Proposed Generic Issues Submittal on Trapped Hydrogen and Oxygen Fire and Explosion During Fluid Transients

Situation: In my opinion, the possibility of explosions in nuclear reactors should be further investigated through research. To document this opinion, I have written a technical article for the American Society of Mechanical Engineers, Mechanical Engineering (ASME) Magazine, which will be published in the December, 2014 edition (See attached). This article is the latest in a series of publications that I have written to present new theory that I have invented to describe explosions in nuclear reactors and off-shore oil rigs. Recently my concern was partially addressed when I filed a concern through allegations@nrc.gov. NRC staff provided technical references that were used to write the referenced ASME magazine article, "From water hammer to ignition, the spark that ignited Three Mile Island burst from a safety valve", by Robert A. Leishear. This article discusses my explosions and fire research, and the article focuses on the reactor accident at Three Mile Island. This theory is also applicable to accidents and Pennsylvania; Brunsbuettel, Germany; and Hamaoka, Japan, and may also be related to the accident at Fukushima Daiichi. Explosions can be stopped if they are better understood. Issues of such consequence should be considered by the U.S. Nuclear Regulatory Commission (NRC).

My explosions and fire theory is discussed in the referenced ASME magazine article. Basically, fires and explosions are ignited in piping when a trapped gas is compressed by changing fluid flow rates that cause the gas to compress and autoignite, similar to ignition in a diesel engine. This ignition process is rather complicated in nuclear reactor systems, where trapped hydrogen and oxygen can ignite during fluid transients. For the Hamaoka and Brunsbuettel explosions, the transients were caused during system operations when flow rates suddenly changed and high pressures were induced. U. S reactor operators have taken steps to prevent hydrogen accumulation during normal operations to prevent similar explosions in U. S. reactors. The Three Mile Island accident hydrogen fire was similar in cause, and the ASME article is attached to provide a better understanding of the hydrogen burn at Three Mile Island (TMI).

In other words, the primary research proposal is directed toward nuclear reactor meltdowns, but this research will also provide insight into other reactor piping and building explosions. The risk of reactor meltdowns were considered to be incredible by the governments of the U. S. the Soviet Union, and Japan, but each of these countries experienced reactor meltdowns. This research should investigate the causes of reactor explosions and possible actions to prevent explosions in the event of a nuclear accident. As concluded in the ASME article, "If the causes of reactor explosions and fires were unknown for decades, the implications of this new theory are certainly not understood. Reactor explosions can be stopped to improve nuclear reactor safety, prevent deaths, and prevent environmental disasters."

Research on this issue has not been supported. The NRC referred me to Grants.gov, where the National Science Foundation (NSF) controls research funding. The NSF declined this research. This research is also pertinent to explosions at off-shore oil rigs, where research has been declined by the Bureau of Science and Environmental Enforcement. I believe these issues to be significant, but all government contacts to date point to some other organization to fund research.

Importance:
This issue may affect the public health, safety and environment. Research can determine operator response to prevent explosions during off-normal conditions. The risk and safety significance may be evaluated once the potential explosions and preventive actions are evaluated through research.

Sources: ASME, Mechanical Engineering Magazine, December 2014.

From Water Hammer to Ignition, The spark that ignited Three Mile Island burst from a safety valve. By Robert A. Leishear

Robert A. Leishear, an ASME Fellow, is a fellow engineer at Savannah River National Laboratory, and a member of the ASME B31.3 Process Piping Design Committee. His book, Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design, was published by ASME Press in 2013.

It can be hard to get even scientifically minded people to reexamine their conclusions; change is hard to hold on to. I have been working toward acceptance of a new theory of mine concerning accidental combustion in nuclear facility and oil industry pipelines. The theory has safety implications for any pipeline where explosive gases can form in liquid filled systems, and describes pipeline accidents in nuclear power plants, such as Three Mile Island. I suggest that this theory is certainly worthy of further study.

I wrote to the NRC and suggested that the theory had direct application to the hydrogen burn that followed a nuclear reactor meltdown in Unit 2 at Three Mile Island. The agency thanked me and politely said I was mistaken. They also sent me a report published under the designation GEND-INF-023, “Analysis of the Three Mile Island Unit 2 Hydrogen Burn.” It was prepared for the Department of Energy by J.O. Henrie and A.K. Postma of the Electric Power Research Institute.

