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Comments on the proposed rule to amend NRC regulations for combustible gas control in power reactor containment --- Federal Register, Vol. 67 -- August 2, 2002, at p. 50374.

Everyone knows that nuclear power is, "lest we forget, an inherently dangerous activity that Congress has authorized the NRC to license. The generation of nuclear power can never be risk-free." (from the report on the Three Mile Island accident, submitted to the NRC Commissioners and the Public by the NRC Special Inquiry Group, Mitchell Rogovin, Director. NUREG/CR-1250, Vol. I, January 1980, page 91)

Why, then, is the NRC considering relaxing requirements that provide protection against some of the uncertainties and hazards of this technology --- specifically, in this rulemaking, requirements for **(1)** hydrogen and oxygen monitoring equipment and **(2)** hydrogen recombiners and purge systems that could be needed following a loss-of-coolant accident?

The first time I read about radiolysis was in the early 1980s when many of us here in St. Louis were expressing our concerns about the impending shipments of the melted, but re-hardened fuel debris from the Three Mile Island accident. As you know, the accident began on March 29, 1979; about two dozen rail shipments occurred between July 1986 and around April 1990, moving from Pennsylvania out to the Idaho National Engineering and Environmental Laboratory, through Missouri and seven other states in between. One of the challenges posed by the decision to transport the fuel cross-country centered on the residual water that was entrapped in the fuel canisters. It was expected to be zapped by radioactive particles and rays emitted by the fuel, causing the generation of potentially combustible hydrogen and oxygen gas mixtures, via the process known as radiolysis.

Any time you have hydrogen gas evolving near oxygen, you have the potential for an explosion. In order to try to prevent an explosion or other uncontrolled hydrogen-oxygen recombination, the NRC required that "recombiner catalysts" be installed in each shipping canister --- to recombine the gases back into water. Although various problems developed with the design and installation of the catalysts, no one suggested abandoning them. And no one suggested that the NRC should "risk-inform" or reconfigure its shipping regulations in order to dismiss the likelihood of radiolytic decomposition and the potential of an explosion.

While I realize that some of today's NRC staff may be too young to have personally experienced the fear the rest of us did in the early days of the TMI accident (subsequently described, often, as the "public perception of risk"), many nuclear regulators and citizens nationwide at the time were legitimately concerned --- and particularly about the hydrogen bubble. The reactor operators ultimately figured out they could remove the hydrogen gas bubble from the reactor by using the normal purification system used for shim-bleeding the reactor coolant, and by venting the pressurizer tank into the containment chamber. (Daniel Ford: Three Mile Island--- Thirty Minutes to Meltdown. New York: Penguin Books, 1982, pp. 248-9) Things could have been worse.

But are you now asking the public to forget the unexpected hydrogen bubble, and the earlier unexpected hydrogen burn at TMI? ("While not an explosion, it was a flash, a 6- to 8-second burn of hydrogen from the damaged [fuel] core that has built up within the containment building." Rogovin Report: p. 40) If the NRC is supposed to try to balance known risks against those that are unknown, would the buildup of hydrogen not now

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be considered to be a known risk, and if so, would it not be reasonable to try to control and monitor its generation as thoroughly as possible?

Or are you asking the public to have faith that the hydrogen release from a design-basis loss-of-coolant accident (LOCA) is not risk-significant? If so, are we not back where we started from --- forgetting or ignoring some of the significant discoveries, surprises and lessons learned from the TMI-2 accident? How many of your new data analyses came from reanalyses of the TMI-2 experience? For some reason we rarely see the fact mentioned that the uranium fuel in the TMI-2 reactor had only fissioned for about three effective full-power months. While Unit 2 had been operable for a year when the accident began (having been issued its low-power operating license in February 1978), the reactor had experienced so many problems and shutdowns that the fuel was almost new. We were fortunate that the embrittlement of the Zircaloy metal cladding (the tubing that contained the uranium fuel pellets) had only begun to occur, and therefore also the generation hydrogen and the buildup of solid and gaseous fission products and transuranics. (That is, the waste available to be dispersed to the environment was less than if the fuel had been fissioning longer.) The plant's structures, systems and components (SSCs), were also almost new. Has the NRC staff truly been able to amass adequate data to be able to demonstrate that the amount of residual and radiolytically-generated combustible gases generated during a design-basis LOCA would not be risk-significant --- especially if the LOCA occurred in a plant with older fuel and SSCs than TMI-2's?

