Nuclear safety and regulatory considerations for nuclear hydrogen production

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Abstract

The use of a nuclear power plant to produce hydrogen or for other process heat applications will present challenges to the licensing process. Potential safety and regulatory issues have been evaluated to identify possible research needs, policy concerns and licensing approaches. A brief description of nuclear power plant licensing in the United States and a discussion of specific issues for using nuclear power plants for process heat applications are presented.

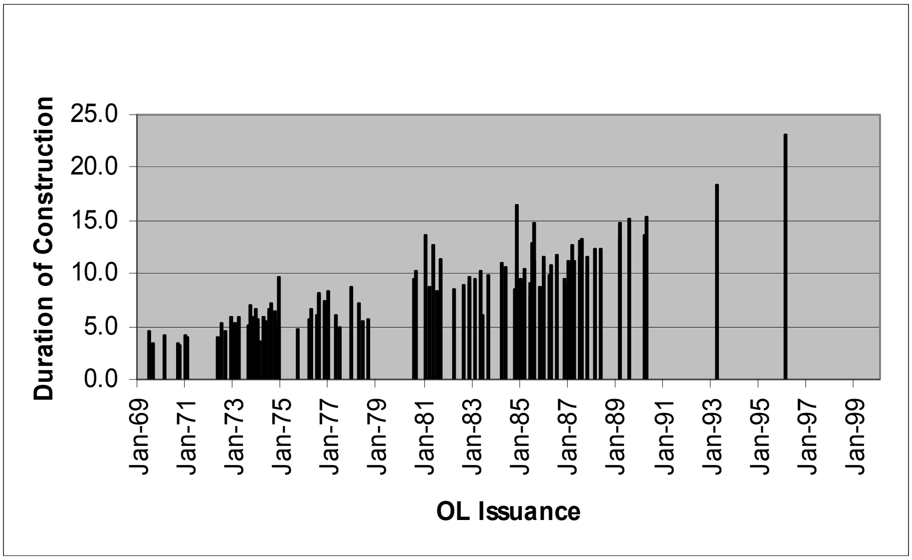
Introduction

The use of nuclear power plants to produce hydrogen or for other process heat applications at chemical or petroleum facilities will introduce some challenges to the licensing of the nuclear plants by the US Nuclear Regulatory Commission (NRC). The use of a nuclear power plant to support hydrogen production is an important part of the Next Generation Nuclear Plant (NGNP) programme that is being co-ordinated by the US Department of Energy (DOE) in accordance with the Energy Policy Act of 2005 (EPAct). A licensing strategy for an NGNP prototype reactor was prepared by a joint working group of staff from DOE and NRC (DOE/NRC, 2008). As part of the NGNP programme, the NRC staff evaluated potential safety and regulatory issues to identify possible research needs, policy concerns and licensing approaches. These efforts included the completion of a phenomena identification and ranking tables (PIRT) evaluation related to process heat and hydrogen co-generation (NRC, 2008).

Licensing approaches

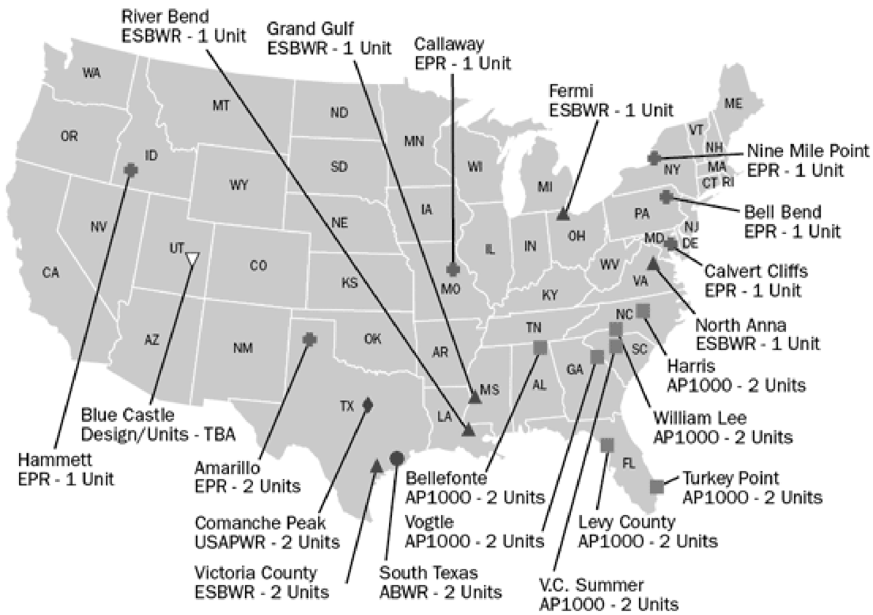
The EPAct assigns the development of the NGNP reactor design and deployment to the DOE and requires that it be licensed by the NRC. In the development of the NGNP licensing strategy, the DOE and NRC considered the various possible approaches that are available using existing NRC regulations. The NRC maintains two general approaches to the licensing of nuclear power plants. The first set of licensing regulations is defined in Part 50 of Title 10 of the Code of Federal Regulations (10 CFR Part 50) and includes the combination of construction permits and operating licenses. This licensing approach was used for the existing operating plants in the United States and is similar to the regulatory approach in many other countries. While offering possible advantages in terms of experience and a possible earlier start for the construction programme, the traditional licensing process under 10 CFR Part 50 included problems for the licensing process such as continual design changes during construction, evolving regulatory requirements between licensing reviews for construction and operations, and legal hearings held for both construction permits and operating licenses. Figure 1 shows the history of the time period in years between issuance of construction permits and operating licenses for nuclear plants operating in the United States.

