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Emergency Planning Considerations for Advanced Nuclear Power Reactors

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ASTRACT

The purpose of this scoping study is to develop an approach for establishing emergency planning requirements for advanced nuclear power reactors and other new reactor technologies. The approach considers existing emergency planning requirements and guidance. More specifically the study focuses on establishing criteria and process to determine the size of the plume and ingestion exposure pathway emergency planning zone. The review of emergency planning in place for existing licensed nuclear facilities provides insight and informs the suggested process for establishing this Emergency Planning Zone (EPZ) process.

Note:

This research and draft document were prepared in 2011/2012 as a scoping study for the Nuclear Regulatory Commission, Nuclear Safety Incident Response Division. This work was re-visited due to recent attention around establishing an Emergency Planning Zone for non-LWRs and other reactor technologies. Authors acknowledge that additional research has been devoted to this subject area in the time following the previous scoping study. This SAND report reflects information available at the time and establishes a referenceable document for on-going work.

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CONTENTS

1. Introduction 13
   1.1 Scope and Objectives 13
   1.2 Background 13
2. Existing Approach to Emergency Planning 15
   2.1 Power Reactors 15
      2.1.1 Large Power Reactors 16
      2.1.2 Small Power Reactors 17
   2.2 Fuel Facilities and Material Facilities 20
   2.3 Independent Spent Fuel Storage Installations (ISFSI) 22
   2.4 Research and Test Reactors (RTRs) 22
   2.5 Summary of Existing Approach to Emergency Planning 23
3. Approach for Establishing EP Requirements for Small Advanced Reactors 25
   3.1 SMR Properties 25
   3.2 Planning Standards Comparison 27
4. Emergency Planning Zone and Collocation of Facilities 28
   4.1 Emergency Planning Zone – Plume Exposure Pathway 28
   4.2 Emergency Planning Zone – Ingestion Pathway 29
   4.3 Collocation of Facilities 30
5. Summary 33
6. References 34

Appendix A. Standard review plans 36
   A.1. NUREG-0800 – SRP for Light Water Reactors – Section 13.3 Emergency Planning 36
   A.2. NUREG-0849 – SRP for Review and Evaluation of Emergency Plans for Research and Test Reactors 37
   A.3. NUREG-1520 – SRP for Fuel Cycle Facilities 37
   A.4. NUREG-1567 – SRP for Spent Fuel Dry Storage Facilities 38

Appendix B. NUREG-0654 planning standards summary 39
   B.1. Emergency Response Planning Standards 39

LIST OF FIGURES

Figure 1: High Temperature Gas-cooled Reactor 19
Figure 2: SMR EPZ .... **Error! Bookmark not defined.**
Figure 3: SMR Combined EPZs 32

LIST OF TABLES

Table 1: EPZ Categories 9
Table 2: 2017 EPA PAGs and Protective Actions for the Early Phase of a Radiological Incident 10
Table 3: Decommissioned Licensed Reactors 18
Table 4: Alternate method for determining the size of an EPZ from ANSI/ANS 15.16-2008 23
Table 5: Small Modular Reactor Binning 25
Table 6: 2017 EPA PAGs and Protective Actions for the Early Phase of a Radiological Incident 28
Table 7: EPZ Categories 29

ACRONYMS AND DEFINITIONS

Abbreviation	Definition
AEC	Atomic Energy Commission
ANL-STAR	Argonne National Laboratory – Secure Transportable Autonomous Reactor
ANSI	American National Standards Institute
ANS	American Nuclear Society
ANTARES	Advance Reactor Energy System
BWR	Boiling Water Reactor
CDE	Committed Dose Equivalent
COL	Combined Operating License
COLA	Combined Operating License Application
CRAC2	Calculation of Reactor Accident Consequences code – 2^{nd} edition
DBA	Design Basis Accident
DOE	Department of Energy
EAL	Emergency Action Level
EOC	Emergency Operations Center
EOF	Emergency Operations Facility
EP	Emergency Planning
EPA	Environmental Protection Agency
EPZ	Emergency Planning Zone. A plume exposure EPZ is the area surrounding a nuclear power plant where preemptive planning is done to reduce radiological dose to the public during the emergency phase or early phase of a radiological accident. The early phase is typically less than a week's duration after an environmental release from a nuclear power plant. A plume exposure EPZ for large light water reactors is approximately a 10-mile radius surrounding the plant. An ingestion exposure EPZ is the area surrounding a nuclear power plant where preemptive planning is done to reduce radiological dose to the public through ingestion pathways. For large light water reactors, the ingestion exposure EPZ is approximately a 50-mile radius surrounding the plant.
ERDS	Emergency Response Data System
ESR	Experimental Superheat Reactor
ETE	Evacuation Time Estimate