Reading about the proposed regulatory amendments on combustible gases reminded me of letters to the editor submitted by the late Earl A. Gulbransen when he was research professor at the University of Pittsburgh's School of Engineering – Department of Metallurgical and Materials Engineering. The first letter I read appeared in the Bulletin of Atomic Scientists, June 1975. Quoting from it:

> After 25 years of research and development work on the chemical and metallurgical properties of metals and alloys used in nuclear power plants, I have come to the conclusion that the current design and materials cannot give us a safe and well-engineered nuclear power plant. . . . The use of zirconium alloys as a cladding material for the hot uranium oxide fuel pellets is a very hazardous design concept since zirconium is one of our most reactive metals chemically. ... At the operating temperature of nuclear power reactors zirconium cladding alloys react with oxygen in water to form an oxide layer which partially dissolves in the metal embrittling and weakening the metal tubing. Part of the hydrogen formed in the zirconium-water reaction dissolves in the metal and may precipitate as a hydride phase also embrittling and weakening the metal tubing. ... At temperatures above 1,100 degrees Celsius zirconium reacts rapidly with steam with a large evolution of heat and the formation of free hydrogen, with most metals to form intermetallic compounds and with other metallic oxides to form its own oxide. (page 5; emphases added)

In Chemical & Engineering News (C&EN), March 31, 1980, Dr. Gulbransen further described the zirconium alloy fuel-rod cladding as a source of oxygen and hydrogen:

> Zircaloy has the dangerous property of reacting explosively with steam under conditions which may occur in loss of coolant accidents (LOCA) and power excursion accidents (PEA). Zirconium dioxide is formed. Oxygen also dissolves in the cladding up to 30 atomic % raising the alpha-beta transition temperature and embrittling the metal. Large amounts of hydrogen are formed which can blow out the cooling water, shatter the reactor vessel releasing radioactive products, or accumulate as a bubble inside the vessel. (page 3)

I do not understand how the NRC could have chosen Section 50.44 of the Code of Federal Regulations as its best "test case for piloting the process of risk-informing" the NRC's technical requirements. (67 FR 50375) Fortunately, no United States reactor has experienced severe core damage since Three Mile Island, but the need to have hydrogen control and monitoring for severe accidents has long been recognized. That's why 50.44 was initially promulgated. For example, to quote from the Reactor Risk Reference Document of February 1987:

> Requirements for control of hydrogen generated during accidents involving significant core degradation and metal-water reactions are included in Section 50.44, 'Standards for combustible gas control system in light-water-cooled power reactors,' of 10 CFR Part 50.
>
> The objective of this rule is to ensure that (1) containment structural integrity is maintained and (2) that systems and components necessary to achieve safe reactor shutdown survive under stresses associated with hydrogen burning. (NUREG-1150, Vol. 1, p.10-18.)

I also do not understand how the NRC staff could have decided, as a part of "risk-informing" its regulations, that combustible gas control following a loss-of-coolant design-basis accident is no longer a major concern. I have often read that enough hydrogen could result from core damage that the integrity of the containment building would be challenged, both as the result of a design-basis loss-of-coolant accident or, of course, a beyond-design-basis accident, as well. I do not understand how the requirement that hydrogen monitors be functional within 30 minutes of the initiation of safety injection could now be considered "overly burdensome." (Draft Regulatory Guide DC-1117, "Control of Combustible Gas Concentrations in Containment." August 2002, pp. 5, 6) Is the proposed substitution of a 90-minute requirement not overly arbitrary?

The NRC published many documents and regulatory changes following the TMI-2 accident under the rubric, "lessons learned." Perhaps the proposed deletions and other changes in 10 CFR 50.44, and in Part 52, and the new 50.46a should be entitled "lessons forgotten." The changes may be cost effective for the NRC's licensees, but I suggest they are not reassuring for the NRC's public.

Whatever happened to the concepts of "defense in depth," and "better safe than sorry"? If a nuclear electric utility, like the Callaway plant's AmerenUE here in St. Louis, or one of the conglomerate corporations like Entergy or Exelon, cannot afford to operate and maintain its nuclear power reactor(s) with the requisite caution and oversight, should it perhaps be asked not to operate it (or them) at all?

As I understand it, an important NRC responsibility is to assess the risk of whether certain events or equipment failures could lead to severe core damage and containment failure, and then to determine whether retrofitting a plant's equipment or modifying its operating procedures should be required in order to reduce such risks. The ability to predict to what extent hydrogen combustion may or may not pose a threat to the integrity of the containment building is unfortunately not an exact science, especially for our US nuclear power plants with their wide range of individualized designs. But as a part of assessing the combustible gas concentrations in the containment building, would you not want your licensees to use the most accurate and precise equipment available to monitor the evolution of hydrogen and oxygen during and following a LOCA transient? As I understand it, equipment that is "safety-related" would have been tested to withstand such regulated maximums as pressure, radiation, and temperature for each phase of an accident's progression. The NRC is instead now proposing to relax the requirement that the hydrogen and oxygen monitors be safety-related, having decided the monitors would no longer be classified as Category 1, "instrumentation designed for monitoring key variables that most directly indicate the accomplishment of a safety function for design-basis accident events." (67 FR 50378, quoting from NRC Regulatory Guide 1.97, "Instrumentation ... to Assess Plant and Environs Conditions During and Following an Accident.")