Figure 1: Duration of construction for US operating nuclear power plants



Although the duration of construction was influenced by various factors, including the accident at Three Mile Island, economic conditions and power needs, the history and trend of extended times to obtain operating licenses was a motivation for the development of an alternate licensing process, which is defined in 10 CFR Part 52. The licensing process in 10 CFR Part 52 involves the possible submittal of a nuclear power plant design for certification and the approval of specific sites via an early site permit before an application is made for a combined construction permit and operating license. The combined license application can then reference the design certification and early site permit having resolved many technical and legal issues during the design or siting processes. However, an applicant need not reference a certified design or early site permit but can instead include all of the required information in the combined license application. An advantage for licensing is that the design information is reviewed only once and supports both the construction and operations phases of the facility. This can, however, be a challenge for the NGNP or other new designs in that design decisions need to be finalised well ahead of actual construction. The licensing reviews under way or expected in the United States are shown in Figure 2, with all combined license applications referencing a design expected to be certified by the NRC and with several referencing early site permits issued or under review by the NRC.

Figure 2: Combined license applications submitted or expected in the United States



The licensing strategy for the NGNP project recommended that the prototype facility develop a combined license application that would not be preceded by a design certification or early site permit. This strategy was developed to support the specific scenario defined in the EPAct and included the location of the prototype in Idaho with a goal for operation in 2021. The project may change following the solicitations of interest by DOE, the subsequent selection of technologies and the identification of possible commercial partners. The licensing approach and schedule may likewise need to change if the NGNP project evolves beyond the specific assumptions in the original licensing strategy.

Safety and regulatory considerations

The mission of the NRC is to license and regulate nuclear power plants and other civilian use of by-product, source and special nuclear materials to ensure adequate protection of public health and safety, promote the common defence and security, and protect the environment. The focus of the agency is, therefore, on keeping radiation exposures to workers as low as reasonably achievable and limiting the release of radioactive materials to the public from power plants through normal effluent pathways and during possible transients or accidents. The NRC staff is assessing various safety and regulatory issues associated with high temperature gas-cooled reactors and other aspects of the NGNP programme. One tool used in this process has been the use of phenomena identification and ranking tables or PIRT to document the current state of knowledge and potential safety significance of various issues. A specific PIRT was developed for the process heat and hydrogen co-generation applications that may be associated with the NGNP prototype or subsequent high temperature gas-cooled reactors (NRC, 2008). As documented in the PIRT, issues associated with coupling a nuclear reactor to a hydrogen production or other facility can be grouped into the three general categories: *i)* events or releases from the hydrogen plants; *ii)* heat transport system events and failures; *iii)* events or releases from the nuclear plant.

Events or releases from the chemical plant

The NRC has traditionally considered during the licensing of nuclear power plants the hazards posed by nearby industrial facilities, nearby transportation routes and hazardous or flammable materials used at the nuclear site. Existing guidance includes the NRC staff's standard review plan for nuclear power plant applications (NRC, 2007) and specific regulatory guides such as Regulatory Guide 1.91, *Evaluation of Explosions Postulated to Occur on Transportation Routes Near Nuclear Power Plant Sites*, (NRC, 1978) and Regulatory Guide 1.78, *Assumptions for Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release* (NRC, 2001). The existing guidance may need to be modified to address different chemicals and/or concentrations than those traditionally evaluated as well as the expected close proximity to the nuclear plant of the hydrogen production or other co-generation facility.

