PRELIMINARY DRAFT

This draft document is being made publicly available to support a future public meeting on the topic of siting considerations related to population for small modular and non-light water reactors. This document is intended to facilitate stakeholder discussion to inform potential future activities on this topic.

PURPOSE

In SECY-10-0034 [Ref. 1], "Potential Policy, Licensing, and Key Technical Issues for Small Modular Nuclear Reactor Designs," the U.S. Nuclear Regulatory Commission (NRC) staff identified a number of potential policy and licensing issues related to the licensing of small modular reactors (SMRs) and non-light water reactors (non-LWRs). One of the issues identified in the paper was the determination of source terms and the resulting dose calculations and siting evaluations. Since 2010, the staff has prepared a series of Commission memos and Commission papers on this topic to resolve the source term and dose calculation issues. Most recently, the staff issued SECY-16-0012 [Ref. 2], "Accident Source Terms and Siting for Small Modular Reactors and Non-Light Water Reactors," which identified the need for stakeholder interactions regarding siting considerations for SMRs and non-LWRs, with regard to population distribution and density. The purpose of this draft white paper is to facilitate stakeholder engagement on these siting considerations to inform the staff's assessment of whether new or revised guidance in this area is needed.

INTRODUCTION

In accordance with Commission expectations, SMRs and non-LWRs might have risk profiles significantly lower than the Commission's Safety Goals and the potential radiological releases from SMRs and non-LWRs are expected to be smaller than the current fleet of large LWRs. Therefore, prospective applicants may consider proposing exclusion areas[1] and low population zones[2] (LPZ) associated with SMRs and non-LWR sites that are reduced in size compared to those established for large LWRs. As a result, these sites could be located closer to densely populated centers, if one were to focus exclusively on the criteria related to potential radiological doses to individuals. However, the Commission's policy [Ref. 3] that reactor sites should be located away from densely populated centers must also be taken into consideration when determining the suitability of a site. The requirements (10 CFR 100.21(h)) and guidance implementing this policy use population density of the surrounding area as a factor to consider when determining the suitability of a site. The scope of this paper is limited to new power reactors that are considered SMRs or non-LWRs.

[1] Exclusion Area Boundary (EAB) defines the boundary of the area surrounding the reactor for which the reactor licensee has the authority to determine all activities, including exclusion or removal of personnel and property from the area.

[2] A Low Population Zone (LPZ) is defined as an area of low population density surrounding the exclusion area. The population density is determined by the number of residents in the zone. The population density in this area must be considered in the unlikely case there is a need for executing emergency plans – so that certain protective measures (such as notification and instructions to residents) can be accomplished in a timely manner.

BACKGROUND

Since 1951 the NRC and its predecessor, the Atomic Energy Commission, have gained valuable experience and developed requirements and guidance for reactor siting with regard to many considerations, including population distribution and density. In 1978, the staff published NUREG-0478, "Metropolitan Siting – A Historic Perspective" [Ref. 4] (for comment) to provide a resource base for staff reviews and applicant guidance related to sites near densely populated areas. Subsequently, in August 1979, the staff published NUREG-0625, "Report of the Siting Policy Task Force" [Ref. 5]. This report was prepared in response to the Commission's request for a comprehensive staff effort to develop a general policy statement on nuclear power plant siting, and it provided nine recommendations, mostly related to enhancements to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 100. The recommendations in NUREG-0625 were intended to "strengthen siting as a factor in defense in depth by establishing requirements for site approval that are independent of plant design consideration, take into consideration in siting the risk associated with accidents beyond the design basis (Class 9) by establishing population density and distribution criteria, and require that sites selected will minimize the risk from energy generation."

In the 1980 Authorization Act for the NRC, Congress directed NRC to decouple siting from design and to specify demographic criteria for siting. In December 1996, the NRC amended its regulations [Ref.3] in 10 CFR Part 100 by establishing the requirements for nuclear reactor sites, and providing evaluation factors for new applications for reactor sites.