Abbreviation	Definition
FEMA	Federal Emergency Management Agency
FSAR	Final Safety Analysis Report
GAO	Government Accountability Office
GFR	Gas-Cooled Fast Reactor
GT-MHR	Gas Turbine Modular Helium Reactor
HPG	Hyperion Power Generation Inc.
HTGR	High Temperature Gas-Cooled Reactor
IRIS	International Reactor Innovative and Secure
ISFSIs	Independent Spent Fuel Storage Installations (ISFSIs)
KI	Potassium Iodide
kW	Kilowatt
LOCA	Loss of Coolant Accident
LPZ	Low Population Zone
LWR	Light Water Reactor
MCA	Maximum Credible Accident
MRS	Monitored Retrievable Storage
mSv	Millisievert
MW	Megawatt
MWe	Megawatt Electric
MWt	Megawatt Thermal
NGNP	Next Generation Nuclear Plant
NPP	Nuclear Power Pplant
NRC	Nuclear Regulatory Commission
NUREG-Series	Nuclear regulatory reports developed by or for the NRC
OL	Operating License
ONTs	Other New Technologies
PAGs	Protective Action Guidelines
PBMR	Pebble Bed Modular Reactor
PWR	Pressurized Water Reactor
rem	Roentgen equivalent man
RTRs	Research Test Reactors

Abbreviation	Definition
SAR	Safety Analysis Report
SCFR	Sodium-Cooled Fast Reactor
SMR	Small Modular Reactor
SRP	Standard Review Plan
TEDE	Total Effective Dose Equivalent
TID	Technical Information Document
TRIGA	Training, Research, Isotopes, General Atomics
TRISO	Tristructural-Isotopic Fuel
UF_6	Uranium Hexafluoride
UO_2	Uranium Dioxide
VHTR	Very-High-Temperature Reactor

Executive Summary

This scoping study identifies that existing nuclear facility types use a dose / distance approach to establish the boundary and planning areas of the Emergency Planning Zone(s) (EPZ), based on the Environmental Protection Agency (EPA) Protective Action Guides (PAGs). A similar methodology such as a neutral dose / distance approach could be applied to Small Modular Reactors (SMRs) and other new technologies (ONTs) using the EPA PAGs as threshold criteria. If model-based analyses for a design-basis accident demonstrates that an EPZ is needed to stay within PAG guidelines, it is suggested that standard EPZ sizes be established at either the 2, 5, or 10 miles radius from the reactor. These radial areas, described in NUREG/CR 7002, are used to establish protective action planning and guidance for the population and facilities located within the defined area. Four categories of EPZ determination are suggested:

- Category I: If the projected dose is less than 1 rem at the site boundary, no EPZ is required.
- Category II: If the projected dose is greater than or equal to 1 rem at the site boundary and is less than 1 rem at 2 miles, then the EPZ will be 2 miles.
- Category III: If the projected dose is greater than or equal to 1 rem at 2 miles and is less than 1 rem at 5 miles, then the EPZ will be 5 miles.
- Category IV: If the projected dose is greater than or equal to 1 rem at 5 miles then the EPZ will be 10 miles.

The above approach provides a standard set of EPZs for ONTs based on the projected source term and reactor specific design and are summarized in Table 1.

Table 1: EPZ Categories

EPZ Category	**Projected Dose Limits***	**EPZ Size**
Category I	Dose TEDE < 1 rem at the site boundary. <	No offsite EPZ required
Category II	Dose ≥1 rem at the site boundary and < 1 rem at 2 miles	2-mile EPZ
Category III	Dose ≥ 1 rem at 2 miles and < 1 rem at 5 miles	5-Mile EPZ
Category IV	Dose ≥ 1 rem at 5 miles	10-mile EPZ

*Dose limits may also include a CDE to the thyroid for each category.