A chemical release from a hydrogen production facility coupled to a nuclear power plant could introduce hazards for both nuclear plant systems, structures and components (SSC) and to plant operators. This includes the possible routine or accidental release of oxygen from the hydrogen production facility. Hazards to SSC could include blast effects from explosions, fires, degradation from chemical exposure and possibly rendering equipment inoperable (*e.g.* starvation of oxygen from diesel generators). The operators of the nuclear power plant could likewise face hazards from explosions, fires or toxic chemicals. The applicant for the NGNP prototype reactor or other nuclear plant coupled to a hydrogen production facility will need to analyse such hazards and demonstrate that nuclear power plant safety is provided by measures such as separation, existing design features (*e.g.* building structures, control room isolation) or special design features (*e.g.* berms, blast walls). A summary of issues from the NRC's hydrogen production PIRT is provided in the following table:

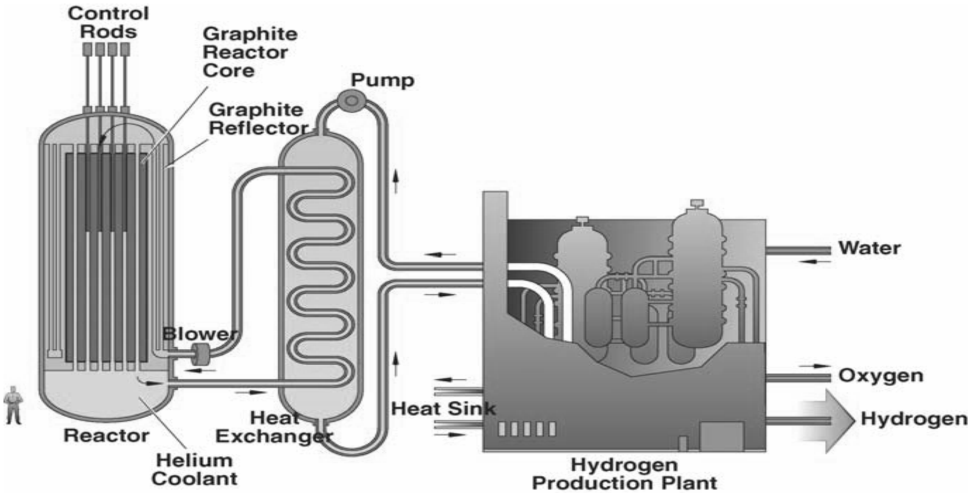
Table 1: Summary of hydrogen PIRT chart for chemical releases

Event	Evaluation criteria	Issue (phenomena, process, etc.)
Hydrogen release	Damage of SSC	Blast effects Heat flux
	Operator impairment	Burn and heat flux to people
Oxygen release	Damage of SSC	Plume behaviour Allowable concentration Spontaneous combustion
	Operator impairment	Burn to plant operators
Flammable release	Damage of SSC	Plume behaviour Heat flux Blast effects
	Operator impairment	Burns to people
Corrosive release	Damage of SSC	Plume behaviour Allowable concentrations
	Operator impairment	Burns to people
Toxic gas release	Operator impairment	Plume behaviour Toxic concentrations and effects
Suffocation gas release	Damage of SSC	Plume behaviour Back-up power/O_2 concentrations
	Operator impairment	Concentration for people

Heat transport system events and failures

The existing nuclear power plants in the United States are used exclusively to generate electricity. As large and relatively complex facilities, there are a number of upsets and accidents that can challenge the operation of the plants and the barriers in place to prevent the release of radioactive materials. As shown in Figure 3, the NGNP prototype or subsequent high temperature gas-cooled reactors will be

Figure 3: Simple schematic of possible nuclear hydrogen production facility



coupled to a hydrogen production facility and possibly other chemical or petroleum facilities. There is also a possibility that the NGNP could serve multiple purposes such as producing energy for electricity generation and process heat applications. The close coupling of a nuclear power plant to a hydrogen production facility or other co-generation facility will introduce additional concerns that will need analysis and possible design features such as control systems, barriers between nuclear and process systems, detection systems and mitigation systems to protect the nuclear fuel and prevent the release of radioactive materials.