Studying this document convinced me that the chain of events proved my theory that accidental combustion in a pipeline caused a dangerous fire at Three Mile Island. The facts presented in the report support conclusions that water hammer and trapped gases in a pipeline ignited the hydrogen burn at TMI-2. In fact, different responses by reactor operators could have even resulted in an explosion at Three Mile Island.

The partial meltdown at TMI-2 began at about 4:00 a.m. on March 28, 1979. According to the NRC, a series of mechanical failures, design flaws, and human errors resulted in a loss of coolant to the reactor.

TMI-2 was one of two pressurized water reactors at Three Mile Island. In pressurized water reactors, the controlled nuclear reaction among the fuel rods heats water, which is pressurized to more than 2,300 pounds per square inch so that it does not boil.

The pressurized water circulates in a closed loop called the primary cooling system. The primary system transfers heat to the secondary system, another closed loop of circulating water, which converts water to steam to run the turbines. A third system of circulating water cools the steam in the secondary system as it exits the turbines and condenses it to water, which is recycled to boil again. The third system is open to cooling towers and takes water from the river. At no point do the three systems share water with each other.

A meltdown may be defined as extreme overheating of fuel rods in a nuclear reactor core. In the case of TMI-2, cooling water flowed out of the reactor core through a valve, referred to as the pilot-operated relief valve, which was stuck in the open position. As the reactor core was uncovered, its shield of water boiled away, the zirconium cladding of the fuel rods ruptured, and fuel pellets wrapped in the cladding melted. Half the core melted at temperatures above 4,200 °F during the early stages of the accident, but an uncontrolled nuclear reaction or criticality accident did not occur.

During the meltdown, the primary reaction to form hydrogen occurred when zirconium cladding reacted with steam to form 126,000 cubic feet of hydrogen. At this time, there was not enough oxygen present to burn the hydrogen in the reactor, since four percent oxygen is required to maintain a flame in hydrogen, and free oxygen does not form in the zirconium-steam reaction. The only reaction that formed oxygen for ignition inside the reactor was that due to radiolysis. During radiolysis, radioactivity separates water into oxygen and hydrogen molecules. There may, or may not, have been a minimal amount of oxygen in the reactor during the meltdown, but there were no reported indications of major fire or explosion in the reactor at that time.

The steam bubbling from the molten reactor core and the newly formed hydrogen increased the reactor system pressure. Due to the pressure increase, steam and most of the hydrogen were then vented from the reactor into the reactor building through a safety valve, which was distinct from the stuck valve that initiated the meltdown. Hydrogen and air then mixed in the building to create flammable conditions.

Later that morning, operators forced water into the reactor core, which cooled, stopping the meltdown and the formation of hydrogen from the zirconium. In less than three hours, the meltdown was under control even though operators were unaware that a meltdown was in progress.

A fire was waiting to happen. Air in the unoccupied reactor building had thoroughly mixed with 703 pounds of hydrogen released from the reactor for approximately seven hours after the meltdown was brought under control. All that was required was a flame to start the fire.

Henrie and Postma's report detailed the complex chain of events that resulted in the release and subsequent burning of hydrogen in the reactor building. Nearly ten hours after the accident started, a hydrogen fire occurred without explosion in the reactor containment building. The report did not, however, identify an ignition or spark source for the fire.

My ignition theory states that the sudden compression of trapped flammable gases due to fluid transients, or water hammer, in pipelines may heat the gases sufficiently to autoignite them, similar to the combustion of fuel with air compressed in a diesel engine. In other words, slugs of liquid squeeze an oxygenated combustible gas until it gets hot enough to burn or explode. I outlined the theory in a paper, "A Hydrogen Ignition Mechanism for Explosions in Nuclear Facility Piping Systems," published by the ASME Journal of Pressure Vessel Technology in 2013 (135(5), 054501).

1. To validate my theory several conditions needed to be present, and those conditions were, in fact, present at the time of the burn. Hydrogen and oxygen needed to be present in the piping. Henrie and Postma acknowledged that the radioactive breakdown of water, or radiolysis, occurred during the accident. Once the zirconium-hydrogen reactions stopped during meltdown, and the hydrogen was released to the reactor building, the only continuing source of hydrogen in the piping was radiolysis. Hydrogen and oxygen formed as the melted fuel pellets

radioactively decomposed water in contact with the exposed reactor fuel. When radiolysis occurs, sufficient oxygen is formed to support a fire or explosion in the presence of an ignition source.