COMMISSION POLICY REGARDING SITING AWAY FROM DENSELY POPULATED CENTERS

The NRC's reactor siting requirements for power and testing reactors are found in 10 CFR Part 100, "Reactor Site Criteria." One aspect of the siting criteria in 10 CFR Part 100 is the location of the reactor relative to a population of more than about 25,000 residents. The requirements in 10 CFR 100.21(b) specify how to calculate the reactor distance to the population center[3] relative to the outer boundary of the LPZ. The distance to the outer boundary of the LPZ is determined by the evaluation of the radiological dose consequences of postulated accidents, with criteria set forth in 10 CFR 50.34(a)(1). Determining these distances based upon projected doses of postulated accidents is necessary to meet acceptability of a site, and it is only one of the siting requirements. Other factors in 10 CFR Part 100 include the use of the site environs, including proximity to manmade hazards; and the physical characteristics of the site, such as seismology, meteorology, geology, and hydrology.

Independent of the dose-based siting criteria, 10 CFR 100.21(h) states that reactor sites should be located away from very densely populated centers. It also states that areas of low population are generally preferred. For a site that is located away from a very densely populated center but is not in an area of low density, the regulation provides a means for

[3] Population Center Distance refers to the distance from the reactor to the nearest boundary of a densely populated center containing more than about 25,000 residents. The nearest distance to the population center must be at least one and one-third times the distance from the reactor to the outer boundary of the LPZ, as required by 10 CFR 100.21.

determining acceptability. In this case, consideration is given to safety, environmental, economic, or other factors, which may result in the site being found acceptable.

DETERMINING SITING DISTANCES

To determine the distance from a reactor to the exclusion area boundary (EAB), it is necessary to consider the potential radiological dose and consequences to the public in the event of an accident. Specifically, to determine the outer boundary of the exclusion area, regulations in 10 CFR 50.34(a)(1)(ii)(D)(1) state that "An individual located at any point on the boundary of the exclusion area for any 2 hour period following the onset of the postulated fission product release, would not receive a radiation dose in excess of 25 rem [Roentgen equivalent man] total effective dose equivalent (TEDE)."

Similarly, to determine the outer boundary of the LPZ, regulations in 10 CFR 50.34(a)(1)(ii)(D)(2) state that "An individual located at any point on the outer boundary of the low population zone, who is exposed to the radioactive cloud resulting from the postulated fission product release (during the entire period of its passage) would not receive a radiation dose in excess of 25 rem total effective dose equivalent (TEDE)."

Consequently, to determine the location of the EAB and LPZ it is necessary to know the minimum distance at which the radiation dose values to an individual are projected to exceed the above limits. Once the LPZ radial distance is determined, the distance from the reactor to the nearest boundary of a densely populated center shall be at least one and one-third times the distance from the reactor to the outer boundary of the LPZ (see 10 CFR 100.21(b)).

POPULATION DENSITY

In the 1996 rulemaking revising the NRC's 10 CFR Part 100 siting regulations [Ref. 3], the Commission examined its siting policy. The statements of consideration (SOC) for this rule discussed the Commission's practice of siting reactors away from densely populated centers. The SOC specifically states that, "The Commission has also had a long standing policy of siting reactors away from densely populated centers, and is continuing this policy in this rule." Furthermore, the final rule states that reactor sites should be located away from "very" densely populated centers. The Commission also made it clear that while maintaining this policy, population density should be considered in the context of all siting factors. A site with significant safety, environmental and economic advantages should not be rejected based solely on a higher population density than other alternative sites.

NRC staff guidance on population density was first issued in 1975 in Regulatory Guide (RG) 4.7, "General Site Suitability Criteria for Nuclear Power Stations." The SOC [Ref. 3] for the 1996 final rule on reactor siting stated that RG 4.7 provided "a means of locating reactors away from population centers, including 'major' population centers, depending upon their size that would limit societal consequences significantly, in the event of a severe accident." The current version of RG 4.7 [Ref. 6] issued in March 2014 states that:

> A reactor should be located so that, at the time of initial plant approval and within about 5 years thereafter, the population density, including weighted transient population, averaged over any radial distance out to 20 mi (cumulative population at a distance divided by the circular area at that distance), does not exceed 500 persons per square mile. A reactor should not be located at a site where the population density is well in excess of this value.
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> If the population density of the proposed site exceeds, but is not well in excess of the above preferred value, the analysis of alternative sites should pay particular attention to alternative sites with lower population density. However, consideration of other factors, such as safety, environmental, or economic concerns, may result in the site with the higher population density being found acceptable.