Specific concerns about the coupling of nuclear and process facilities involve the intermediate heat transport system connecting the primary reactor coolant and the process facility. For example, a failure of the intermediate heat exchanger could lead to a rapid blow-down of the helium coolant from the primary coolant system which could in turn pressurise the intermediate coolant loop and provide a possible pathway for radioactive materials bypassing the nuclear containment structure. Additional concerns would depend on the working fluid in the intermediate loop and the possible introduction of that fluid to the reactor core through the break in the intermediate heat exchanger. The introduction of water and its effects on the graphite used in high temperature gas-cooled reactors is a special concern. Key parts of the research and development efforts related to NGNP will be to develop and assess materials and important SSC such as the intermediate heat exchanger and to develop computer models to analyse the thermal-fluidic behaviour of the nuclear plant systems. A summary of issues from the NRC's hydrogen production PIRT related to the coupling of heat transport systems is provided in the following table:

Table 2: Summary of hydrogen PIRT chart for heat transport systems

Event	Evaluation criteria	Issue (phenomena, process, etc.)
Loss of heat load (process facility)	Damage of SSC	Loss of heat sink to reactor
Temperature transient (process facility)	Damage of SSC	Cyclic loading Harmonics
Intermediate heat exchanger failure	Damage of SSC	Blow-down effects Large mass transfer Pressurisation of either secondary or primary side
Process heat exchanger failure	Damage of SSC	Fuel and primary system corrosion
Mass addition to reactor (He)	Damage of SSC	Turbomachinery response; potential for gas mixture with He
Mass addition to reactor (hydrogenous material)	Damage of SSC	Reactivity spike due to neutron thermalisation Chemical attack of TRISO layers and graphite
Loss of intermediate fluid	Damage of SSC	Loss of heat sink, cooling Hydrodynamic loading

Events or releases from the nuclear plant

Normal operation and some events initiated on the reactor side of the facility can impact the chemical plant and create possible pathways for the release of radioactive materials. During operation of the nuclear plant, tritium will be produced through the fission process, activation and reactions with the ^{3}He isotope present in the coolant. Some of the tritium will migrate through the heat exchangers and make its way to the hydrogen production facility, including the hydrogen produced for subsequent use in the economy. Although the levels of tritium making their way to the hydrogen facility and commercial product may be very small, it may be necessary to evaluate the possible worker and public doses from this source and, if appropriate, establish regulatory limits. In addition to the safety and regulatory issues, the presence of minor amounts of tritium may introduce concerns in the area of public acceptance of hydrogen production using nuclear power plants. The contamination of the hydrogen facility with fission products other than tritium is less likely given the number of barriers but monitoring would likely be required as it is for possible effluents from currently operating nuclear plants. Anticipated operational occurrences and more severe transients can occur within the nuclear plant due to malfunctions of equipment, interruptions of electrical power or other initiating events. Such transients could lead to a loss of heat source to the hydrogen production or other co-generation facility and increase stresses on piping and heat exchanger tubes as a result of the changes in temperature. The NRC would review such transients to ensure that the reaction of the hydrogen production plant would not lead to a more serious challenge to the cooling of the nuclear reactor core or to a possible release of radioactive materials. A summary of issues from the NRC's hydrogen production PIRT related to events or releases from the nuclear plant are provided in Table 3.

Table 3: Summary of hydrogen PIRT chart for nuclear plant events or releases

Event	Evaluation criteria	Issue (phenomena, process, etc.)
Anticipated operations: tritium transport (long-term safety)	Damage of SSC	Diffusion of ^{3}H
	Dose to process gas users: industrial and consumers	Diffusion of ^{3}H
Radiological release pathways through heat exchanger loops and plant	Dose to public	Accidental radionuclide release
Power or thermal transients initiated in nuclear reactor	SSC, stress on heat exchanger or other component in contact with balance of plant	Transient causes stress on SSC; induces possible transient in process facility

Conclusion

The NRC is currently developing the needed infrastructure and knowledge base to prepare for the licensing of the NGNP prototype and other small and medium-sized reactors. The use of high temperature gas-cooled reactors to provide process heat for hydrogen production or other chemical or petroleum facilities will introduce some additional issues for the licensing process. The NRC will build upon existing guidance for topics such as nearby chemical facilities or transportation routes in reviewing the analyses performed by applicants for nuclear plants coupled to chemical facilities. Tools such as the NGNP PIRT will identify issues, assess safety significance and define research and development needs, including the development of computer models to analyse transients and accidents, for DOE, vendors and the NRC.

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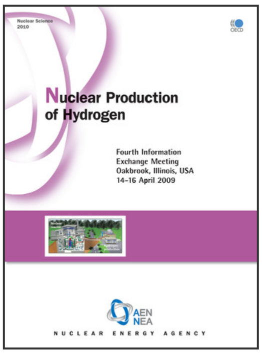

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