And the proposal to remove hydrogen recombiner requirements is equally perplexing. Quoting from the "Regulatory Analysis for 50.44," page 4:

> Recombiners are required to accommodate the amount of hydrogen associated with design basis events. Risk studies have shown that the risk is from beyond design basis events, not from the design basis events postulated in 10 CFR 50.44. For beyond design basis events, recombiners have little to no effect on mitigating the consequences of these events. The requirements for maintaining recombiners and hydrogen monitors as design-basis structures, systems and components (SSCs) have been burdensome to the nuclear power industry. (emphasis added)

Regarding the recombiners: it is interesting that France, with its more standardized nuclear plant designs, is now requiring the installation of "passive autocatalytic recombiners (PARs) for severe accident hydrogen control in all [pressurized water] PWR reactors by the end of 2007. This approach requires approximately 40 PARs per plant to achieve a capacity appropriate for severe accidents." (from the 50.44 Regulatory Analysis, page 5; emphasis added) What research has led the French Nuclear Installations Directorate to add this requirement? Are the French regulators more stringent, or is it that they do not have to worry about a private nuclear power industry, and its complaints about regulatory burdens and "value impacts" (costs) ?

I do not believe most members of the public care about whether recombiners are burdensome to the nuclear power industry. The requirements governing the operation, oversight and maintenance of the SSCs in a nuclear power plant are surely burdensome --- particularly those located where the radiation fields are high. The tasks are no doubt burdensome and, unfortunately, dangerous for the nuclear workers, but are they not also essential?

Concerns about threats to the reactor containment building have been discussed since before the TMI accident. For example, quoting from the NRC Regulatory Guide 1.7 ("Control of Combustible Gas Concentrations in Containment Following a Loss-of-Coolant Accident," Rev. 2, November 1978):

> Following a loss-of-coolant accident (LOCA), hydrogen gas may accumulate within the containment as a result of: **1.** Metal-water reaction involving the zirconium fuel cladding and the reactor coolant, **2.** Radiolytic decomposition of the postaccident emergency cooling solutions (oxygen will also evolve in this process), **3.** Corrosion of metals by solutions used for emergency cooling or containment spray.
>
> If a sufficient amount of hydrogen is generated, it may react with the oxygen present in the containment atmosphere or, in the case of inerted containments, with the oxygen generated following the accident. The reaction could take place at rates rapid enough to lead to high temperatures and significant overpressurization of the containment, which could result in a breaching of containment or a leakage rate above that specified as a limiting condition for operation in the Technical Specifications of the license. Damage to systems and components essential to the continued control of the post-LOCA conditions could also occur. (p.1)

The NRC's plans for the resolution of "Unresolved Safety Issues," mandated by Section 210 of the Energy Reorganization Act of 1974, as amended, initially included 133 generic issues pre-TMI 2. (NUREG-0410, January 1978). One of those was the "Study of Hydrogen Mixing Capability in Containment Post-LOCA," described briefly in NUREG-0471 as the need to prevent the accumulation of excessive hydrogen concentrations in the containment atmosphere after a LOCA. (Generic Task No. B-14; page B-17; July 1978.)

Subsequent to the TMI-2 accident, discussions about the knowns and unknowns of hydrogen generation and its hazards have continued to appear in the literature. According to the "Reactor Risk Reference Document," NUREG-1150, February 1987, hydrogen-related questions listed in the "containment event tree" of the Surry plant (in Virginia), included the following: Is there containment heat removal after the early hydrogen burn? Does a later hydrogen burn occur? What pressure rise would occur if combustible gases were to burn late in the accident? Would containment fail due to a late hydrogen burn or steam production? What is the ultimate containment failure mode, if any, resulting from core-concrete interactions? (Vol. 2, pp. A-15, –16)

Every one of the 103 operating reactors is unique. Even if the initial designs of some were the same, by now the operating experiences have been different. It seems reasonable for the NRC to continue requiring its licensees to use and maintain safety-grade hydrogen and oxygen monitors, rather than the lesser quality commercial-grade monitors. Quoting further from the above "Reactor Risk" document:

