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EMERGENCY PLANNING ISSUES RELATING TO GALENA'S PROPOSED LICENSING OF A 4S REACTOR-BASED POWER GENERATION FACILITY

Prepared for the City of Galena, Alaska

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I EXECUTIVE SUMMARY

U.S. Nuclear Regulatory Commission (NRC) regulations require that those applying for licenses to operate a nuclear power reactor must develop and submit approval plans (emergency plans) to the NRC for coping with radiological emergencies at their facilities. The regulations require that two sets of emergency plans be developed: onsite plans, to deal with radiological emergencies at the facility, and offsite plans to be developed by State and local authorities, to provide appropriate responses to an emergency in the areas surrounding the facility.

While all aspects of emergency planning and preparedness are important, this paper focuses on the size of the staff that will need to be deployed to handle emergencies at the 4S Nuclear Reactor Based Power Generation Facility (NPF) proposed to be located in Galena, Alaska. Another aspect of emergency planning addressed in the paper is the size of the emergency planning zone (EPZ) around the NPF in which actions in response to a radiological emergency must be taken.

The unique characteristics of the 4S design provide the basis for significantly reducing staffing requirements and the size of the EPZ. Such reductions are an important consideration when evaluating the practicality of using the 4S NPF at the Galena site.

Emergency response staffing levels are not set by regulation, but are established through guidance issued by the NRC Staff based on the operating characteristics and postulated accident sequences for current generation light water reactors. These levels may be greatly reduced for the 4S NPF without compromising safety. The small size of the 4S NPF and its inherently safe, passive design eliminate the need for a plant operation staff of the magnitude employed at current commercial Nuclear Power Plants (NPPs). The operation of the 4S NPF is automatic and no human intervention is required. All reactivity control is performed automatically, although the plant operator can take action to shut down the plant if necessary. Given the wholly passive nature of the 4S design, operator action is not required to place the plant in a safe condition for either design basis or beyond-design basis ("severe") accidents.

The EPZ around a nuclear power plant is the area, defined based on experience and the characteristics of the NPF and the anticipated releases, where exposure to the radioactive plume could impart on a member of the public a radiation dose in excess of the protective action guidelines set by the Environmental Protection Agency. Measures must be taken to protect members of the public located within the EPZ in the event of an emergency leading to the release of radioactive materials from the NPF.

For conventional, higher output NPPs, the NRC has designated the plume exposure EPZ to be 10 miles in radius. The NRC regulations provide that the size of the EPZ is to be determined on a case-by-case basis for reactors with an authorized power level less than 250 megawatts thermal (MWt). Since the power output of the 4S NPF to be deployed in Galena is only 30 MWt, the size of its EPZ qualifies for a case-by-case determination.

Available documentation indicates that an 800-meter distance to an EPZ boundary can be readily justified for small NPFs such as Galena. The issue of a smaller EPZ has been previously raised and the NRC Staff has indicated a willingness to consider emergency planning requirements for small, advanced reactors on a case-by-case basis. The technical approach to justifying a smaller EPZ is based on establishing the likelihood of design basis and beyond-design basis accidents and the potential consequences of such accidents. Once established, the plant's risk profile can be used to demonstrate that a smaller EPZ adequately allows for protective actions to be taken and show that protective action guidelines will not be exceeded at a distance less than 800 meters. Establishing an EPZ with an 800-meter (half a mile) radius would eliminate the need to provide protective measures beyond the site boundary, and thus avoid the need to implement sheltering, evacuation or other measures to protect the population outside the plant.

It is expected that the NRC will approve reduced emergency response staffing and a small EPZ for the 4S NPF proposed to be located in Galena, and that such approval will be obtained within the framework of existing emergency planning regulations. Nevertheless, 10 C.F.R. § 50.12 allows seeking exemptions from regulatory requirements when warranted. Galena should be prepared to ask for such exemptions in the emergency planning area if the need for them is identified after discussions with the NRC Staff. Early discussions between representatives of Galena and the NRC Staff concerning emergency planning should be held to determine, among other things, whether seeking such an exemption in one or more areas will be necessary.

II BACKGROUND

A. THE CITY OF GALENA

The City of Galena, Alaska (Galena) is a small community (pop. 700) located in west-central Alaska, along the banks of the Yukon River. The closest communities to Galena (within 100 air miles or less) are Koyukuk (pop. 100) approximately 30 miles to the west, Nulato (pop. 330), approximately 40 miles to the west, Kaltag (pop. 230), approximately 60 miles to the west, Ruby (pop. 190) approximately 50 miles to the east, and Huslia (pop. 300), approximately 70 miles to the northeast. The nearest major population center is Fairbanks (pop. 30,500), 270 miles to the east.[1]

Galena has no roads linking it to the rest of the state. A former United States Air Force base, now known as the Edward J. Pitka Sr. (PAGA) Airport, is located 1.5 miles west of the city. The main runway of the airport (runway 7-25) is 7,254 feet long, and is capable of handling heavy transport type air traffic. The airport is the primary access point into and out of the Galena area, and operates year-round. The Yukon River serves as the major heavy transportation resource during the unfrozen summer months. Galena serves as an educational and cultural center for the region. There are many public use and commercial buildings in the area of the airport and the city itself including schools, workshops, and municipal buildings. Homes are predominately located around the "New Town" area, 1.5 miles east of the airport.

B. THE GALENA POWER SUPPLY

Galena has no connection to an outside power grid. The city currently depends on diesel generators for its electric power supply. Galena experiences long, severe winters (winter low

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[1] U.S. Census Bureau, 2000 Census data, available online at http://www.census.gov/popest/cities/tables/SUB-EST2004-04-02.csv.

temperatures may reach –50°C (-60°F) or below and temperatures below -40°C (-40°F) are common). The lack of low cost year-round heavy transport into Galena requires the city to maintain large diesel fuel tanks in order to meet energy demand. The escalating price of fuel and the associated costs of fuel transportation, storage, and financing make the cost of electricity prohibitively high to Galena residents. These economic issues, coupled with environmental pollution concerns, make it prudent for Galena to explore alternative ways to meet its energy needs.[2]

C. THE GALENA 4S PROJECT

In 2004, Galena received presentations from Toshiba Corporation (Toshiba) on a "Super-Safe, Small and Simple" (4S) Nuclear Based Power Generation Facility. The 4S reactor was developed jointly by Toshiba and the Central Research Institute of Electric Power Industry (CRIEPI) of Japan.[3] Following those presentations, Galena secured the preparation of a U.S. Department of Energy (DOE) sponsored study on ways to meet Galena's power requirements.[4] The study included analyses of the thermal and electric load profiles for Galena, technologies available to meet those loads (the technologies evaluated in detail were enhanced diesel power, coal, and a 4S NPF, which were determined to be the only viable alternatives), the environmental and regulatory issues associated with each of these technologies, and the overall economics of each energy option. The DOE study concluded that the 4S NPF is the best economic and environmental choice for Galena.

On December 14, 2004, the Galena City Council passed a resolution calling for the deployment of a 4S NPF in the community. The resolution stated, among other things, that: "It is in the public interest to pursue the siting of a Toshiba 4S nuclear battery in Galena." The council further directed the City Manager to "establish a process and timeline leading to evaluations, industrial partners, and financial and contractual arrangements necessary to bring the economic and environmental benefits of the 4S to Galena."

Since the passing of the resolution, Galena has been investigating the regulatory and economic feasibility of locating a 10 MWe 4S NPF in Galena. In parallel, Toshiba has been developing a preliminary design document (PSID) to submit to the U.S. Nuclear Regulatory Commission (NRC) for its review.[5]

In order to move the siting evaluation process forward and open lines of communication with various stakeholders and the NRC, Galena has commissioned a set of white papers that discuss important aspects of the small nuclear power facility project including a General Overview,

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[2] Adams Atomic Engines, Inc., Atomic Insights, "Nuclear Power for Galena, Alaska" (March 2005), available online at http://www.atomicinsights.com/AI_03-20-05print.html.

[3] See, e.g., http://www.uaf.edu/aetdl/Presentations.htm.

[4] Robert E. Chaney et al., "Galena Electric Power- A Situational Analysis" (DE- AM26-99FT40575) (December 2004). Science Applications International Corporation (SAIC) coordinated the study, in which the University of Alaska and Idaho National Engineering and Environmental Laboratory participated.

[5] "Galena Project Officials Gear Up for Pre-Application Activities," Inside NRC, February 6, 2006.

