. The key material parameter that dictates the extent of heat radiated from the surface is emissivity, which is defined as the ratio of emissive power of the materials' surface to that of an ideal black body. Emissivity is a surface phenomenon and is dictated by the materials' surface chemical composition as well as the physical nature of the surface such as roughness, porosity, and texture. Since oxidation or some type of surface corrosion will inevitably at high temperatures, it is important that these surface effects be taken into account in emissivity evaluations.

The research involves a study of emissivity of a range of materials of relevance to a variety of reactor concepts. We will measure hemispherical emissivity, which provides an integrated measurement, as well as spectral emissivity from which the integrated quantity can be obtained. Hemispherical emissivity is needed for MELCOR, RELAP, and FLUENT type calculations, while spectral emissivity is needed for a detailed Monte Carlo Transport theory computation of heat transfer. In recent years, both universities have conducted short-tem emissivity studies of materials and we will use this data in conjunction with reaction kinetics and transport calculations on oxide/corrosion product film formation and spallation, to develop and validate long-term models for emissivity.

While the focus of research will be on the RPV and related materials such as A533B and A508 steels, we will also extend this study to a broader range of reactor concepts, materials, and environments. We will study Fe-9Cr-1Mo ferritic steel which is being considered as an RPV material for high temperature reactors, 316 stainless steels which has broad usage in the fluoride salt-cooled high temperature reactor (FHR) and sodium fast reactor (SFR), Alloy 800H and IN 617 for high temperature gas-cooled reactor (HTGR), and Hasteloy-N for the FHR. The differences in material chemistries among these alloys, temperature of operation, and the fundamentally different environments will result in the evolution of vastly different surface corrosion product films and consequently different emissivity behaviors. The alloys will be exposed to their respective environments to understand emissivity changes as a function of chemistry, morphology, and growth trends of corrosion product films that form on these alloys, that can be then used to develop models for long-term emissivities.

The emissivity data and models developed will also be used to assess changes in core heat removal from the Reactor Cavity Cooling System (RCCS) where emissivity data for the absorbing riser ducts intended to remove heat from the simulated reactor pressure vessel is crucially important.