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POTENTIAL FOR HYDROGEN COMBUSTION IN A HIGH LEVEL WASTE STORAGE TANK

OBJECTIVE

In 1990, the NRC authorized licensees to store spent nuclear fuel at reactor sites in NRC-approved storage casks. Of recent concern is the vulnerability of this temporary storage medium to hydrogen combustion events. This technical bulletin outlines one method in use at a DOE facility to assess the potential for the generation and ignition of hydrogen in high level waste storage tanks. The approach can be applied at commercial nuclear power plants to evaluate spent fuel storage in response to NRC Bulletin 96-04: Chemical, Galvanic, and other Reactions in Spent Fuel Storage and Transportation Casks" (July 5, 1996).

OVERVIEW OF HYDROGEN COMBUSTION

Hydrogen combustion is a chemical reaction between gaseous hydrogen and gaseous oxygen producing steam and releasing energy:

$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O + 242 \text{ MJ}$$

Necessary conditions for hydrogen combustion are the presence of flammable amounts of hydrogen and oxygen and the presence of an ignition source. Hydrogen can be generated by oxidation-reduction reactions, as in the case of zinc coated materials immersed in borated water. The presence of another "inert" gas that does not participate in the combustion reaction (such as steam or nitrogen) acts to inhibit combustion. Extensive laboratory research has been performed for numerous combinations of hydrogen, oxygen, and inert gases to map out the hydrogen and oxygen concentrations that are combustible, i.e., the flammability limits.

SINGLE SHELL TANK (SST) ANALYSIS

Single Shell Tanks (SSTs) have been used to store high level nuclear waste. These large, domed tanks contain the high level waste, air and, possibly, combustible gas. The tanks can be vented through a High Efficiency Particulate Adsorption (HEPA) filter system.

An investigation of the SST vulnerability to hydrogen combustion events quantifies the impact of various activities and equipment usage by evaluating their influence on the frequency and consequences of credible accident scenarios. The quantification is structured around event trees for in-tank and ex-tank gaseous release events (GREs). Each tree may include an incoming probability density function (PDF) for hydrogen production, a set of scenarios is defined where the basic event is the sudden release of an amount of flammable gas sufficient to cause a non-trivial portion of the headspace to exceed the lean flammability limit (LFL) for a period of time. The incoming PDF is the frequency of release for a given volume of flammable gas. Global flammability (i.e., the entire tank exceeds the LFL) and local flammability (i.e., a plume of gas exceeds the LFL) are both considered through branches in the tree.

The in-tank burn GRE tree, illustrated in Figure 1, considers:

GRE Occurs
A distinct PDF for the frequency of flammable gas volume released is developed for each of several initiating events (i.e., earthquake-induced, waste disturbance-induced).

Plume or Mixed
Flammable gas volumes from the GRE PDF are compared to the flammability limits to determine if the release amount is large enough to cause the headspace as a whole to exceed the LFL, or if a distinct flammable plume will exist.

HEPA Failure
The split fraction is the probability of HEPA failure, calculated by combining a distribution for post-combustion pressure and a HEPA fragility curve (i.e., a curve of conditional probability of failure vs pressure). The post

combustion pressure is determined from an adiabatic, unvented combustion calculation for the distribution of flammable gas volumes derived from the GRE PDF. The PDF of gas volume is thus converted into a PDF of post-burn pressure.

In-tank Spark
The frequency of a spark is quantified by summing over the equipment types and activities such as welding, gas sampling, and video inspection.

In-tank Ignition
Whether or not ignition occurs is decided based upon relative location of the spark source and the flammable gas.

Dome Failure
The split fraction is the probability of dome failure, calculated by combining the post-combustion pressure PDF and a dome fragility curve.

Damage States
Damage states are determined from the major branch paths: PL (Plume burn); MX (mixed headspace burn); DM (dome failure); HP (HEPA failure); and No burn (combination of flammable gas concentration and ignition source required for combustion not present).

The complete analysis included quantification of the GRE event tree to identify credible accident scenarios, a mechanistic analysis of chemical reactions to determine the quantity of hydrogen gas produced, and a consequence analysis to determine the impact of hydrogen combustion on storage tank integrity and radiological releases.

SUMMARY

The waste storage tank analysis combines probabilistic (GRE event tree quantification, GRE PDF development, fragility analysis) and deterministic (adiabatic combustion calculations, sequence modeling and consequence analysis) aspects to investigate vulnerabilities to hydrogen combustion events. This approach is not limited to a specific geometry, but can be readily adapted to the analysis of dry fuel storage casks used in the commercial nuclear industry.

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