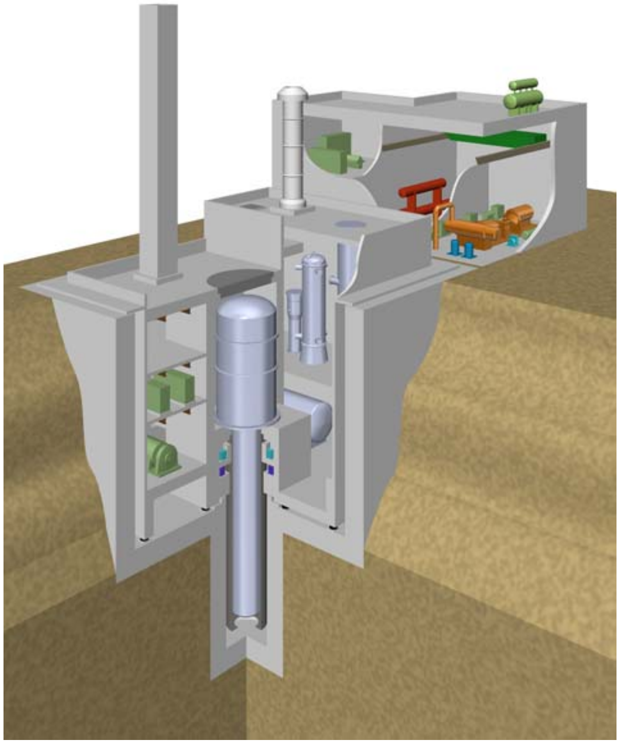
Nuclear Liability and Insurance, Emergency Planning, Physical Security, Decommissioning, Containment, and Seismic Isolation. This paper is part of the white paper series.

D. FEATURES OF THE 4S REACTOR

The 4S design introduces a small liquid metal nuclear reactor to the commercial power industry in the United States. Liquid metal reactors (LMRs) have been operated successfully worldwide and have been used in the United States at test facilities, with over 300 reactor years of operational experience. The small, advanced design of the 4S has several important operational and safety advantages, particularly for remote location deployment, when compared to the large light-water commercial nuclear power plants currently operating in the United States. The peak thermal output of the 10 MWe 4S NPF is approximately 30MW thermal (MWt), which is a small fraction of the power output of a standard sized commercial reactor. Important features of the design of the 4S include:

- Modular construction, which will reduce costs and construction time
- Nuclear systems that are embedded below grade, resulting in safety and security benefits
- Liquid sodium coolant, which does not react with core internals or piping
- Sodium coolant that is not highly pressurized, which minimizes stresses on the plant systems
- Passive safety systems that do not depend on emergency power to function
- Negative reactivity temperature coefficients, including coolant void reactivity, that cause the reaction rate in the core to slow down as temperatures rise
- Air-cooled reactor vessel, steam generator and condenser, so that no coolant water or intake structures are required
- 30-year core life, which avoids the need to refuel, eliminates fuel storage, and minimizes fuel handling concerns
- Capability of load following without mechanical operation of reactor control system
- Ease of decommissioning by containment of all radioactive materials within the reactor module throughout the life of the plant.

These unique features are among those that provide the 4S reactor system with significant benefits in operational capability, physical security, and protection of public safety. Many of the systems that increase cost, raise safety concerns, and pose potential security hazards at current plants (such as use of numerous mechanical pumps and valves, the need for a spent fuel pool, and the reliance upon high and low pressure water injection systems) have been eliminated in the design of the 4S. While the 4S reactor system does raise some new issues, such as the need to deal with highly reactive liquid sodium and potential accident scenarios involving sodium-water interaction, these issues have been addressed in the 4S system design and in past LMR facilities. The licensing of a 4S NPF should therefore be a relatively straightforward process, provided that good communications are maintained between all parties involved and there is a timely flow of complete and accurate technical information.

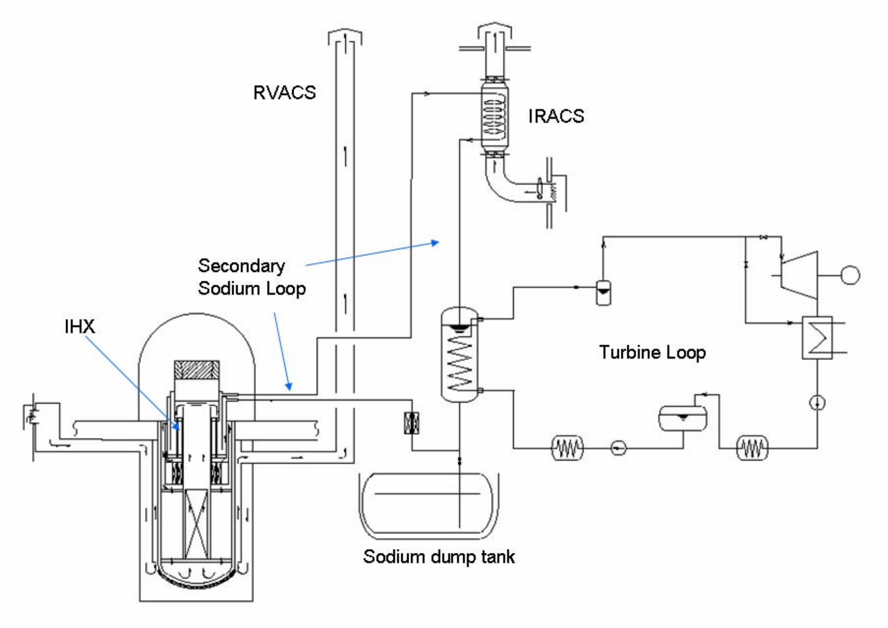


On balance, the small size of the 4S NPF and its many inherently protective features should greatly facilitate plant licensing. The figure to the right is a 3D rendition of the 4S power generation facility. It depicts the reactor building (lower left), which is below grade, and the turbine generator building (upper right). To put the small size of this facility in perspective, the overall dimensions of the below ground and above ground structures are approximately 190 feet long and 90 feet wide, and can be accommodated in less than ½ acre of land.

The reactor building (also referred to as the Nuclear Island) houses the reactor module (lowest left corner of figure), the steam generator (slightly higher and to the right of the reactor module), and other vital safety equipment. As can be seen in the figure, the lower part of the reactor module (containing the reactor core) is located in its own below grade silo-like reinforced concrete structure. The heavy reinforced concrete cap like structure on the top of the reactor module encloses the reactor assembly and core and provides the only access to the nuclear fuel, which is placed within the reactor module. Heavy lifting equipment is required to remove the cap and gain access the nuclear fuel.

The major components enclosing the reactor assembly and core are the reactor vessel, the containment guard vessel, and the guard vessel closure head (the heavily reinforced concrete cap on top of the reactor module). The containment guard vessel surrounds the reactor vessel and ensures that the core will not be uncovered and core cooling can be accomplished even if the reactor vessel leaks. The reactor vessel is the container and support for the reactor core, the primary radioactive sodium coolant, and the primary sodium intermediate heat exchanger structures. The reactor core is designed to have negative reactivity temperature coefficients, including coolant void reactivity, meaning that the nuclear reactivity of the fuel decreases as the reactor heats up, such that nuclear reactions in the core would cease for beyond design basis events that would raise the temperature of the core, such as loss of coolant flow without scram or loss of heat sink without scram.

The primary heat transport system (PHTS) through which the radioactive sodium coolant flows is wholly contained within the sealed reactor vessel. The radioactive sodium heated by the reactor core enters and flows through two intermediate heat exchangers (IHX), located within the reactor vessel, where it is cooled as it heats non-radioactive sodium that circulates through the intermediate heat transport system (IHTS). All radioactive materials in the 4S are limited to the PHTS and the fuel, both of which are wholly contained within the reactor vessel. No radioactive materials are ever removed from 4S reactor vessel throughout its 30-year life.



The IHTS transports heat from the primary system to the steam generator (SG) where it produces steam that drives convention steam turbine equipment. The IHTS is comprised of a piped loop thermally coupled to the primary system by the IHXs located in the reactor vessel and to the SG located in the SG compartment. The sodium that is circulated through the IHTS to transfer the heat from the primary system to the SG system is non-radioactive. The non-radioactive IHTS sodium entering the shell side of the SG heats the water on the tube side to produce steam, which drives a steam turbine located within the turbine generator building. The steam is cooled by the main condenser, which is also located with the turbine generator building. The condensed water is re-circulated through the SG system to repeat the process.

The 4S reactor shutdown heat removal systems consist of main condenser cooling, an intermediate reactor cooling auxiliary system (IRACS) for the SG, and the safety related reactor vessel auxiliary cooling system (RVACS) which removes heat directly from the reactor. The RVACS is a passive safety related system that transports heat to the atmosphere by natural circulation of air. It functions continuously with its heat transport rate governed by the reactor vessel temperature. During an event involving loss of ability to remove heat via the main condenser or the IRACS, the resultant higher primary sodium temperatures will raise the reactor vessel temperature and cause the RVACS to respond automatically with a corresponding increase in heat removal rate sufficient to maintain cooling of the 4S.

The above features of the 4S design and related features of the design are discussed at greater detail in the overview white paper[6] prepared as part of this series of white papers.

There are a number of features of the design and operation of the 4S that relate to emergency planning and preparedness. Those features are described below. Generally, the passive nature of safety systems, the low power output, and the underground location of the nuclear steam supply system (NSSS) make it unlikely that there will be a need to take actions (in accordance with NRC protective action guidelines) to protect the health and safety of persons outside the NPF site

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[6] Overview of Galena's Proposed Approach to Licensing a 4S Reactor-Based Power Generation Facility (Overview White Paper).

boundary.[7] Furthermore, potential radiological emergencies at the Galena 4S would be handled safely by the facility's operating and maintenance personnel who will have training in accident-coping skills. Thus, simplified emergency planning and response processes can be implemented while still ensuring adequate measures to protect public health and safety.