Table 2-1 of the EPA PAG document provides projected dose guidelines during the early phase of the accident. The EPA PAGs and Protective Actions for the Early Phase of a Radiological Incident are provided in Table 2 of this report. The EPZ category is determined from the lower PAG values of 1 rem total effective dose equivalent (TEDE).

Table 2: 2017 EPA PAGs and Protective Actions for the Early Phase of a Radiological Incident[1]

Protective Action Recommendation	PAG	Comments
Sheltering-in-place or evacuation of the public[2]	PAG: 1 to 5 rem (10-50 mSv) projected dose over four days	Evacuation (or, for some situations, sheltering-in-place) should be initiated when projected dose is 1 rem (10 mSV)

When trying to determine an EPZ category for a SMR or ONT analysts should assume normal activity for the population surrounding the site. No type of protective action should be applied, i.e. sheltering-in-place, or evacuation.

Regarding the ingestion pathway EPZ, a graded approach may be appropriate because the source terms are generally smaller, and ingestion represents a longer-term problem (NRC, 1980). There has been considerable experience with the expedient large-scale quarantine of foods in the United States in response to contamination outbreaks of E. coli, Salmonella, bovine spongiform encephalopathy (mad cow disease), etc. The successful quarantine and removal from public access of contaminated products suggests that an ad hoc approach may be appropriate in response to an accident with a release to the environment. For SMRs where the plume exposure EPZ is determined to be 5 miles or less, the size of an ingestion pathway area would likely be small enough to be manageable on an ad hoc basis.

When multiple facilities are collocated on the same site the effects of interconnected reactors and integrated safety systems must be considered in developing the source terms for the supporting analyses as required under 10 CFR 100.11(b). An approach is suggested where the size of the EPZ would be the maximum aggregate size of the collocated facilities where the EPZ for an SMR collocated with another reactor would be the maximum of the individual EPZs, or the overlapping area if appropriate.

In addition to developing a concept for establishing EPZ limits, the scoping study included a qualitative comparison to the 16 planning standards in NUREG-0654/FEMA REP-1, Rev.1. This review shows that most planning standard criteria will likely be directly applicable to SMRs although the application of some of these criteria may be affected by the size of the EPZ and other factors. A detailed review of NUREG-0654 for application to SMRs should be completed.

The results of this scoping study are consistent with the staff findings in SECY 97-020 and SECY 10-0034, which determined that the rationale upon which emergency planning (EP) is based for current reactor designs is appropriate for use as the EP basis for SMRs. The rationale used in NUREG-0396 to establish the EPZ limit of about 10 miles, applied the state of knowledge of severe accidents and the prevailing view on risk that existed at that time (NRC, 1978). Current policy supports risk informed applications and suggests that a risk informed approach be used in the development of EP guidance for SMRs. Gaps remain in SMR design information that do not

[1] Table does not reflect EPA guidance regarding the supplemental administration of prophylactic drugs such as KI.

[2] Should begin at 1 rem (10 mSv) if advantageous except when practical or safety considerations warrant using 5 rem (50 mSv); take whichever action (or combination of actions) that results in the lowest exposure for the majority of the population. Sheltering-in-place may begin at lower levels if advantageous.

currently allow for a comprehensive understanding of SMRs. Some of these gaps include final design information, source term information, and operational plans regarding fuel cycles.

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1. INTRODUCTION

For some time the nuclear industry has pursued the development of smaller nuclear power reactors that could be constructed or installed in a modular application to serve power needs as they arise. This initiative has gained momentum in the last few years with multiple companies developing conceptual reactor designs. Small reactor concepts have advanced to the point that guidance is needed regarding expected licensing requirements. A licensing pathway currently exists for these small modular reactor (SMR) and other new technologies (ONT) reactors via an exemption process; however large industry interest warrants a review of policy to determine an appropriate licensing strategy for these reactors.

This scoping study documents existing emergency planning (EP) requirements for a variety of licensed nuclear facilities to identify areas of EP consistency across nuclear facility types. The review revealed a consistent approach regarding EP for nuclear facilities. In general, the EP areas around a facility are determined by the projected dose that a member of the public would receive if a radiological release occurred.