2. Water hammer had to occur in the piping. Flowing steam and water were simultaneously present in the primary system at the time of ignition. Conditions were right for water hammer. Condensate-induced water hammer occurs when water and steam flow together in piping systems. Steam vapor bubbles, or steam voids, collapse to induce sudden pressures of thousands of pounds per square inch as shock waves resonate the piping system. Water hammer behavior is detailed in my book, Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design, published by ASME Press.

3. Piping near the relief valve should increase in temperature as the hydrogen and oxygen in the piping burns or explodes. Henrie and Postma acknowledged this temperature increase.

4. The ignition source of the fire had to occur at the safety valve in the reactor building. Henrie and Postma stated that the fire started near the safety valve at the time that the safety valve opened.

In short, water hammer started a fire or explosion in the primary system piping by compressing hydrogen and oxygen. The piping near the safety valve increased in temperature immediately prior to the hydrogen burn, which is consistent with an explosion or fire in the piping. Increasing pressures then opened the safety valve to start the fire in the reactor building.

Approximately seven hours after the meltdown was brought under control, the safety valve opened at 13:49, and a flame front fired from the reactor piping into the reactor building. That is, a flame shot from the safety valve into the building filled with hydrogen and air. The resulting 1,400 °F fire was detected by pressure increases at 13:50; one minute after the safety valve opened. In other words, the safety valve opening was nearly coincident to the time that the burn started.

All of the reported facts are consistent with the new ignition theory. More than 35 years after the accident, the cause of the Three Mile Island fire has an explanation.

Why is further research required? The NRC documented extensive actions to improve reactor safety after the Three Mile Island accident, but this new ignition theory has yet to be fully evaluated with respect to off-normal reactor operations in the U.S. and abroad. Several nuclear reactor fires and explosions warrant consideration.

This fire-and-explosion theory is consistent with past piping explosions at nuclear reactors in Brunsbuettel, Germany, and Hamaoka, Japan, where eight-inch diameter steel pipes shredded like paper firecrackers. When my theory was first published, the causes of German piping explosions were unknown, but later reports concluded that water hammer probably caused the explosions. The Japanese piping was removed from service.

With respect to Three Mile Island, there was no explosion in the containment building during the accident, since 99.4 percent of the hydrogen had already burned. Only half of the reactor core was affected by the meltdown. Slower response times by operators could have destroyed the entire core and more than doubled the hydrogen in the reactor building. This additional hydrogen may have been sufficient to cause an explosion rather than a fire. Following the TMI-2 accident, unburned hydrogen was safely vented from the reactor building to the atmosphere by reactor operators. The hydrogen burn was contained in the reactor building.

Hydrogen burns were not so well contained, however, at Fukushima Daiichi in Japan. Several hydrogen explosions accompanied meltdown caused by a tsunami that damaged nuclear reactors. During this reactor accident, radioactive clouds blasted into the air from hydrogen explosions that devastated nuclear reactor buildings.

Mild winds then dispersed the radioactive contamination across the surrounding Japanese countryside, where 300,000 residents were evacuated. Some accident details of these Japanese explosions are available from the Tokyo Electric Power Co. (Fukushima Nuclear Accident Analysis Report, 2012), and the conditions to apply this new ignition and combustion theory to these explosions were present. Specifically, for two of the reactors, at the time of explosions sea water was abruptly added to reactor cores experiencing meltdown accidents. That is, water hammer was potentially applied to hydrogen in the pipelines to ignite flames, which in turn could have entered the reactor buildings to initiate explosions of hydrogen. If the sea water had been added at a slower rate, perhaps the explosions could have been prevented.

The Japanese report neglected the ignition source of the explosions. Neither the Tokyo Electric Power Co., the International Atomic Energy Agency, nor the Japanese Atomic Energy Agency answered correspondence with respect to this nuclear safety and environmental concern.

Nuclear reactor accidents deserve further investigation, since reactor fires and explosions were ignited by sources that were reported to be unknown. This new theory proposes a source of ignition.

If the causes of reactor explosions and fires were unknown for decades, the implications of this new theory are certainly not understood. Reactor explosions can be stopped to improve nuclear reactor safety, prevent deaths, and prevent environmental disasters.