

Hydrogen Production Safety at Nuclear Power Plants



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Flexible Plant Operation and Generation Pathway



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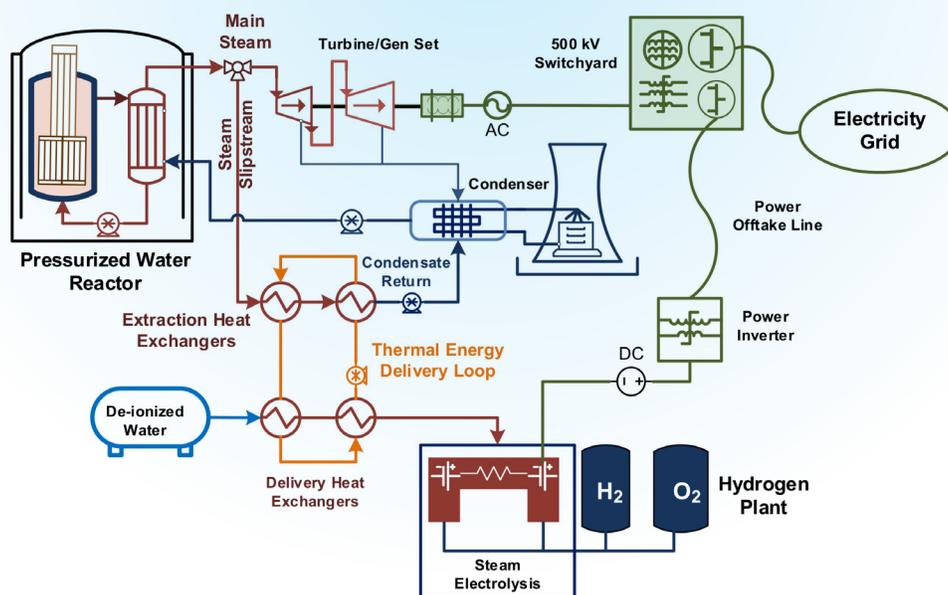
Technical and economic assessments for hydrogen and hydrogen-user industries were completed by the LWRS Program in 2019, which built upon previous accomplishments of the NE Program for Crosscutting Technologies Development and the Department of Energy Office of Energy Efficiency and Renewable Energy's Fuel Cell Technology Office. These efforts have focused on large energy consumers in the U.S. that incorporate hydrogen mainly for fuel-cell vehicles, hydrotreatment of petroleum fuels, and production of ammonia-based fertilizers and steel [1]. The studies have shown nuclear power plants can competitively provide the energy required to produce hydrogen and other valuable chemicals and products. These analyses indicate that hydrogen plants tied to or integrated into a light water reactor will be competitive with natural-gas reforming. As such, several large energy companies are realizing this is an important step to reducing greenhouse-gas emissions. Many nuclear power plants could be employed in this market [2]. The Flexible Plant Operation and Generation (FPOG) Pathway

is conducting research to identify and bound the hazards of connecting a high-temperature electrolysis plant to a nuclear power plant. Figure 10 illustrates the connection of a nuclear power plant to a steam electrolysis plant. The steam is generated by a heat delivery loop that picks up thermal energy from a steam bypass line (or slip stream) that is positioned just ahead of the high-pressure steam turbine. The slip stream returns condensate back into the main condenser. A secondary heat transfer loop delivers thermal energy to a non-nuclear steam generator that feeds the electrolysis plant.

Risk Information Used in Design

The FPOG Pathway has developed thermal hydraulic models for the thermal energy extraction and delivery systems. A full-scope nuclear power plant simulator has also been modified to include the steam slip stream and thermal energy delivery loop. The design of the heat extraction system has been made in consultation with industry experts at EPRI. Through a series of sensitivity studies, the research team was able to identify

Figure 10. Thermal and electrical energy dispatch to high-temperature electrolysis plant.