1.1 Scope and Objectives

The scope of this task was to evaluate the current basis used for establishing EP requirements for the following classes of licenses:

- Large power reactors,
- Small power reactors,
- Material facilities,
- Fuel facilities,
- Independent spent fuel storage installations (ISFSIs), and
- Research and test reactors.

The objective was to describe quantitatively how EP has been considered for the above facilities and use this information to develop an approach for establishing EP requirements for SMR designs. Development of the approach considers the possibility of multiple reactors being located at the same site.

1.2 Background

Nuclear power plant licensees have been required to have procedures for coping with radiological emergencies since 1958. However, specific offsite EP requirements had not been established before the 1979 accident at Three Mile Island. In 1962, 10 CFR 100 was published requiring licensees to derive a Low Population Zone (LPZ), for which protective actions could be taken for residents. In 1978, NUREG-0396, “Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants" established a plume exposure pathway EPZ of about 10 miles and an ingestion exposure pathway EPZ of about 50 miles. These were shortly thereafter incorporated into 10 CFR 50, Appendix E. Reactors with an authorized power level less than 250 MW thermal and gas-cooled reactors were exempt from this determination and treated on a case-by-case basis.

Consideration of issues regarding smaller reactors is not new to the NRC. In 1997, NRC conducted an “Evaluation of Emergency Planning for Evolutionary and Advanced Reactors” to determine whether simplification of existing EP requirements for evolutionary and advanced reactor designs was technically defensible (SECY 97-020, 1997). Staff reviewed the rationale, criteria, and methods that form the EP basis for currently licensed reactor designs as discussed in NUREG-0396 and then evaluated whether improved safety features of evolutionary and passive advanced light water reactor (LWR) designs may warrant changes in the technical criteria or methods and, hence, the EP requirements for these designs. The staff determined that the EP rationale for current reactor designs is also appropriate for evolutionary and passive advanced LWR designs. This rationale is based on potential consequences from a spectrum of accidents. This included changes to EP requirements if the associated technical criteria 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 (SECY 97-020, 1997).

In 2010, staff again considered potential issues related to small reactors and in SECY 10-0034, "Potential Policy, Licensing, and Key Technical Issues for Small Modular Nuclear Reactors," identified a number of potential policy and licensing issues that were centered on the implementation of the Defense-in-Depth Philosophy for Advanced Reactors (SECY 10-0034, 2010). These issues include the following.

- The need to establish appropriate bounding source terms for high-temperature, gas-cooled reactors and other SMRs.
- Some SMR designs may use multiple modules at one site, but current regulations do not address the possibility of more than two reactors being controlled from one control room.
- Other potential SMR policy issues include the possible need for requirements on control room staffing during refueling operations, reactor staff who interact with an interconnected manufacturing plant, as well as supervisory, shift work, and training staff.

A fundamental element of the emergency response planning for reactors and other nuclear facilities is the use of PAGs. In 1992, the EPA published the "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," referred to as the PAG Manual, providing dose limits for use in determining protective actions (EPA, 1992). The PAG Manual is referenced in NUREG 0654/FEMA REP-1, Rev.1 as the basis for emergency response. The EPA updated this document in 2017.

The size and shape of the recommended EPZs were only partially based on consideration of the PAG values and a principle additional basis was that the planning zone for evacuation and sheltering should be large enough to accommodate any urban and rural areas affected (EPA, 1992). The PAG Manual notes that the 10-mile EPZ for the early phase is large enough to avoid exceeding the PAGs for the early phase at the boundary for low-consequence nuclear reactor core melt accidents and to avoid early fatalities for high consequence nuclear reactor core melt accidents.

PAGs are expected to be used for planning purposes and should not be regarded as dose limits (EPA, 1992) because situations could occur where impediments to evacuation or sheltering exist. The PAG is expressed as a range of 1 to 5 rem; however, EPA emphasized in the PAG Manual that under normal conditions, evacuation of the general population should be initiated for most incidents at projected doses of 1 rem. Sheltering should always be implemented when evacuation is not carried out (EPA, 1992). In Table 2-1, "PAGs for the Early Phase of a Nuclear Incident," of the PAG Manual a range of 1 to 5 rem is provided for the evacuation PAG. The PAG Manual emphasizes that the PAG is calculated for the early phase of the accident and assumes that within 4 days after the incident the population would be protected. If PAGs cannot be exceeded offsite an EPZ does not need to be established (EPA, 1992).