Applying this population density guidance would be more limiting, in some cases, than the dose-based criteria in 10 CFR part 100. For example, under this guide, the population within a 1 mile radius of the reactor should be less than approximately 1,500 persons, the population within a 5 mile radius of the reactor should be less than approximately 40,000 persons, the population within a 10 mile radius should be less than approximately 150,000 persons, and the population within a 20 mile radius should be less than approximately 625,000 persons.

SITING CONSIDERATION FOR SMRs AND NON-LWRs

The NRC staff identified in SECY-10-0034 [Ref. 1] that determining appropriate source term, dose calculations, and siting for SMRs is a potential policy and licensing issue for SMRs and non LWRs. In accordance with Commission expectations, SMRs and non-LWRs might have risk profiles significantly lower than the Commission's Safety Goals and the potential radiological releases from SMRs and non-LWRs are expected to be smaller than the current fleet of large LWRs. In SECY-16-0012 [Ref. 2], the staff stated that appropriate use of mechanistic source term analysis methods could "…allow future COL applicants to consider reduced distances to EABs and LPZs, and potentially increased [SMR] proximity to population centers." This could be the case if an applicant would propose deployment of SMRs or non-LWRs as replacement for existing coal plants located in areas that are close to densely populated centers. This could also be the case for non-LWRs that are intended to generate process heat for industrial applications.

SMRs and non-LWRs may be designed with relatively small cores, passive safety features, or other design features, which are anticipated to result in smaller postulated accident releases. Using the current regulations and guidance, the smaller postulated accident releases may result in the potential for the EAB and LPZ to be smaller than for large LWRs, and could potentially be as small as a few hundred meters. NRC regulations require that the nearest boundary of the population center from the reactor be at least one and one-third times the distance from the reactor to the outer boundary of the LPZ. Based on this requirement alone, an applicant may propose a site location closer to a population center.

In the SOC for the 1996 revision to 10 CFR Part 100 [Ref. 3], the Commission discussed its view on siting the next generation of reactors, and stated the following:

> In summary, next-generation reactors are expected to have risk characteristics sufficiently low that the safety of the public is reasonably assured by the reactor and plant design and operation itself, resulting in a very low likelihood of occurrence of a severe accident. Such a plant can satisfy the QHOs [quantitative health objectives] of the Safety Goal with very small exclusion area distance (as low as 0.1 miles). The consequences of design basis accidents, analyzed using revised source terms and with a realistic evaluation of engineered safety features, are likely to be found acceptable at distances of 0.25 miles or less. With regard to population density beyond the exclusion area, siting a reactor closer to a densely populated city than is current NRC practice would pose a very low risk to the populace. Nevertheless, the Commission concludes that defense-in-depth considerations and the additional enhancement in safety to be gained by siting reactors away from densely populated areas should be maintained.

This statement could be interpreted to mean that the guidance in RG 4.7 [Ref. 6] on population density (less than 500 people per square mile) should be applied, or new guidance would need to be developed for SMRs and non-LWRs to ensure that the Commission's policy of siting reactors away from densely populated areas is maintained. It should also be noted that since 1996, research efforts such as State-of-the-Art Reactor Consequence Analyses (SOARCA) indicate that likely radiological health effects of severe accidents would be significantly less than previously thought.

STAKEHOLDER ENGAGEMENT

There are currently no combined license (COL) applications scheduled that employ an SMR or non-LWR design, nor have any pre-application discussions to date specifically indicated that an applicant plans to site its facility closer to densely populated centers. However, the NRC staff understands that future applicants may propose to site SMRs or non-LWRs at retired fossil fuel plants or other industrial sites in densely populated areas. Therefore, in SECY-16-012, the staff committed to engage proactively with stakeholders to determine whether clarification on siting is needed, prior to determining whether direction from the Commission is needed. Since that time, the staff has discussed this topic in several meetings, as discussed below. The staff has also prepared this draft white paper to support additional discussion with stakeholders.