III RELEVANT LAW

A. INTRODUCTION

NRC regulations require that those applying for licenses to operate a nuclear power reactor must develop and submit for NRC approval plans (emergency plans) for coping with radiological emergencies at their facilities. In particular, applicants for early site permits (ESPs) under Subpart A of 10 C.F.R. Part 52 to locate a reactor at a specified site must: (1) identify physical characteristics unique to the proposed site, such as egress limitations from the area surrounding the site, that could pose a significant impediment to the development of emergency plans, and (2) either (i) propose major features of the emergency plans that can be reviewed and approved by NRC in consultation with the Federal Emergency Management Agency, or (ii) propose complete and integrated emergency plans for review and approval by the NRC, in consultation with FEMA, in accordance with the applicable provisions of 10 C.F.R. § 50.47.[8]

As discussed in the white paper on "Overview of Galena's Proposed Approach to Licensing a 4S Nuclear Reactor Based Power Generation Facility," Galena currently intends to_seek an ESP for a site (yet to be selected) in the vicinity of the city, where a 4S NPF would be located. Preparation of an ESP application for such a site will require Galena, at a minimum, to develop and submit for NRC and FEMA approval the proposed major features of the emergency plans for the facility.

Emergency planning is to some extent related to plant physical security, since sabotage or external attacks against a NPF could trigger the need for emergency response actions. Physical security issues are addressed in a separate white paper.[9] As discussed in that paper, physical security risks for the 4S are considerably lower than for conventional NPPs and the probability that an adverse external action against the facility will require emergency response measures is accordingly much smaller.

B. REGULATORY REQUIREMENTS

1. Overview

Emergency planning regulations are mainly contained in 10 C.F.R. § 50.47 and Appendix E to 10 C.F.R. Part 50. The regulations require that two sets of emergency plans be developed: onsite plans, to deal with radiological emergencies at the facility, and offsite plans, to be

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[7] The term "site boundary" is defined in 10 C.F.R. § 20.1003 as "that line beyond which the land or property is not owned, leased, or otherwise controlled by the licensee."

[8] 10 C.F.R. §52.17(b).

[9] See "Safety and Security For Galena 4S Nuclear Power Generation Facility."

developed by State and local authorities, to provide appropriate responses to the emergency in the areas surrounding the facility. In addition to the regulations, there are a number of guidance documents that describe means deemed acceptable by the NRC Staff for meeting the requirements in the regulations. Particularly important among those guidance documents is NUREG-0654/FEMA-REP-1, "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants" (NUREG-0654/FEMA-REP-1) and supplements to it.

10 C.F.R. § 50.47(b) sets forth sixteen planning standards that must be satisfied by an acceptable onsite or offsite emergency plan. These planning standards cover the following areas:

> (1) Assignment of primary responsibilities for emergency response by the nuclear facility licensee and by State and local organizations, including the identification of the staffing required by each principal response organization.
>
> (2) Definition of on-shift facility licensee responsibilities for emergency response and assurance of adequate staffing at all times to provide accident response in key functional areas and specification of the interfaces among various onsite response activities and offsite support and response activities.
>
> (3) Description of arrangements made for requesting and using assistance resources and for accommodating State and local staff at the licensee's emergency facilities.
>
> (4) Establishment of a standard emergency classification and action level scheme for determinations of minimum initial offsite response measures.
>
> (5) Development of procedures for notification, by the licensee, of State and local response organizations and for notification of emergency personnel by all organizations, and establishment of means to provide early notification and clear instruction to the populace.
>
> (6) Deployment of mechanisms for prompt communications among principal response organizations to emergency personnel and to the public.

(7) Institution of means for informing the public on a periodic basis on how they will be notified and what their initial actions should be in an emergency.

(8) Establishment of adequate emergency facilities and equipment to support the emergency response.

(9) Provision of adequate methods, systems, and equipment for assessing and monitoring actual or potential offsite consequences of a radiological emergency condition.

(10) Definition of a range of protective actions for the plume exposure pathway EPZ for emergency workers and the public, potentially including evacuation, sheltering, and the prophylactic use of potassium iodide (KI), as appropriate, and development of guidelines for the choice of protective actions during an emergency.

(11) Institution of means for controlling radiological exposures, in an emergency, for emergency workers.

(12) Provisions for medical services for contaminated injured individuals.

(13) Development of plans for recovery and reentry.

(14) Plans for conducting periodic exercises and drills to evaluate major portions of emergency response capabilities.

(15) Training programs on radiological emergency response for those who may be called on to assist in an emergency.

(16) Establishment of responsibilities for development review and distribution of emergency plans are established.

While all aspects of emergency planning and preparedness covered in these planning standards are important, it is not the purpose of this paper to explicitly address the implementation of all of the planning standards at the 4S NPP in Galena. Rather, the discussion that follows will concentrate on standards (1) and (2) (which address emergency organization staffing issues), and (4) and (10), which refer to the action levels at which various offsite responses will be required, the nature of those responses, and EPZ over which those responses must be taken. As will be seen, the unique characteristics of the 4S design provide the basis for significantly reducing staffing requirements and the size of the EPZ. Such reductions are an important consideration when evaluating the practicality of using the 4S NPF at the Galena site.

2. Onsite Emergency Response Staffing

Section B.5 and Table B-1 of NUREG-0654/FEMA-REP-1 establish minimum staffing requirements for nuclear power plant emergencies. Those minimum requirements fall into three categories: (1) minimum staffing levels that must be provided on each operating shift; (2)

minimum additional staffing levels that must be available within 30 minutes of the declaration of an emergency; and (3) minimum additional staffing levels that must be made available within 60 minutes of the declaration of an emergency. Table B-1 lists the total minimum emergency staffing requirements as 10 staff members on each shift, 11 additional staff members to be available within 30 minutes, and 15 additional staff members that must be available within 60 minutes of an emergency being declared, for a total minimum staffing of 36 individuals per shift.

These staffing levels are not mandated by regulation, but are merely guidance issued by the NRC Staff based on the operating characteristics and postulated accident sequences for current generation light water reactors. The discussion in Section IV will address how these levels can be greatly reduced without compromising safety. The small size of the NPF and its inherently safe, passive design eliminates the need for a plant operation staff of the size employed at large, current generation NPPs. The operation of the 4S reactor is automatic and no human intervention is required. All reactivity control is performed automatically, although the plant operator can effectuate shutdown of the nuclear plant by directing insertion of the main control rod into the core. Indeed, operator action is not required to place the plant in a safe condition for either design basis or beyond-design basis ("severe") accidents.

The issue of operator staffing to handle normal and accident conditions was considered by the NRC Staff in its pre-application review of the design of the PRISM reactor.[10] In its evaluation of the PRISM, the Staff left the door open to considering reduced staffing levels for particular designs if a sufficient case is made by the applicant:

> The staff believes that operator staffing may be design dependent and intends to review the justification for a smaller crew size for the PRISM design by evaluating the function and task analyses for normal operation and accident management.[11]

It is reasonable to expect that the Staff would adopt the same position with respect to the 4S NPF, which has a much lower power output than the PRISM and is simpler in design.

3. Offsite Emergency Response Staffing

In the event of a radiological emergency at a nuclear power plant, the State and the local jurisdictions in the vicinity of the plant must take appropriate response actions in accordance with established emergency plans. Those plans identify which agencies must have personnel

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[10] The Power Reactor Innovative Small Module (PRISM) sodium-cooled reactor was proposed by the DOE for NRC pre-design certification review in November 1986. PRISM is a small, modular, pool-type sodium cooled reactor whose standard design consists of three identical power blocks, each comprising three reactor modules, with each module being located in its own below-grade silo. The PRISM design is analogous to that of the 4S reactor, although the power output of the PRISM facility is much larger (1395 MWe) than that of the 4S (10MWe). In February 1994, the NRC Staff completed its pre-application review of the preliminary PRISM design and concluded that no obvious impediments to the licensing of the PRISM design had been identified. Reference: NUREG-1368, Pre-application Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISM) Liquid Metal Reactor (Feb. 1994) (NUREG-1368). DOE ultimately cancelled the PRISM project.

[11] NUREG-1368 at 3-11.

available to discharge the various response activities (e.g., police, fire fighting, emergency transportation, hospital and other health services, evacuations of schools and other institutions). At the time an ESP application is filed, the applicant need not have formulated a complete set of state and local emergency plans; however, at a minimum, the ESP application must include (pursuant to 10 C.F.R. § 52.17(b)(3)), a description of contacts and arrangements made with local, state, and federal government agencies with emergency planning responsibilities.

Offsite emergency planning (except for notification to the Federal, State and local agencies) should not be required for the 4S NPF in Galena because, for all postulated accidents, the probability that the doses at the boundary of the plant will exceed the regulatory limits should be extremely low. Accordingly, there will be no need to define offsite emergency response staffing levels.