2. EXISTING APPROACH TO EMERGENCY PLANNING

A review of the approach to licensing existing nuclear facilities was conducted to understand and identify common aspects or differences in licensing among facility types. A review was completed of existing requirements for the following licensed nuclear facility types:

- Large power reactors,
- Small power reactors,
- Material facilities,
- Fuel facilities,
- Independent spent fuel storage installations (ISFSIs), and
- Research and test reactors.

The review included existing regulations, guidance documents, regulatory guides, Commission policy documents, technical documents, and other information related to EP for these facilities. The common elements of the EP guidance and requirements were identified for the facilities and a comparison made to understand any differences.

2.1 Power Reactors

The Atomic Energy Commission (AEC) published 10 CFR 100, "Reactor Site Criteria," which provided that an exclusion area, LPZ, and population center distance be established around nuclear power plants. These zones are to be established following the methods provided in the Technical Information Document 14844 (TID-14844) "Calculation of Distance Factors for Power and Test Reactor Sites" (AEC, 1962). As provided in 10 CFR 100.11, "Determination of exclusion area, low population zone, and population center distance," an applicant for a construction permit must determine, among other things:

- An exclusion area of such size that an individual located at any point on its boundary for two hours immediately following onset of the postulated fission product release would not receive a total radiation dose to the whole body in excess of 25 rem or a total radiation dose in excess of 300 rem to the thyroid from iodine exposure.
- A low population zone of such size that an individual, if exposed to the radioactive cloud resulting from the postulated fission product release (during the entire period of its passage), would not receive a total radiation dose to the whole body in excess of 25 rem or a total radiation dose in excess of 300 rem to the thyroid from iodine exposure.
- A population center distance of at least 1 and 1/3 times the distance from the reactor to the outer boundary of the low population zone. In applying this guide, due consideration should be given to the population distribution within the population center. Where very large cities are involved, a greater distance may be necessary because of total integrated population dose considerations.

10 CFR 100(a) states that as an aid in evaluating a proposed site, an applicant should assume a fission product release from the core, the expected demonstrable leak rate from the containment and the meteorological conditions pertinent to the site to derive the above. The fission product release assumed for these calculations should be based upon a major accident, hypothesized for purposes of site analysis or postulated from considerations of possible accidental events, that would result in potential hazards not exceeded by those from any accident considered credible. Such accidents have generally been assumed to result in substantial meltdown of the core with subsequent

release of appreciable quantities of fission products. Where multiple reactor facilities are to be constructed on one site, 10 CFR 100.11(b) states the following:

- If the reactors are independent to the extent that an accident in one reactor would not initiate an accident in another, the size of the exclusion area, low population zone and population center distance shall be fulfilled with respect to each reactor individually. The envelopes of the plan overlay of the areas so calculated shall then be taken as their respective boundaries.
- If the reactors are interconnected to the extent that an accident in one reactor could affect the safety or operation of any other, the size of the exclusion area, low population zone and population center distance shall be based upon the assumption that all interconnected reactors emit their postulated fission product releases simultaneously. This requirement may be reduced in relation to the degree of coupling between reactors, the probability of concomitant accidents and the probability that an individual would not be exposed to the radiation effects from simultaneous releases. The applicant would be expected to justify to the satisfaction of the Commission the basis for such a reduction in the source term.
- The applicant is expected to show that the simultaneous operation of multiple reactors at a site will not result in total radioactive effluent releases beyond the allowable limits of applicable regulations.

TID-14844 was developed to provide reference information and guidance on procedures and basic assumptions for the calculation of distance requirements for reactor sites (TID-14844, 1962). TID-14844 established a method of computing distances and exposures for one general class of reactors and explained that conservative assumptions were intentionally selected.

2.1.1 Large Power Reactors

In 1970, explicit requirements for plans to cope with emergencies were published in 10 CFR 50, Appendix E. NRC guidance in 1974 described it as reasonable to consider potential consequences of accidents of severity up to and including the most serious design basis accident analyzed for siting purposes (NRC, 1978). In 1975 guidance requested applicants provide plots showing doses for individuals resulting from the most serious design basis accident analyzed in the Safety Analysis Report for the purpose of showing conformance to the siting dose criteria of 10 CFR Part 100 (NRC, 1978).