> In particular, there are several phenomenological issues, such as the expected rise in containment pressure should direct heating occur following vessel failure, in which estimates diverge widely. In

> these cases, it is inappropriate to characterize such a range as, for example, a normal or log-normal distribution, since such a distribution bears no relation to the experts' range of opinions.
>
> In the analyses other than the estimates of core-damage frequencies, there was virtually no experience or experimental data for the various events and issues in the analyses. (p. A-31; emphases added)

In a special report to Congress, published in March 1981, the NRC identified additional unresolved safety issues that resulted in part from the major investigations of the TMI-2 accident. A description of Task A-48, entitled "Hydrogen Control Measures and Effects of Hydrogen Burns on Safety Equipment," included the following:

> Following a LOCA in a LWR [light-water-reactor] plant, combustible gases, principally hydrogen, may accumulate inside the primary reactor containment as a result of: (1) metal-water reaction involving the fuel element cladding; (2) radiolytic decomposition of the water in the reactor core and the containment sump; (3) corrosion of certain construction materials by the spray solution; and (4) synergistic chemical, thermal, and radiolytic effects of post-accident environmental conditions on containment protective coating systems and electric cable insulation.
>
> In the event of degraded or melted core, a large additional amount of hydrogen would be generated as a result of a reaction between the molten fuel and the concrete containment base. ...
>
> Conventional hydrogen control systems (for example, hydrogen recombiners) have historically been installed to provide the capability to control the hydrogen accumulation as a result of radiolytic decomposition of water, corrosion of metals inside containment, and environmental effects on coatings and insulation. ...
>
> The accident at TMI-2 on March 29, 1979, resulted in a metal-water reaction which involved hydrogen generation well in excess of the amounts specified in 10 CFR Section 50.44. As a result, it became apparent to NRC that additional hydrogen control and mitigation measures would have to be considered for all nuclear power plants. (NUREG-0705, pp. A-11 through A-19)

According to the NRC's "Finding of No Significant Environmental Impact " (FONSI) regarding this rulemaking:

> There may be a reduction of occupational radiation exposure since personnel will no longer be required to maintain or operate, if necessary, the hydrogen recombiner systems which are located in or near radiologically controlled areas." (67 FR 50380; emphasis added)

To reduce the amount of time during which workers must be exposed to radiation and to reduce the number of workers needed at a nuclear power plant are certainly important goals. If the proposed regulatory amendments on combustible gas concentrations in containment were to cause an increase in the probability or consequences of an accident, the reduction in person-hours of workers exposed to radiation (as essential as that is) could well prove to have been an unfortunate tradeoff.

I also question the following claim in the FONSI about the proposed amendments:

> No changes are being made in the types or quantities of radiological effluents that may be released off site, and there is no significant increase in public radiation exposure since there is no change to facility operations that could create a new or affect a previously analyzed accident or release path. (loc. cit.)

The new proposed Section 50.46a "eliminates a requirement prohibiting venting the reactor coolant system if it could 'aggravate' the challenge to containment. . . . such venting will reduce the likelihood of further core damage." (loc. cit.) I would think this venting could indeed mean an increase in the radiological effluents released off site and a resulting potential increase in public exposure. Since no economically viable technology exists for the filtering of tritium (radioactive hydrogen) and noble gases from liquid and gaseous nuclear plant effluents, I would think the vented gases would increase the radiation risks of the public and the environment. Just for the record: when I first began reading in 1977 about the amount of tritium that was estimated to be released to the air and water during the routine operation of a nuclear power plant, I phoned a health physicist at Oak Ridge National Laboratory for further information. He replied, "Tritium is no big deal. All it can do is destroy a DNA molecule." I've subsequently learned a great deal more about the health hazards of tritium. (I would be happy to send you a packet of abstracts of some of my favorite papers.)

Nuclear industry representatives also belittle the health hazards of noble gases --- saying that, like the nobility, noble gases do not interact with the hoi polloi (that is, with materials such as human tissues). I have learned that some noble gases decay into highly radiotoxic and long-lived materials, e.g., krypton into strontium, and xenon into cesium, and that the noble gases can release radioactive particles and rays when inhaled and lodged in the lungs.

Research and debates will no doubt continue regarding the need for safety-grade hydrogen and oxygen monitors, the wisdom of permitting the high-point venting of the reactor coolant system to the environment (in order to try to protect the containment and reduce the likelihood of further core damage), and the effectiveness of hydrogen recombiners and hydrogen purge systems following a design-basis or beyond-design-basis LOCA.

In assessing the pending regulatory amendments, I hope the NRC will look at public safety not as a "burden," but as a responsibility and an obligation.

Sincerely,

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