4. Emergency Planning Zone

As noted earlier, planning standard 10 in 10 C.F.R. § 50.47(b) states:

> A range of protective actions has been developed for the plume exposure pathway EPZ for emergency workers and the public. In developing this range of actions, consideration has been given to evacuation, sheltering, and, as a supplement to these, the prophylactic use of potassium iodide (KI), as appropriate. Guidelines for the choice of protective actions during an emergency, consistent with Federal guidance, are developed and in place, and protective actions for the ingestion exposure pathway EPZ appropriate to the locale have been developed.

Implementation of this planning standard requires (1) development of a set of protective actions to be taken depending on the nature and severity of the radiological emergency, and (2) definition of the geographic area, that is, the "plume exposure pathway EPZ" over which these actions must be taken.

The range of protective actions to be taken is defined based on the protective action guides (PAG) established by the Environmental Protection Agency (EPA). The PAGs call, for example, for protective actions to be taken if the radiation dose received by an individual is 1 rem to the whole body or 5 rem to the thyroid gland. The protective actions that the NRC and FEMA associate with various conditions at a reactor site are as follows:

> Notification of Unusual Event - Under this category, events are in process or have occurred which indicate potential degradation in the level of safety of the plant. No release of radioactive material requiring offsite response or monitoring is expected unless further degradation occurs.
>
> Alert - If an alert is declared, events are in process or have occurred which involve an actual or potential substantial degradation in the level of safety of the plant. Any releases of radioactive material from the plant are expected to be limited to a small fraction of the PAGs.
>
> Site Area Emergency - A site area emergency involves events in process or which have occurred that result in actual or likely major failures of plant functions

> needed for protection of the public. Any releases of radioactive material are not expected to exceed the PAGs except near the site boundary.
>
> General Emergency - A general emergency involves actual or imminent substantial core damage or melting of reactor fuel with the potential for loss of containment integrity. Radioactive releases during a general emergency can reasonably be expected to exceed the PAGs for more than the immediate site area.[12]

Under the above classifications, actions to protect the public are not needed until a General Emergency is declared, although the NRC regulations and regulatory guidance require the licensee to notify State and local authorities promptly (within 15 minutes or less) once the existence of an Unusual Event is detected.[13]

The members of the public for which protective actions would be required in the event a General Emergency was declared would be those located in the "plume exposure pathway EPZ." A plume is a cloud that discharges from the nuclear power plant and generally travels in the same direction as the wind. As the plume travels, it expands in the horizontal and vertical direction, and in doing so the concentration of radioactivity in the plume decreases with distance from the point of release.

The EPZ around a nuclear power plant is the area, defined based on experience and the characteristics of the reactor and the anticipated releases, where exposure to the radioactive plume could impart on a member of the public a radiation dose in excess of the PAGs. For conventional, large nuclear reactors, the NRC has designated the plume exposure EPZ to be 10 miles in radius.[14] The NRC regulations provide that the size of the EPZ is to be determined on a case-by-case basis for reactors with an authorized power level less than 250 MWt.[15] Since the 4S power output is considerably less than 250 MWt, it qualifies for a case-by-case determination of the appropriate EPZs.

As further discussed in Section IV, a much smaller plume exposure pathway EPZ can be justified for the Galena 4S NPF, coincident perhaps with the site boundary. Beyond the EPZ, there would be no need to take measures to protect the public because no credible accident sequence would lead to a condition beyond a "site area emergency" – meaning that the radioactivity doses at the EPZ would be at or below the PAG. It would not be necessary for the offsite authorities to develop plans to shelter, evacuate, or supply potassium iodide to the members of the public. The emergency preparedness requirements for a 4S NPF would be analogous to those imposed by the

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[12] See, e.g., http://www.fema.gov/hazards/nuclear/radiolo.shtm.

[13] NUREG-0654/FEMA-REP-1, Appendix 1 at 1-3.

[14] 10 C.F.R. §50.47(c)(2). There is another EPZ, the ingestion exposure pathway EPZ, in which there may be contamination of the water or other foodstuffs so that measures may be taken to prevent the potential ingestion of radioactivity-contaminated materials by the public. The ingestion exposure pathway for conventional, higher power reactors is a circle 50 miles in radius. Actions associated with ingestion pathway include identification of potential uptake sites (dairy farms, water intakes) and identification of protective actions. Protective actions for ingestion pathway releases are longer term concerns and do not bear on the onsite staffing needs.

[15] 10 C.F.R. §50.47(c)(2).

NRC on research and test reactors (RTRs), because the anticipated radioactive releases associated with an accident at an RTR will not result in doses to the general public in excess of the PAGs. Research and test reactors are subject to reduced emergency planning requirements, and in particular the plume exposure pathway EPZs for RTRs licensed for 20 to 50 MWt is 800 meters (half a mile)[16] as determined in ANSI Standard 15.16.[17]

IV ANALYSIS

A. 4S DESIGN FEATURES BEARING ON EMERGENCY PLANNING

The following discussion summarizes those features of the 4S NPF that most directly affect emergency planning. The features provide the bases for an anticipated low probability of an accident requiring emergency plan implementation. The 4S features of a sodium cooled reactor and a low power output would result in an extended time period for an accident to progress to the point where emergency actions would be required outside the plant. The energy release mechanism of an accident and containment capability indicate that the containment provides a highly reliable barrier to radionuclide release.

1. Accident Prevention

a. Normal operation

A desirable feature of a power generation source such as a reactor is the ability to follow the system load, that is, to adapt the power output to meet moment-to-moment demand in the electric load it serves, in order to ensure that the power source is producing neither too little nor too much energy. Load-following is achieved in the 4S in an innovative way by controlling the water flow to the steam generator, thus manipulating the core inlet temperature. As the generator output matches the load, changes in the coolant temperature introduce a positive or negative reactivity effect in the core, causing the reactor power to follow. The load-following capability simplifies operation of the 4S power plant and reduces the likelihood of reactor trips. The ability to remain operating during significant load changes increases plant safety by avoiding the occurrence of off-normal events. The simplicity of the 4S design also reduces the need for online testing of safety systems. Online testing is itself a source of plant transient initiators.

The use of liquid sodium as a coolant for the 4S reactor permits operation at nearly atmospheric pressure with a large margin to the boiling point of the coolant (subcooling margin). Maintaining the core coolant subcooled provides assurance that the fuel cladding is not being overheated. The subcooling margin in the 4S reactor is much greater than in a conventional pressurized water reactor.

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[16] The ANSI Standard specifies an EPZ of 800 m for reactors with an authorized power level between 20 and 50 MWt.

[17] ANSI Standard 15.16-1982, Emergency Planning For Research Reactors, American Nuclear Society. 555 North Kensington Avenue. La Grange Park, Illinois 60525.

b. Criticality and power control

The 4S reactor has a negative sodium void reactivity coefficient that is achieved by keeping the core diameter small, thus enhancing radial neutron leakage. The fuel temperature coefficient is also negative, so that reactor power inherently decreases with increasing temperature.

Reactivity is controlled by a unique neutron reflector system surrounding the core that slowly moves upward from the bottom of the core to compensate reactivity loss from fuel burnup. A drive system moves the reflector at a rate of 1 mm per week. If an accident should occur, the reflector would drop down and make the core subcritical; that is, would stop the nuclear reactions in the core.

A gravity-driven neutron absorber rod located at the center of the core provides a second independent shutdown system.

c. Safety Systems

The safety systems of the 4S include a Reactor Shutdown System (RSS). The RSS is activated either by loss of power, by the neutron detector installed outside of the reactor vessel, or by the core outlet temperature detector in the reactor vessel. When activated, the RSS causes the reactor to shut down. Should the RSS fail to be activated, the reactor power level would nonetheless drop due to the above described negative reactivity coefficient, bringing the reactor to a shutdown state.

The Reactor Vessel Auxiliary Cooling System and the Intermediate Reactor Auxiliary Cooling System (RVACS / IRACS) are passive systems that remove energy from the reactor guard vessel and secondary sodium loops, respectively. These passive safety systems do not require power for valve movements to initiate them.

The inherent capability of the design to remove decay heat through passive means avoids the need to resort to active systems to maintain the plant in a safe shutdown condition. Table 1 below illustrates the simplicity of the 4S safety systems by comparing them to those in current generation nuclear power plants. The improvement in plant safety of the 4S design over conventional designs is illustrated by the fact that none of the systems/features upon which a current generation reactor relies is required to maintain plant safety in a 4S NPF. The 4S design eliminates the need for these active systems and thus increases plant safety.