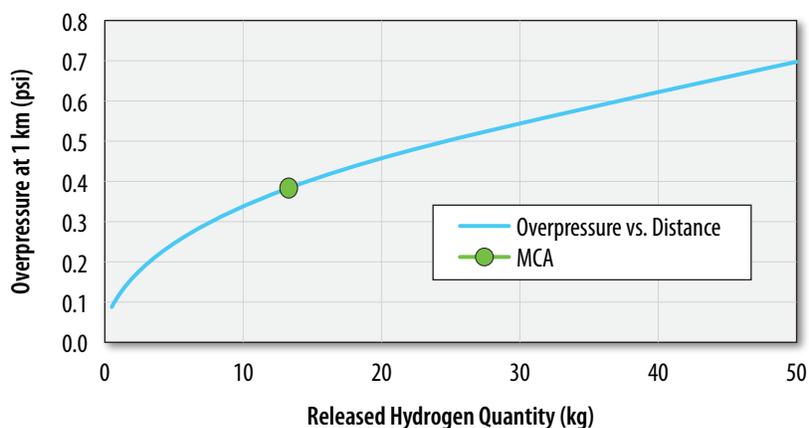


Figure 11. Overpressure at 1 km distance showing the MCA.

a preferred location for the steam bypass location and an upper rate of steam extraction that would not impact normal operation of the nuclear power plant. This provided a starting basis for a study of new risks introduced by the systems. Fault trees were developed for potential accident-initiating events, such as a steam rupture, a hydrogen leak, or a catastrophic detonation of a large volume of hydrogen in the vicinity of the nuclear power plant. A detonation could propagate a pressure wave that damages the plant's reactor containment walls, power systems, and other critical infrastructure and services.

Detailed Hazard Analysis and Modeling

The likelihood and consequences of an initiating event on the reactor are being evaluated and used to update a PRA for a representative pressurized water reactor. The risks associated with the hydrogen plant have been assessed by hydrogen and fire experts at SNL, where a blast code with representative industry hydrogen leakage rate information was used for the pipes and components of the hydrogen plant to calculate overpressure event frequency and consequences for various nuclear power plant targets. The "maximum credible accident" (MCA), which is a measure of the accident event that is used to determine the vulnerability of specific targets, was calculated for a range of hydrogen plant leakage rates based on building containment assumptions and hydrogen-air mixture detonation types (e.g., a flame jet or a cloud detonation). Figure 11 plots the calculated overpressure curve at 1 km distance versus the amount of hydrogen detonated, along with the position of the MCA. The analysis found that only the switchyard components have a significant probability of failure based on the MCA value. None of the other critical targets in the nuclear power plant have fragility to the overpressure produced by the detonation. The result of this analysis indicates that it may be possible to position the hydrogen plant closer to the nuclear power plant, thereby saving money on the pipeline and decreasing thermal losses—all without compromising plant safety. This would also increase the dynamic response of the system, which would allow the nuclear/hydrogen plant to ramp-up

and ramp-down to send power as needed to the electricity grid to provide spinning or non-spinning reserve capacity. An evaluation of the safety effects relative to the separation distance from the nuclear power plant is now underway.

Licensing

The results of a preliminary PRA and hazardous analysis performed in 2019 indicate either U.S. Nuclear Regulatory Guide RG 1.174 [3] or Code of Federal Regulations 10 CFR 50.59 [4] could be workable approaches to licensing nuclear power plant operations that supply process heat to a hydrogen plant. An overall core damage frequency change was within the acceptable limits of the RG 1.174 pathway. However, based on an initial conservative design of the thermal hydraulic system, the frequency of transients adversely affected two "design basis accidents" by a percentage that was unacceptable for license provisions under 10 CFR 50.59. A more thorough design of the thermal energy extraction systems is now underway, which will likely reduce the frequency of system transients to a point that 10 CFR 50.59 can also be exercised for licensing FPOG.

References

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3. U.S. Nuclear Regulatory Commission Regulatory Guide 1.174, *An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decision on Plant-Specific Changes to the Licensing Basis*, August 2009, <https://www.nrc.gov/docs/ML1009/ML100910006.pdf>.
4. U.S. Code of Federal Regulations, § 50.59 Changes, Tests and Experiments, <https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0059.html>.