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Fission Product Source Terms and Engineered Safety Features

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Interest in source term research was clearly waning in January, 1978. The Reactor Safety Study, WASH-1400, had been published over two years previously, and although some of the conclusions and the methodology had been criticized, the areas of contention largely concerned the probabilistic approach that was employed and thermalhydraulics features. As best I can ascertain, however, not a single criticism was made regarding the manner in which fission product release and transport was handled.

There was, in fact, a slight flurry of activity in the source term area shortly after the release of WASH-1400, but this was motivated by the very large uncertainties which were cited in the Reactor Safety Study for the fission product release values. Curiously, however, the main concern was not with so-called "risk dominant" or "degraded core" accidents; the low probabilities of occurrence predicated for such accidents were apparently accepted by the nuclear community as tolerable.

Instead, the main thrust of the research was directed toward a realistic evaluation of the consequences of design basis accidents, and foremost among these was the controlled loss-of-coolant accident. From the standpoint of the safety of the general public, controlled loss-of-coolant accidents proved to be relatively benign, regardless of the probability of occurance or of the details of the thermalhydraulics. For the most recent studies at that time indicated that only about 1% of the noble gas

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inventory of the entire core, 0.03% of the cesium inventory, and 0.05% of the iodine inventory would be released from failed fuel rods in the course of a controlled loss-of-coolant accident in a light water reactor.[1] For radioiodine, then, only a few thousand curies would be released from the fuel rods, and ample opportunities existed for significant attenuation of this release regardless of its chemical form. Moreover, the newer release values were themselves some two orders of magnitude less than corresponding results derived from the Reactor Safety Study.[1]

The accident at Three Mile Island (TMI) in March, 1979 of course had a significant impact on the course of reactor safety research in general, and of studies of fission product source terms in particular. The accident, which could be described as a "nearly controlled" loss-of-coolant accidents, also served to turn the attention of the nuclear community away from more probable, relatively benign, design basis accidents and toward considerations of much less likely, but more consequential, severe core damage accidents.

Early interest in fission product release and transport during the accident at Three Mile Island did not focus on what did happen, but rather on what did not occur. In particular in this regard, a major problem involved the relative releases of radioiodine and the noble gases. during the accident, about 8 million curies of ^{133}Xe were released into the atmosphere, but only about 15 curies of ^{131}I similarly escaped. In contrast, the accident at the Windscale reactor in 1957 resulted in the release into the atmosphere of only some 300,000 curies of ^{133}Xe but about 20,000 curies of ^{131}I.

The answer to the problem of almost negligible iodine release at TMI lay, of course, in a more careful consideration of the chemistry involved. Radioiodine released from defected fuel rods was traditionally considered to be in elemental form. As a consequence, it had been assumed that the fission product similarly exists primarily in elemental form in the containment building, although a small fraction was additionally assumed to convert to organic iodides and to become associated with particulates. In view of the chemically reducing conditions which are an inherent characteristic of severe core damage accidents in light water reactors, and the likely formation of cesium iodide within the fuel rod or within the core region, the release and transport of fission product iodine in elemental form is most improbable.[2] Moreover, with the exception of silver iodide, the most likely iodides involved are extremely soluble in water; this factor can result in a significant reduction of the source terms for radioiodine for those accidents in which the escape pathway is intercepted by water. As a consequence, except for accidents involving the introduction of aerosols in high concentration in the containment building atmosphere, the dominant volatile form of radioiodine is probably organic in nature. Moreover, this form would be dominant, not because of its presence in high concentration, but because the remaining chemical forms are nonvolatile. Interestingly, the precise mechanisms for the formation of organic iodides in reactor accidents is not clearly established.

Since March, 1979, considerable research has been performed on severe core damage accident source terms. This research will culminate shortly in the development of new methodologies for establishing source terms, as embodied both in the Industry Degraded Core Rulemaking (IDCOR) Program and in the Nuclear Regulatory Commission's Severe Accident Program. These approaches will unquestionably lead to more sophisticated and more realistic evaluations of the consequences of severe nuclear reactor accidents.

Unfortunately, these evaluations will largely be directed toward giving people (mostly pro-nuclear) a warm feeling about the consequences of highly improbable events. Thus far, however, little use has been made of the knowledge gained of the behavior of fission products to modify existing strategies for mitigating the consequences of accidents of high or low probability. Nor has the adequacy of these strategies been re-examined in light of current research findings.

For example, caustic is added to containment building spray systems, presumably to capture radioiodine (in the wrongly assumed elemental form) in order to prevent its escape into the environment. Spurious trips of the spray system of course result in the dispersal of caustic solutions into the containment building.

The use of sprays of caustic solutions appears to be totally unwarranted to mitigate the consequences of traditional design basis accidents. The need for caustic is likewise questionable at the other extreme as well, for in severe core damage accidents the dominant carrier of airborne radioiodine is believed to be aerosol particles. In addition, containment building spray systems are normally activated by indications of high pressure, not of high radiation level, and these two parameters are not necessarily related. At Three Mile Island, for example, the spray system was activated, because of a hydrogen burn, long after fission products had been introduced into the containment building. There is thus adequate reason to re-examine the use of caustic in such spray systems.

In a similar vein, although the situation is more complex, the strategy for the use of standby off-gas treatment systems, as well as their design, should be re-examined in light of current research results.

I seriously doubt whether any of the engineered safety features that are installed in currently operating reactors would aggravate the consequences of a serious reactor accident, but this aspect certainly merits examination. However, there is reason to believe that some of these systems will never perform their intended function, or that their efficiency will be severely compromised, primarily because the assumptions underlying their design and operation, though conservative, are wrong.

In summary, we shall have in hand shortly new, technically defensible, methodologies to establish realistic source term values for nuclear reactor accidents. Although these methodologies will undoubtedly find widespread use in the development of accident response procedures, it is less clear that the industry is preparing to employ the newer results to develop a more rational approach to strategies for the mitigation of fission product releases.