Table 1
Comparison of Current Generation Plant Safety Systems to the 4S Design

Current Generation Safety Related Systems	**4S Reactor Safety Systems**
High Pressure Injection System Low Pressure Injection System	No active safety injection system required. Core cooling is maintained without injection because of the low pressure and high heat capacity of liquid sodium
Emergency sump and associated NPSH requirements for Safety related pumps	No safety related pumps therefore no need for sumps and protection of their suction supply
Emergency Diesel Generators	Passive design does not require emergency AC power to maintain core cooling. Core heat removed by heat transfer through vessel
Active Containment Heat Systems Containment Spray System	None required because of passive heat rejection out of containment Spray systems are not required to reduce steam pressure or to remove radioiodine from containment
ECCS Initiation, Instrumentation and Control Systems. Complex systems require significant amount of online testing which contributes to plant unreliability and challenges of safety systems with inadvertent initiations.	Simple monitoring of core outlet temperature and neutron flux initiates reactor trip. No other protective actions are required. (The reactor still shuts down even without an automatic trip signal.)
Emergency Feedwater System, Condensate Storage Tanks and associated emergency cooling water supplies	Ability to remove core heat without an emergency feedwater system is a significant safety enhancement.

d. Support systems

Auxiliary or supporting systems can affect the reliability of safety systems. Use of passive systems in place of active systems improves reliability. In the 4S plant, elimination of all active cooling systems from the reactor side and elimination of all emergency cooling systems from the reactor building results in greatly improved plant reliability. Radiated heat from the reactor vessel is removed by the Reactor Vessel Auxiliary Cooling System. The conducted heat into the containment is also removed by the natural air cooling from the surface of the containment. The primary pump is a sodium-immersed electromagnetic pump, so no motor or pump seal cooling is required. As the result, all active cooling systems are eliminated. This is illustrated in Table 2.

Table 2
Comparison of Current Generation Plant Safety Systems to the 4S Design

Current LWR Support Systems	**4S Reactor Support Systems**
Reactor Coolant Pump Seals. Leakage of seals has been a safety concern. Seal maintenance and replacement is costly and time consuming	The EM pumps in 4S design eliminates the need for seals.
Ultimate heat sink and associated interfacing systems. River and seawater systems are active systems, subject to loss of function from such causes as extreme weather conditions and bio-fouling	4S design is passive and rejects heat by conduction and convection. At Galena, heat rejection to the Yukon river is not required.
Closed cooling water systems are required to support safety related systems for heat removal of core and equipment heat	No closed cooling water systems are required for safety-related systems.
Heating, ventilation and air conditioning (HVAC). Required to function to support proper operation of safety-related systems	The reactor building contains the primary flow coastdown system and electric panels. On loss of power, the rooms are cooled by the heat storage system. The plant design does not require safety-related room cooling eliminating both the HVAC system and associated closed water cooling systems.[18]

2. Time Between Accident Initiation and Potential Release

Liquid sodium is a coolant with excellent heat absorption capacity, very high thermal conductivity, low operating pressure (basically atmospheric), and superb natural convection capability. Decay heat is removed from the core by natural circulation of the primary coolant, and discharged by a coil system placed above the intermediate heat exchanger. If the main electromagnetic pump used to deliver coolant fails, passive cooling is also provided by natural air circulation around the exterior of the reactor vessel. The large heat capacity of liquid sodium provides a large heat sink for the core. The time to heat up the fluid is substantially longer than for water cooled reactors and the available time for responding to accidents is thus significantly increased.

3. Containment

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[18] Hattori, S. and A. Minato, ASME 1993. "Passive Safety Features In 4S Plant," Central Research Institute of Electric Power Industry. Tokyo, Japan ASME/JSME Nuclear Engineering Conference, Volume 1.

The 4S containment is composed of the guard vessel and a nearly impenetrable outer concrete vault. The entire assembly is installed underground. Pressurization of the 4S containment appears much less likely than in light water reactors because the reactor coolant system is operated at ambient pressure. The high boiling point of liquid sodium means that less energy is transferred to the containment vapor space if reactor pressure boundary fails. Use of liquid sodium eliminates hydrogen generation due to water-cladding interaction. As a result, the guard vessel and containment dome containment volume can be small, which allows for effective passive cooling.[19] These features of the 4S containment mitigate potential releases of radioactive materials in the event of an accident.

B. RISK PERSPECTIVE ON EPZ SIZE

1. Justification for Using a Risk-Based Approach to Determining EPZ Size

As discussed in Section III, the NRC regulations allow individualized determination of the size of the EPZs for low power reactors (i.e., those with output less than 250 MWt). As indicated, the radius of the inhalation (plume exposure pathway) EPZ for large power reactors is typically 10 miles. There appears to be no firm guidance or stated precedent which strictly correlates EPZ size with power level or design. However, there is a basis for assuming that an EPZ based on an 800 m distance from the 4S NPF could be readily justified.[20]

A risk based approach can be used to provide a technical basis for establishing the EPZ size for the Galena 4S NPF.[21] The risk based approach could be used to establish that the EPZ for a low power reactor could be smaller than the typical 10 miles, and perhaps need not extend beyond the site boundary. Reductions in the EPZ for small advanced reactors is consistent with DOE goals for Generation IV reactors.[22]

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[19] Safety and Security Features of 4S Type Reactors," D. Wade (Argonne) presentation to Alaska Rural Energy Conference, Sept 20-22, 2005.

[20] Regulatory Guide 2.6 endorses ANSI 15.16-1982 as "generally acceptable to the NRC staff as a means for complying with the requirements of §50.54 and in Appendix E, 'Emergency Planning and Preparedness for Production and Utilization Facilities' to 10 CFR Part 50…". The ANSI standard cites an EPZ of 800 m for reactors of power 20 to 50 MWt and an EPZ of 400m for reactors with an authorized power level between 10 and 20 MWt. Since the 4S reactor would have a power output of approximately 30MWt, an EPZ of less than 800 m would seem appropriate.

[21] In SECY-97-020, the NRC Staff has given a qualified endorsement to the risk-based approach to emergency planning requirements: "The staff recognizes the industry's significant effort to make evolutionary and passive advanced LWRs safer than current designs. The staff also recognizes that changes to EP requirements may be warranted if the technical criteria for the EP requirements were modified to account for the lower probability of severe accidents or the longer time period between accident initiation and release of radioactive material for most severe accidents associated with evolutionary and passive advanced LWRs. In order to justify these types of changes to the EP basis, the staff believes that several issues, which would require significant expenditure of staff resources, need to be addressed: (1) the probability level, if any, below which accidents will not be considered for EP, (2) the use of increased safety in one level of the defense-in-depth framework to justify reducing requirements in another level, and (3) the acceptance of such changes by Federal, State, and local emergency response agencies. Because industry has not petitioned for changes to EP requirements for evolutionary and passive advanced LWRs, the staff did not dedicate the resources to fully evaluate these issues." SECY-97-020, "Results of the Evaluation of Emergency Planning for Evolutionary and Advanced Reactors," January 27, 1997.

[22] "Safety and reliability goals focus on safe and reliable operation, improved accident management and minimization of consequences, investment protection eliminating the technical need for off-site emergency

The risk-based approach provides a basis for scaling down emergency planning requirements for small, advanced reactor designs. For example, a minimum EPZ could be established by first evaluating the probability that an accident at the Galena site will result in doses at the site boundary in excess of the PAGs. This evaluation of probability and consequences could then be compared to the probability of exceeding a PAG for current generation large reactors at the typical 10-mile EPZ. Due to the lower probability of core damage, reduced energy of a release and the smaller source term associated with the 4S NPF, an EPZ corresponding with the site boundary could well be technically justifiable.[23]

A risk-based evaluation of the EPZ would be consistent with the approach utilized by the NRC Staff in the late 1970s to determine the appropriate size of the EPZ for power reactors. That approach used the following criteria to determine the generic distance for the plume exposure pathway EPZ:

- The EPZ should encompass those areas in which projected dose from design-basis accidents could exceed the EPA PAGs.
- The EPZ should encompass those areas in which consequences of less severe Class 9 (core melt) accidents could exceed the EPA PAGs.
- The EPZ should be of sufficient size to provide for substantial reduction in early severe health effects in the event of the more severe Class 9 accidents.[24]

In evaluating these criteria, as they would apply to advanced reactors, the NRC Staff recognized in SECY-97-020 that the EPZ size could be reduced from the typical 10-mile radius and still satisfy the first criterion. Further, the need to satisfy the other criteria could be relaxed by excluding from consideration some accident sequences "… due to the low probability of their occurrence or because of the existence of design features to prevent their occurrence."

In other words, the NRC Staff would accept the use of a "truncation probability" as part of a risk-based EPZ evaluation. A postulated accident that would result in a release exceeding a PAG would not need to be considered in establishing an EPZ if its probability of occurrence was

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response", pg. 6, "A Technology Roadmap for Generation IV Nuclear Energy Systems, GIF-002-00, December 2002.

[23] One of the criteria used for determining the EPZ size was that "the EPZ should encompass those areas where the projected dose from design basis accidents could exceed the Environmental Protection Agency (EPA) Protective Actions Guidelines (PAGs)." NUREG-1465. The NRC has not yet formally adopted this criterion alone for large power reactors (SECY-97-020), but this criterion may provide a basis for setting the EPZ at the site boundary for smaller reactors. 10 C.F.R. §§ 40.31, 70.22 and 76.91 define how emergency planning requirements are scaled down for non-power reactor licensees (radiological, SNM, gaseous diffusion). The 4S could be analogized to these facilities.

Other factors may play a role in establishing the EPZ for a given facility that cannot be addressed solely by the risk-based approach, e.g., acceptance by local officials and the general public. However, the risk based approach provides a sound technical justification for a small EPZ.

[24] SECY-97-020, *supra,* citing NUREG-0396, "Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants" (1978).

below the truncation probability.[25] Application of this concept would assist in effectively applying probability insights to the small advanced reactor design rather than relying on a hypothetical, non-mechanistic accident to evaluate the PAG dose at the EPZ.

