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Understanding the Consequences of Liquid Sodium Metal Fires

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Many Generation IV reactor designs use liquid sodium (Na) as the primary and secondary coolant (as do other advanced reactor concepts). While the use of sodium enhances safety in many aspects related to the high boiling temperature of the sodium coolant, sodium and other materials do pose unique risks in these reactors. In particular, sodium is able to ignite and oxidize (combust) at cooling-loop operating temperatures. Sodium also presents challenges because it is reactive with water, carbon dioxide, and concrete which are unfamiliar oxidizers. The summary will addresses some of the potential thermal consequences of sodium leaks into oxidizing atmospheres through an experimental investigation of heat flux from sodium pool fires along with supporting model predictions [1]. An understanding of these consequences is directly relevant to safety analyses for new reactor designs.

While sodium fires have been studied over the decades, fundamental challenges and unknowns remain. Based on a literature review and a PIRT (phenomenon identification and ranking table) exercise carried out in an earlier phases of this project [2, 3] a number of research priorities have been identified. One aspect that has largely been ignored in the past work is the potential thermal damage to hardware in a metal fire. For pool fires, it is expected that thermal damage to the surface on which the pool is resting will be most significant. While experimental measurements and models have been developed for deep pools of sodium thermally insulated from their environment [4, 5], the more likely accident scenario will involve moderately shallow pools that interact thermally with their environment. These shallow pools are expected to be produced in a scenario where sodium-leak-mitigation practices cause excessive sodium to drain into inerted tanks [6] resulting in relatively thin layers of sodium exposed to the plant atmosphere. This can lead to combustion occurring at pool temperatures for which the formation of an oxide crust is important. To the best of the authors' knowledge there are no systematic experimental measurements or physical models to describe pools burning under these conditions.

The experimental results and a model for sodium pool burning will be presented. Challenges to be overcome in development of a sodium pool model include the fact that surface burning for sodium pools is complicated by the formation of an oxide-layer (crust) leading to a different mode of burning than that encountered with other types of pool burning materials. The model presented is similar to other existing models, and the primary purpose of the present study is to identify the limitations of such an approach when pool heat transfer is significant [1-3].

A series of experiments have been carried out with sodium pools formed in steel pans of non-negligible thermal mass. When the mass of the steel pan dominates that of the sodium, the sodium temperature rapidly equilibrates with the steel at a temperature in the vicinity of observed sodium ignition temperatures. If this temperature exceeds these observed sodium ignition temperatures, the pools generally burn in a manner similar to other observed sodium pool fires and predictable using models based on gas-phase combustion limited by sodium-oxygen mixing. These models are able to predict, subject to transport parameter knowledge, the final pool temperature and the rate of heating. On the other hand, when the pool cools to temperatures below the typically observed sodium ignition temperatures, a different mode of combustion is observed. This mode is characterized by vigorous combustion occurring over only a portion of the surface and by the eventual predominance of a porous oxide layer that reduces, but does not appear to quench, rates of oxidation. Known combustion models do not appear suitable for predicting this regime. The primary thermal consequence of this situation is reduced heating rates of the substrate.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

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