The existing technical basis for the EPZ is contained in NUREG-0396 which was developed by a joint NRC/EPA task force (NRC, 1978). NUREG-0396 contains projected dose levels and associated probabilities that are based on the accident frequencies and consequences of severe accidents from WASH-1400, which was published in 1975. WASH-1400 was the first light water reactor probabilistic risk assessment performed in the United States and reflects the perspectives and state of knowledge of severe accidents that existed in the early 1970s. The Task Force considered various rationales for establishing a planning basis; including risk, probability, cost effectiveness, and consequence spectrum. They chose to base the rationale for the planning basis on a spectrum of consequences, tempered by probability considerations. The Task Force decided that the consequences of a spectrum of accidents should be the principal rationale behind the planning basis (NRC, 1978). For purposes of the calculations, it was assumed that the dose of any individual would be limited to that of the first 2 hours after the accident (NRC, 1978). Figure I-11, "Conditional Probability of Exceeding Whole Body Dose Versus Distance," of NUREG-0396 showed that the probability of large doses drops off substantially at about 10 miles from the reactor supporting the basis for establishing a 10-mile plume exposure pathway EPZ.

The analysis in NUREG-0396 of the design basis accident (DBA) loss of coolant accident (LOCA) concluded that the PAG plume exposures of 25 rem thyroid and 5 rem whole body would not be exceeded beyond 10 miles for any site analyzed, and even under the most restrictive PAG plume exposure values of 5 rem (child) to the thyroid and 1 rem whole body over 70 percent of the plants would not require any consideration of emergency response beyond 10 miles. For the ingestion pathways, under the same DBA-LOCA conditions, the downwind range within which a PAG of 1.5 rem thyroid could be exceeded would be limited to within 50 miles even under the conservative assumptions. The 50-mile distance was justified as a maximum ingestion planning distance because likely significant wind shifts within this distance would further restrict the radius of the spread of radioactive material (NRC, 1978).

The Task Force determined that the following three elements needed to be considered in establishing requirements for EP (NRC, 1978):

- The distance to which planning for the initiation of protective actions is warranted – where the Task Force stated that the most important guidance for planning officials is the distance from the nuclear facility for which predetermined actions should be carried out.
- The time dependent characteristics of potential releases and exposures – where the Task Force concluded that EP requirements should be based on releases that may start as early as 30 minutes following the initiation of an event; and
- The kinds of radioactive materials that can potentially be released to the atmosphere – where the Task Force concluded that emergency plans should focus on the release of gaseous materials and volatile solids.

To establish the distance to which planning for the initiation of protective actions is warranted, as described in item 1 above, information from items 2 and 3 are needed. Currently this level of detailed information is not available for SMRs.

NUREG-0396 used the state of knowledge of severe accidents and the prevailing view on risk that existed at that time. Current policy supports risk informed applications, which have since been developed and are routinely applied, such as the use of advanced consequence models, updated source terms, and advancements in the knowledge of accident progression.

2.1.2 Small Power Reactors

Some of the very first reactors constructed were small reactors, such as the General Electric Vallecitos plant licensed in 1957. These reactors were designed and built prior to modern EP but did recognize the need for and established a technical basis for developing distances for the exclusion zone. Siting criteria described in the 1950 WASH-3, established that an exclusion radius around a plant should be maintained. The distance was determined based on the equation:

$R = 0.01 \sqrt{P}$: where R is in miles and P is in reactor thermal power in kilowatts (kW).

For a 50 MWt reactor, the equation provides an exclusion distance of about 2 miles; however, for a 3,000 MWt reactor the exclusion radius would be more than 17 miles. Using TID-14844 analytical method results in an exclusion area distance of 0.21 miles for a 50 MWt reactor which is considerably less than the earlier WASH-3 guidance.

Around this time period, the AEC developed and published 10 CFR 100, "Reactor Site Criteria," which provided that an exclusion area, LPZ, and population center distance be established around nuclear power plants. NUREG-0396 later provided the basis for establishing a plume exposure pathway EPZ of about 10 miles and an ingestion exposure pathway EPZ of about 50 miles. Smaller reactors and gas-cooled reactors were exempt by regulation with 10 CFR 50.33 and 10 CFR 50 Appendix E which provide that the size of the EPZ may be determined on a case-by-case basis for gas-cooled nuclear reactors and reactors with an authorized power level less than 250 MWt. A list of commercial nuclear power reactors formerly licensed to operate and now permanently shut down was obtained from the NRC 2009-2010 Information Digest (NRC, 2009) and selected reactors are identified in Table 3.