A formal probabilistic risk assessment for the 4S NPF is not currently available. It is expected, however, that a 4S NPF located at the Galena site would have a much lower calculated probability of release than current generation plants.[26] This degree of risk reduction is consistent with the significantly improved risk profile due to the smaller core inventory and inclusion of advanced design features such as passive safety systems.[27]

The discussion that follows addresses some of the key features of the 4S NPF that contribute to a reduced likelihood of core damage and release in comparison to the large, current generation facilities. These features would be taken into account in implementing a risk-based approach to sizing the plume exposure pathway EPZ for the Galena 4S. Such a risk evaluation would include consideration of three broad elements of a risk: (i) accident initiating events, (ii) probability of failure of a fission product boundary (i.e., core damage/vessel failure), and (iii) probability and consequences of release to the environment due to a failure of the containment. Also, the timing of the releases (i.e., the response time between the initiation of the event and the arrival of the radioactive contamination at the site boundary) is of interest, since it allows assessment of the viability of potential response measures.

2. Accident Initiators for Galena 4S

Potential accident initiators are grouped into two categories: (i) "internal" events and (ii) "external" events. Internal event initiators include system failures such as loss of site power. External events include natural occurrences such as earthquakes and common mode failures such as fires. The remote location of the Galena 4S NPF introduces the possibility that some external events initiators may have a higher frequency than typically observed for a large power reactors. For example, external initiating events associated with extreme weather conditions might be more likely at the Galena site. Thus, the 4S design must compensate for potential increased initiator frequencies if a detailed probabilistic risk analysis (PRA) demonstrates this to be the case.

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[25] Consideration of the environmental effects of such postulated accidents would be addressed, to the extent required, in the environmental impact study for the 4S NPF.

[26] Advanced light water reactor core damage frequencies due to internal events are in the range of 10^{-6} to 10^{-7} per reactor year compared to the NRC safety goal of 10^{-4} per year.

[27] S. Hattori, "Energy Source for the Human Demand," Central Research Institute of Electric Power Industry, Japan cites a potential risk reduction of more than a factor of 1000 for small passive reactors in comparison to large current generation plants.

In general, it is anticipated that the frequency of events that could lead to core damage in the 4S is less than that for current generation plants due to the simplicity of the design, reduced need for operator action, and the physical capability of the 4S to passively accommodate heat removal functions from both the reactor and containment.

a. Internal Events

The spectrum of internal events typically considered as accident initiators for the current generation light water reactor includes anticipated transients during normal operation and the less likely postulated accidents such as a loss of reactor coolant. Transients may be associated with the reactor function (e.g., failure to scram) or with the power generation function (e.g., closure of steam stop valves). Some of these events have a reduced frequency or can eliminated as accident initiators in the 4S design based on the plant's capability to cope with the event. Table 3 below provides examples of typical current generation plant accident initiators and their applicability to the 4S plant. A 4S-specific PRA would identify initiators which are unique to that design and the associated frequencies of such initiators.

Table 3
Applicability of Typical Internal Accident Initiators to 4S Plant

Initiator from Current Generation Plant	Applicability to 4S Design
Inadvertent Reactivity Insertion (Transient Overpower) Events: Rod ejection accident Boron dilution accidents Rod withdrawal	The 4S plant does not have control rods or rely on boron for reactivity control. The reactivity control for start-up, shutdown and core burnup is performed automatically without operator intervention. Rapid withdrawal of the reflector at cold shutdown leads to a reactivity accident. The system must be heated to 350°C by the primary pump heat entering before start up to preclude excess reactivity additions from this event. At system temperatures below 350°C, the neutron absorber is physically prevented from being withdrawn. The most limiting reactivity insertion is the reflector rising continuously to its highest position at the highest speed mechanically possible.[28] Neither the coolant nor the center of the fuel rises higher than 750°C[29]. With this reactivity the low linear power design (about 1/3 of an ordinary design) gives a significant margin to fuel melting.**[30]**
Overcooling transients	The overcooling events that have been evaluated result in small positive reactivity caused by changes in pump speed causing reduced primary system temperatures. Core temperatures increase slowly and the peak temperature is bounded by the transient overpower events.
Loss of reactor coolant flow Loss of Load Loss of Electro Magnetic Pump (EMP)	In Loss of Flow events, the fuel integrity depends on the peak fuel/cladding interface temperature. Important key quantities are the primary flow coastdown characteristics and the reactivity feedback. Analyses performed for this event shows acceptable transient response. Pump flow coastdown and negative reactivity feedback caused by core and axial fuel expansions maintained fuel integrity protection during this event.[31]
Loss of heat sink Partial loss of feedwater Complete loss of feedwater	System behavior for a Loss of Heat Sink is similar but milder than a Loss of Flow. **[21]**
Loss of Coolant Accident (LOCA)	The 4S core structure is not subject a loss of coolant accidents such as those that may occur in light water reactors. The core is near the low point of the reactor vessel and the system operates at nearly atmospheric pressure. Failures in the system boundary do not uncover the core. Since the liquid sodium operates at hundreds of degrees below its boiling point, there is no loss of inventory by vaporization out of a break. Core cooling is maintained by conduction of heat to the vessel walls.
Local blockage [21] **[CHECK]**	Small potential of local blockages because the 4S design has a low potential for creating loose parts. The 4S

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[28] "Passive Safety Features in 4S Plant," Hattori, S. and A. Minato, ASME/JSME Nuclear Engineering Conference, Vol. 1, 1993.
[29] "Meet Global Needs by 4S Plant," Hattori, S. and A. Minato, ASME/JSME Nuclear Engineering Conference, Vol. 2, 1993.
[30] "Present Design Features Of The Super Safe, Small And Simple Reactor," Hattori, S. et al., Central Research Institute of Electric Power Industry.
[31] Ibid.

Table 3
Applicability of Typical Internal Accident Initiators to 4S Plant

Initiator from Current Generation Plant	Applicability to 4S Design
	maintains the coolant in an enclosed cover gas, and the 4S metallic fuel is compatible with sodium. The excellent thermal conductivity of metallic fuel mitigates the fuel temperature rise if a blockage were to occur.
Steam generator tube rupture	Conservative analysis indicates that the maximum pressure remains lower than 0.7 MPa and the boundary tube is maintained. [32]
Total loss of all station power	The system temperature does not exceed 650°C in either accident.[33]
Loss of decay heat removal	The system temperature does not exceed 650°C in either accident.[34]
Anticipated Transient without Scram Reactivity insertion and loss of offsite power under horizontal earthquake Reactivity insertion by sudden ΔT Loss of load Sudden loss of EMP Total loss of electric power	The largest temperature rise is caused by a horizontal earthquake accompanied by simultaneous insertion of reactivity and loss of flow under assumption of without scram. Temperature of the fuel cladding rises up to 850°C but it drops in a short period of time without causing cladding damage by eutectic reaction. The fuel does not melt.[35]

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[32] "Passive Safety Features In 4S Plant", Hattori, S. and Minato A**.,** ASME/JSME Nuclear Engineering Conference, Vol 1, 1993.

[33] "The Super Safe, Small and Simple Reactor (4S-50)", Hattori, S. and Minato A., International Conference on Design and Safety of Commercial Nuclear Power Plants. Oct 25-29, 1992 Tokyo, Japan.

[34] Ibid.

[35] **"**Current Status Of 4S Plant Design," Hattori, S. and A. Minato, ASME/JSME Nuclear Engineering Conference, Vol. 2 ASME 1993.

b. External Events

The characteristics of the Galena site introduce the possibility that certain external events may be the dominant accident initiators. In particular, earthquake risk is a dominant contributor in some Japanese reactors; the Galena location could introduce a similar situation. Additional external events that would be of particular concern for the Galena reactor include:

- Flood: The site is located adjacent to the Yukon River but is flat. It appears that flood levels would not be substantial. However, the reactor is located underground and groundwater intrusion or flooding of the buildings would be a design consideration.
- External fire: the site includes wooded areas that could challenge plant operation from an offsite forest fire.
- Extreme cold: Temperatures of -60°F represent unique challenges to equipment. A reactor trip under extreme cold conditions could challenge plant equipment until auxiliary power is available to provide heat (e.g. a long station blackout coping period).
- Extreme snow or ice: Conditions preventing access to the plant.
- Volcanic ash conditions: Affects machinery and could limit access to the plant.

Although requiring formal demonstration in a risk assessment, it is expected that the safety design of the 4S could accommodate these challenges because of the capability to provide core cooling with natural circulation in the absence of offsite power and without operator intervention.

3. Probability of core damage/vessel failure

Analysis of the Argonne EBR-II, a sodium cooled reactor, indicates a core damage frequency (CDF) one to two orders of magnitude below that calculated for current generation large commercial reactors.[36] Until the results of a 4S-specific PRA are available, the EBR II analyses could be reviewed and modified for applicability to 4S. An area of potential focus would be damage associated with sodium-water reaction if the double walled interface fails. Although such an event may have a very low probability, it would be relevant to establishing the EPZ unless its probability can be demonstrated to be vanishingly small.