On August 3, 2017, the staff held a public meeting with nuclear industry groups and other stakeholders on possible regulatory process improvements for non-LWR designs (ML17213A032) and briefed the participants on this issue. The staff plans a more in-depth discussion at another similar public meeting scheduled on December 14, 2017, where this draft white paper will be discussed. Additional meetings will be scheduled as needed.

STAFF'S ASSESSMENT OF POTENTIAL ALTERNATE APPROACHES

The current siting approach for nuclear power reactors is centered on determining the EAB and LPZ sizes based on dose criteria for postulated accidents. Once the distance to the outer boundary of the LPZ is determined, then the distance from the reactor to the nearest boundary

of a densely populated center containing more than about 25,000 residents must be at least one and one-third times the distance from the reactor to the outer boundary of the LPZ. The staff also ensures that the population density is not well in excess of 500 persons per square mile averaged over any radial distance out to 20 miles to ensure that the site is "away from densely populated centers." These criteria were generally used to determine the population center distance in siting the current operating reactor fleet and for determining the site acceptability for new reactor combined licenses.

Based on dose considerations alone, SMRs and non-LWRs could be sited in a closer proximity to a densely populated center due to the anticipated smaller LPZ size based on lower postulated doses. However, applying the guidance of RG 4.7 [Ref. 6] may preclude certain sites based on the population density guidance (e.g., less than 500 persons per square mile out to 20 miles).

The Department of Energy, developers of SMRs and non-LWRs, and other stakeholders have considered siting issues within their assessments of potential uses for and deployment of small modular and advanced reactor technologies. Examples include DOE evaluations of using advanced reactor designs to replace retiring fossil-fueled power stations and as a means to provide reliable power to government installations. Oak Ridge National Laboratory (ORNL) performed several evaluations of potential siting of SMRs and non-LWRs including case studies of population sensitivity for the siting at candidate locations [References 7, 8, 9 and 10]. In Reference 7, ORNL performed a screening of potential sites in the U.S. and when applying the population density guidance of RG 4.7, it was concluded that approximately 8% of the area of the continental U.S. would be screened out based solely on this population density guidance. Subsequent ORNL case studies evaluated the suitability of sites using a screening criteria of 500 persons per square mile averaged over any radial distance out to 10 miles instead of 20 miles.

The staff is assessing various considerations regarding SMR or non-LWR siting to ensure conformance with the Commission's "long standing policy of siting reactors away from densely populated centers." The following questions are being posed to facilitate stakeholder discussion during a public meeting to inform the staff's assessment:

1. Should the NRC consider a different approach be used to determine the minimum distance to the population center for SMRs and non-LWRs? If so, how should this minimum distance be established?

2. Should the NRC consider different criteria or guidance be developed for SMRs and non-LWRs to make the determination that the site is "away from densely populated centers"? If so, how should defense-in-depth be considered in developing the criteria? For example, should more complete, more realistic, and site-specific radiological release, transport, and dispersion models be used to evaluate societal risk to inform siting decisions?

3. Additionally, the staff is seeking feedback from SMR and non-LWR designers and potential applicants regarding their plans for proposing to site reactors closer to densely

populated centers, or in areas with a population density in excess of 500 persons per square mile out to 20 miles.

PATH FORWARD

The staff will consider insights obtained from stakeholder discussions and determine whether clarifications to RG 4.7 [Ref. 6], or other actions would be beneficial to address siting criteria for SMRs and non-LWRs. As appropriate, the staff would then report back to the Commission on proposed actions, as described in SECY-16-0012 [Ref.2].

REFERENCES

1. SECY-10-0034, Potential Policy, Licensing, and Key Technical Issues for Small Modular Nuclear Reactor Designs (ADAMS Accession No. ML093290268).

2. SECY-16-0012, Accident Source Terms and Siting for Small Modular Reactors and Non-Light Water Reactors (ADAMS Accession No. ML15309A319).

3. 61 FR 65157, Reactor Site Criteria Including Seismic and Earthquake Engineering Criteria for Nuclear Power Plants, December 11, 1996.

4. NUREG-0478, Metropolitan Siting – A Historic Perspective, October 1978 (ADAMS Accession No. ML12187A192).

5. NUREG-0625, Report of the Siting Policy Task Force, August 1979 (ADAMS Accession No. ML12187A284).

6. Regulatory Guide (RG) 4.7, Rev. 3, General Site Suitability Criteria for Nuclear Power Stations, March 2014.

7. ORNL/TM-2011/157/R1, Application of Spatial Data Modeling and Geographical Information Systems (GIS) for Identification of Potential Siting Options for Various Electrical Generation Sources, May 2012.