The 4S design tolerates design basis and beyond design basis events without sustaining fuel failure. Events that cause sodium explosions because of sodium water reactions would have to be postulated and evaluated for probability of occurrence. A LOCA that fills a guard vessel with water might provide a hypothetical mechanism for such a release. The hypothetical explosion

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[36] "Safety and Security Features of 4S Type Reactors", D. Wade (Argonne) presentation to Alaska Rural Energy Conference, Sept 20-22, 2005, Sht 18.

would have to cause a breach of containment and allow a sodium fire that burns until the core is uncovered to cause core damage.

4. Probability and Consequences of Containment Failure

Maintaining the integrity of the containment function remains an important NRC regulatory requirement, regardless of reactor design.[37] Accordingly, there is a need to demonstrate the containment effectiveness as a radionuclide barrier; a typical means of doing so is to evaluate the conditional containment failure probability (ccfp). The ccfp illustrates the probability of a release given core damage. Traditionally, containment failure modes that require evaluation can be grouped into three categories: those that involve failure at the time of core damage, those involving early and potentially energetic failure, and those with longer term failure.[38]

Causes of energetic failure include steam and hydrogen explosion as well as direct containment heating. Steam and hydrogen explosions do not occur in the 4S design due to the use of sodium coolant. Direct containment heating is a phenomenon that is associated with reactor vessel failure at high pressure; this phenomenon appears unrealistic given the low system operating pressure.

Sodium-water reactions require evaluation for the 4S design, although the probability of such reactions is anticipated to be low. There are no water systems inside the 4S containment (guard vessel), so sodium-water interactions inside containment could only be caused by water intrusion from some unlikely, unanticipated condition. To ensure safety, the plant has been designed with multiple containment barriers which protect against such water intrusion scenarios. Protection against groundwater intrusion from normal hydrologic conditions is a fundamental aspect of the plant design, and will be addressed comprehensively. .

The intermediate sodium circulating through the IHTS, and the steam generator comprising part of the IHTS, does not come into direct contact with the radioactive core or the radioactive primary sodium. Rather, the intermediate sodium extracts heat from the PHTS via the intermediate heat exchangers and, as such, remains non-radioactive and free of corrosion products. Because the intermediate sodium is non-radioactive, it does not add to the risk of

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[37] In SECY-05-0006, the Staff states: "Of the four options evaluated, the current staff position endorses Option 3:

> The containment must adequately reduce radionuclide releases to the environs to meet the onsite and offsite radionuclide dose acceptance criteria for the events selected for the event categories and have the capability to establish controlled leakage and controlled release of delayed accident source term radionuclides.
>
> Resolution of this issue will also establish a key element of the policy description of defense-in-depth. Option 3 requires that the containment have an independent capability to reduce delayed radionuclide releases to the environment independent of other radionuclide transport barriers associated with the fuel, core, and reactor coolant pressure boundary. This is consistent with the Commission's defense-in-depth safety philosophy that safety functions (e.g., control of fission product release) should not depend on a single element of design, construction, maintenance, or operation.

SECY-05-006, "Second Status Paper on the Staff's Proposed Regulatory Structure for New Plants and Update on Policy Issues Related to New Plant Licensing" (Jan. 7, 2005).

[38] It will also be necessary to demonstrate that releases to the groundwater and the ingestion pathway do not require emergency response actions.

radioactive release in the event of a sodium-water interaction. The steam generator tubes are constructed of double walled tubing and integrated with a leak detection system to minimize the potential for sodium-water interactions. In the unlikely event of an sodium-water interaction in the steam generator, the IHTS is designed so that the rise in pressure caused by high temperature water intrusion and the ensuing chemical reactions will cause the IHTS dump tank valves to open, releasing the IHTS sodium into the inert atmosphere dump tanks, which are appropriately designed to handle the sodium and reaction by-products.

Barring explosion (e.g. sodium-water explosion, steam explosion, hydrogen explosion, or an energetic release, direct containment heating, core containment/concrete interaction) the only mechanisms for containment releases are the bypassing of containment (i.e. containment failure at the time of core damage) or containment overpressurization caused by inadequate cooling of containment (i.e., longer term failure). As indicated earlier, containment overpressurization is likely to have a very low probability. Containment bypass conditions are also less likely in a 4S than in current generation light water reactors because there are fewer active systems (thus fewer penetrations).

Because there are no probable causes of energetic releases to significantly pressurize containment, the energy associated with a release path is low and likely to result in a small plume exposure pathway. As such, a small EPZ would appear to be supportable once the formal analyses are available.

5. Timing of Releases

The time of potential releases should be determined to establish the range of required emergency response actions. Current advanced designs for large power reactors demonstrate that releases will not occur for at least 24 hours without operator intervention or active safety systems. This seems like a reasonable target to demonstrate for the 4S design; indeed, for comparison purposes, it should be possible to demonstrate a longer release time for the 4S. Analyses performed for the PRISM design indicated that for all but the most energetic release categories, the time to guard vessel/containment dome failure exceeds 24 hours.[39] Given the lower power level associated with the 4S design, it is anticipated that credible release scenarios would require an even longer time for releases to occur.

C. STAFFING REQUIREMENTS FOR EMERGENCY RESPONSE

The 4S reactor is designed to function without operator intervention during normal, accident, and post-accident conditions. The passive safety design of the plant places fewer requirements on the staff when dealing with emergencies. Abnormal and emergency plant procedures would probably not contain many required immediate actions. Those actions that were required would

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[39] PRISM Preliminary Probabilistic Risk Assessment, Amendment 8, Appendix A, Section A4.

largely be in the nature of monitoring the plant's condition, which can be accomplished by a small staff.

As shown in Table 4 below, a current generation large scale reactor control room crew consists of five people. Two console operators manipulate the controls for the primary and secondary plant with a shift foreman reading the Emergency Procedures out loud. The Shift Supervisor and shift technical advisor (STA) perform higher level monitoring functions to assure that the plant is within expected parameters. By contrast, in the 4S NPF the control console can be managed by a single operator. A senior reactor operator (SRO) can perform the necessary supervisory functions.

The physical layout and reduced size of the 4S plant also contribute to making management of an emergency simpler. The Galena 4S buildings will occupy less than 1 acre with perhaps 3 acres of land needed to support plant activities. All radioactive systems are located inside the guard vessel/containment dome and are inaccessible to operations personnel. Limited radiological controls are required during normal or accident conditions.

NUREG-0654/FEMA-REP-1 provides guidance on staffing requirements for nuclear power plant emergencies (10 staff members present on each shift and 11 available within 30 minutes). This guidance provides a framework for addressing the Galena 4S staffing needs during an emergency. The normal complement of on-shift staff is able to cope with all events and support the Emergency Plan and Emergency Plan Implementing Procedures. Table 4 summarizes how the Galena 4S plant would fill these positions.

Both the on-site and near-site Emergency Plan staffing requirements of the 4S NPF can be satisfied with the operating/maintenance staff at already deployed at plant. Normal power operation is expected to require no more than 3 operations/maintenance personnel per shift.[40] This crew would discharge the functions of Senior Reactor Operator, Reactor Operator, Shift Technical Advisor, Auxiliary Operator and Maintenance Technician. In order to do so, however, it would be necessary to ensure that the crew on each shift has the required training and expertise to carry out all of these different functions.[41] Security personnel would assume administrative fire brigade and onsite emergency medical support responsibilities. The role of Security personnel is discussed further in the Physical Security white paper.

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[40] The licensee could utilize three standard 8-hour shifts, or if feasible, two 12-hour shifts which are utilized at some nuclear plants. With two 12-hour, shifts, the licensee should be able to operate the facility with fewer personnel, and generally speaking staff often prefer 12 hour shifts because it allows longer time off between work weeks. For example, with two 12-hour shifts per day, the facility could be operated with two day shifts and two night shifts, with one day/night shift working four days one week and three days the following week and so forth.

[41] For example, to perform the necessary functions of a Shift Technical Advisor, it may be necessary for one of the three operations/maintenance personnel manning each shift to possess an engineering degree and the necessary engineering experience and expertise.

Table 4
Expected Galena Control Room Staffing versus NUREG-0654/FEMA-REP-1 Recommendations

NUREG-0654/FEMA-REP-1 Recommended Staffing						**Expected Galena 4S Staffing**			
Functional Area	Major Tasks	Position Title or Expertise	On Shift	Capability for Additions		On Shift	Capability for Additions		
				30 min	60 min		30 min	60 min	
Plant Operations Assessment		Shift Supervisor (SS) – A Senior Reactor Operator (SRO)	1	-	-	1 (SS)	-	-	Simple passive design and simple control console eliminates need for multiple operators. Response to events is to monitor plant response and confirm expected response.
		Shift Foreman (SRO),	1	-	-	0	-	-	
		Control Room Operators (Reactor Operators) (RO) Auxiliary Operators (AO)	2 2	- -	- -	1 (RO)	- -	- -	
Notification/ Communication	Notify licensee, State and Federal personnel and Maintain Communication		1[42]	1	2	1(SS) (AO)	1 (security)	-	Since the EPZ is small, there are only basic notification requirements: Town of Galena, USNRC

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[42] May be performed by engineering aid to shift supervisor.

NUREG-0654/FEMA-REP-1 Recommended Staffing						**Expected Galena 4S Staffing**			
Functional Area	Major Tasks	Position Title or Expertise	On Shift	Capability for Additions		On Shift	Capability for Additions		
				30 min	60 min		30 min	60 min	
Emergency Direction and Control		Shift Technical Advisor (STA) (or Shift Supervisor)	1[43]	-	-	1 (SS)	-	-	Alaska Division of Homeland Security and Emergency Management and Activation of the duty roster. Fire, police or medical notifications can be made by the security force as necessary.
Radiological Accident Assessment	Emergency Operations Facility (EOF) Director Offsite Dose Assessment	Senior Manager	-	-	1	-	-	1	
		Senior HP expertise	-	1	-	-	-	1	
	Offsite Surveys	HP Technicians	-	2	2	1 (AO)	-		All radioactive systems are inside sealed guard vessel. Radiation surveys should be very basic for the areas that are accessible to plant staff.
	Onsite (out of plant)		-	1	1		-		
	In-plant surveys		1	-	-		-		
	Chemistry/ Radiochemistry	Rad Chem Technicians	1	-	1		-		

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[43] may be assigned to personnel assigned to other functions.

NUREG-0654/FEMA-REP-1 Recommended Staffing						Expected Galena 4S Staffing			
Functional Area	Major Tasks	Position Title or Expertise	On Shift	Capability for Additions		On Shift	Capability for Additions		
				30 min	60 min		30 min	60 min	
Plant System Engineering, Repair and Corrective Actions	Technical Support	Shift Technical Advisor	1	-	-	1	-		Slow development of any reactor related emergencies. Operations personnel have skills to cope with events until near site or offshift support is provided.
		Core / thermal hydraulics	-	1	-		-	1	
		Electrical	-	-	1		-	1	
		Maintenance	-	1	1		-	1	
	Repair and Corrective Actions	Mechanical Maintenance/ Rad Waste Operator	1[44]	-	1	AO	-		Since nearly all of the safety systems are inside the sealed guard vessel, there are not many safety significant maintenance items that would be required in the short term
		Electrical Maintenance	1	1	1		-	1	
		Instrumentation and Control (I&C) Technician	-	1[44]	-		-	1	
Protective Actions (In Plant)	1. Access Control 2. HP Coverage for repair corrective actions	HP Technicians	2[44]	2	2	1 (AO) (security)	1		

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[44] (may be assigned to personnel assigned to other functions)

NUREG-0654/FEMA-REP-1 Recommended Staffing						**Expected Galena 4S Staffing**			
Functional Area	Major Tasks	Position Title or Expertise	On Shift	Capability for Additions		On Shift	Capability for Additions		
				30 min	60 min		30 min	60 min	
	search and rescue first aid & firefighting 3. Personnel monitoring 4. dosimetry								
Firefighting			Fire brigade as per Tech Specs	Local support		Fire brigade as per Tech Specs	Local support		
Rescue Operations and First Aid				2 [44]			Local support		
Site Access Control and Accountability	Security, firefighting, personnel accountability	Security personnel	As per security plan			As per security plan			
Total			10	11	15	3	2	7	

The time interval of greatest activity for the licensed reactor operators is the period immediately after an accident/transient or other plant event. The responsibility of the licensed operator(s) is to establish that the plant is performing within its specified safety limits and is achieving a known safe state in accordance with the plant emergency procedures. The emergency procedures identify the actions that need to be taken in a given plant condition. In the earliest phases of an event, the 4S operator is aided by the other two operator/maintenance personnel on shift. For events where there is no security risk, the guard staff can also provide predefined administrative, communications and planning help such as making initial notification of government agencies, calling up the duty roster or calling for fire or medical support.

D. OTHER RELEVANT CONSIDERATIONS TO EMERGENCY PLANNING

While this paper focuses on emergency plan staffing and the size of the EPZ, the following observations are pertinent regarding other aspects of emergency planning:

- Accident dose projections, typically developed after accident initiation by person(s) with onsite radiological controls capabilities, could be developed in advance for the 4S facility, given the limited number of potential accident scenarios.
- Establishing a working relationship with State and local agencies is still required (for example implementation of ingestion pathway protective actions), although only limited support from offsite organizations would be necessary to respond to emergencies.
- Onsite facilities necessary for treating accidents, e.g., first aid and decontamination functions, could be replaced with near-site facilities that are used to handle other medical issues.
- Personnel training would still be required.
- Potential accident sequences would be defined by probabilistic risk analyses.
- If the EPZ can be limited to site boundary, then notification requirements for agencies and population may be necessary only to support emergency on-site response (e.g., fire department response) rather than off-site protective actions.
- Emergency planning exercises may be reduced in frequency or limited in required governmental participation given the limited potential for governmental supported emergency response.

E. POTENTIAL REQUESTS FOR EXEMPTIONS FROM REGULATORY REQUIREMENTS

Under 10 C.F.R. § 50.12, the NRC may grant nuclear power plant licensees an exemption from otherwise applicable regulatory requirements upon determining that (1) the requested exemption is "authorized by law, will not present an undue risk to public health and safety, and [is] consistent with the common defense and security,"[45] and (2) "special circumstances are present" which warrant the granting of the exemption.[46] The regulation identifies the "special circumstances" or justifications for which an exemption may be granted.[47]

It is not anticipated that Galena would need to seek exemptions in order to be able to deploy a small number of personnel with emergency response duties, or to have the plume exposure pathway EPZ defined so that it extends for only 800 meters (half a mile) or so. However, if requesting an exemption were to become necessary or advisable, the basis for seeking it would probably be the provisions of 10 C.F.R. § 50.12(a)(2)(ii), which authorize an exemption where no undue risk to public health and safety is otherwise presented upon showing that application of the regulation "is not necessary to achieve the underlying purpose of the rule."

V CONCLUSIONS

As indicated in Section III, this paper focuses primarily on (1) staffing requirements necessary to support emergency planning requirements for a 4S NPF located in Galena and (2) the size of the EPZ for such a facility. Documentation of regulatory consideration of emergency planning for small and advanced reactors indicates that emergency planning requirements for the Galena NPF may be reduced in comparison to those applied for larger plants.

The staffing requirements for the 4S NPF were compared to the NRC functional area requirements recommended staffing of NUREG-0654/FEMA-REP-1. The activities needed to operate the 4S NPF and respond to an emergency event were seen to require an on-shift operational staff of two licensed operators and one auxiliary operator. The factors that contributed to this reduced number of operating staff are:

- Inherent safety, reduced number of systems and passive safety design requires almost no operator intervention. One console operator can monitor the plant condition and take any necessary mitigating actions.
- The small site can be monitored and maintained by fewer people.
- Radioactive systems are contained within the guard vessel/containment dome and health physics requirements are greatly reduced.
- The EPZ of 800 m reduces the post accident monitoring and notification operator burden.
- Personnel would be cross-trained to perform multiple duties.

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[45] 10 C.F.R. § 50.12(a)(1).

[46] 10 C.F.R. § 50.12(a)(2).

[47] 10 C.F.R. § 50.12(a)(2)(i)-(vi).

EPZs are established to prevent unnecessary radiation exposure by persons within the postulated area in the unlikely event of a nuclear incident. The typical plume exposure EPZ for a large power reactor assumes a 10 mile radius from reactor center. Available documentation indicates that an 800 meter distance to an EPZ boundary can be readily justified for small reactors such as Galena. The issue of a smaller EPZ has been previously raised and the NRC staff has indicated a willingness to consider emergency planning requirements for small, advanced reactors on a case-by-case basis.

The technical approach to justifying a smaller EPZ is based on establishing the likelihood of design basis and beyond-design basis accidents and the potential consequences of such accidents. Once established, this risk profile can be used to demonstrate that a smaller EPZ adequately allows for protective actions to be taken and show that protective action guidelines will not be exceeded at a distance less than 800 meters.

While a formal probabilistic risk assessment for the 4S NPF has yet to be issued, the calculated probability of a significant release from the Galena 4S NPF based power facility and potential for offsite dose consequences can be expected to be lower than those for both advanced reactor designs and current generation reactors. The reasons for this are:

- The simple, passive features in the Galena reactor should result in a lower calculated probability of core damage than current generation plants.
- The capability of the containment structure and its passive nature cooling capability provides a reliable barrier to release.
- The radionuclide inventory is approximately two orders of magnitude less than that used in the advanced designs undergoing certification.

Thus, it can be expected that a formal probabilistic analysis would demonstrate that an EPZ less than 800 meters from the NPF can be justified. If possible, the goal of the formal analysis would be to demonstrate that the site security boundary and the EPZ boundary can be coterminous.

VI RECOMMENDATIONS

Galena should engage in early discussions with the NRC Staff to confirm the willingness of the agency to consider a much smaller EPZ for the Galena facility and to establish the minimum size of the operating staff that would be required to respond to radiological accidents. These determinations would be of vital importance in predicting the plant operating costs and the overall economic viability of the project.

Final decisions on both the EPZ and the size of the operating staff would be based on the results of risk-based accident evaluations that assess the bounding accident sequences and the required responses to them.