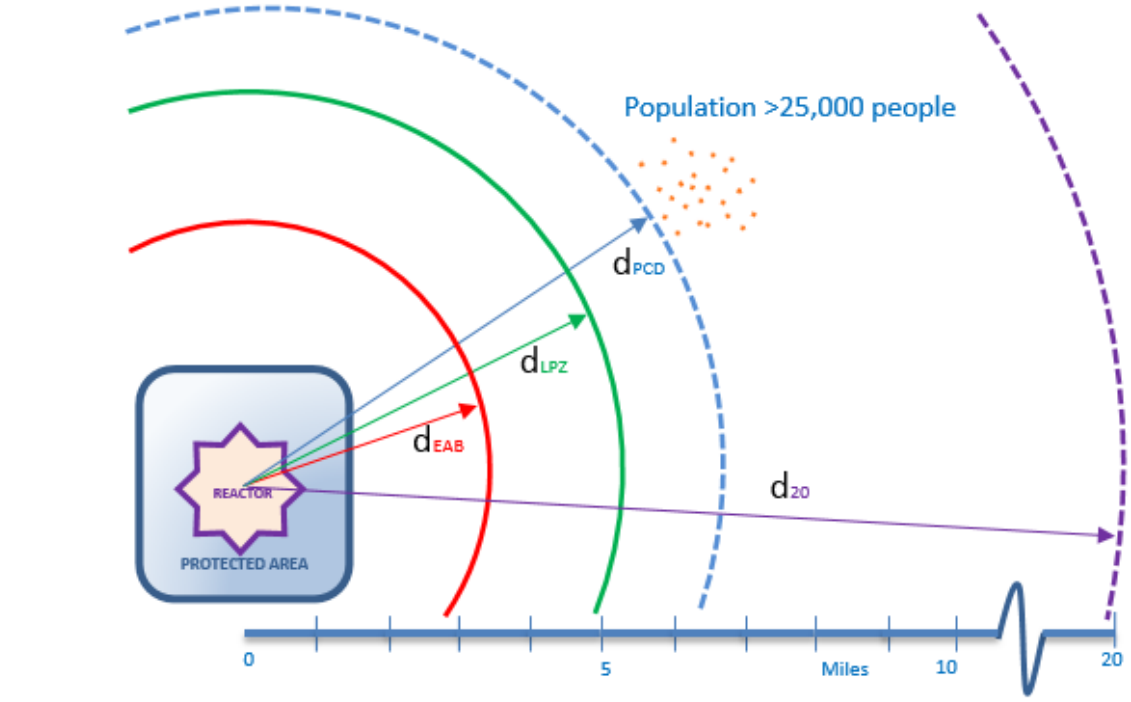
8. ORNL/TM-2013-109, Evaluation of Suitability of Selected Set of Coal Plant Sites for Repowering with SMRs, March 2013.

9. ORNL/TM-2014-300, Population Sensitivity Evaluation of Two Candidate Locations for Possible Small Modular Reactor Siting, August 2014.

10. ORNL/TM-2014-433, Evaluation of Potential Locations for Siting Small Modular Reactors near Federal Energy Clusters to Support Federal Clean Energy Goals, September 2014.

Figure 1

Reactor Proximity to Population Centers



d_{EAB} – exclusion area boundary (EAB) radial distance

d_{LPZ} – low population zone (LPZ) radial distance

d_{PCD} – population center distance (PCD) to the nearest boundary of a densely populated center

d_{20} – 20 mile outward radial distance (population density of <500 persons per square mile - RG-4.7)

EAB – radial distance based on the 25 rem criteria for any 2 hour period

LPZ – radial distance based on the 25 rem criteria during the entire period of the radioactive cloud passage

PCD – radial distance from the reactor to the nearest boundary of a densely populated center at least 1⅓ that of the outer boundary of the LPZ

Population Density – the staff also considers the population density of 500 persons per square mile out to 20 miles (RG-4.7)