Table 3: Decommissioned Licensed Reactors

#	Unit	Type[3]	Location	MW(t)	OL Issued	Shut Down	Comment
1	Big Rock Point	BWR	Charlevoix, MI	240	05/01/64	08/29/97	General Electric
2	Fermi 1	SCFR	Progress Newport, MI	200	05/10/63	09/22/72	Combustion Engineering Prototype fast breeder
3	Fort St. Vrain	HTGR	Platteville, CO	842	12/21/73	08/18/89	General Atomics
4	GE VBWR	BWR	Sunol, CA	50	08/31/57	12/09/63	GE Vallecitos BWR[4]
5	NS Savannah	PWR	Baltimore, MD	74	08/65	11/70	B&W First nuclear cargo/passenger ship.
6	Humboldt Bay[5]	BWR	Eureka, CA	200	08/28/62	07/02/76	General Electric
7	La Crosse	BWR	Genoa, WI	165	07/03/67	04/30/87	Allis Chalmers[3]
8	Pathfinder	BWR	Sioux Falls, SD	190	03/12/64	09/16/67	Allis Chalmers
9	Peach Bottom 1	HTGR	Delta, PA	115	01/24/66	10/31/74	General Atomics
10	General Electric	ESR	Sunol, CA	17	11/12/63	02/01/67	ESADA[6] Vallecitos Experimental Superheat
11	Saxton	PWR	Saxton, PA	23.5	11/15/61	05/01/72	Westinghouse

All but two of the reactors in Table 3 were shut down before the publication of NUREG-0396 in 1978, which first provided a general definition of the EPZ for large nuclear power plants. A few of these reactors are discussed in greater detail below in order to understand an example of each reactor type.

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[3] BWR – Boiling Water Reactor; ESR – Experimental Superheat Reactor HTGR – High Temperature Gas-cooled Reactor; PWR – Pressurized Water Reactor; SFR – Sodium-cooled Fast Reactor

[4] First privately owned NPP to deliver significant quantities of electricity to an electric utility.

[5] Built to demonstrate viability of peacetime nuclear power

[6] Empire States Atomic Development Associates

Fort St. Vrain

Fort St. Vrain was a high temperature gas cooled reactor (HTGR) designed by General Atomics, and built and operated near Platteville, Colorado (see Figure 1). The plant was completed in December 1973, achieved criticality for the first time on January 31, 1974, and began commercial operation on July 1, 1979 (FSAR, Rev.7). Fort St. Vrain used a fuel consisting of coated uranium-235 and thorium particles encased in a graphite matrix and molded into rods which were inserted into hexagonal graphite blocks (GAO, 1987) in a fashion very similar to current designs for prismatic HTGR's. The reactor was cooled by pressurized helium gas, while the graphite acted as a moderator. At full power the reactor had a thermal output of 842 MWt, and a net electrical output of 330 MWe, considerably smaller than commercial LWR's (FSAR, Rev.7). During its operation, Fort St. Vrain was the only commercial reactor of its type in the U.S.

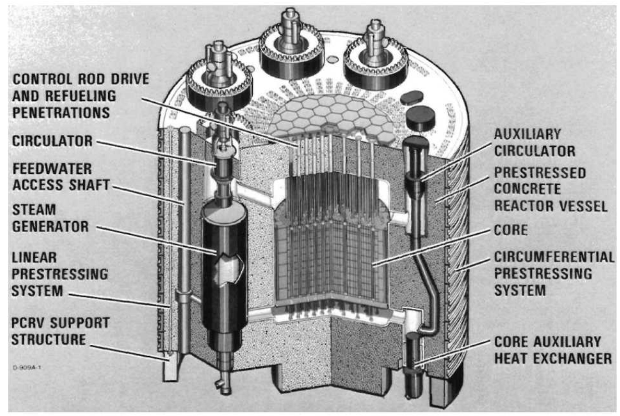

Figure 1: High Temperature Gas-cooled Reactor

As a one-of-a-kind reactor, Fort St. Vrain presented several licensing issues to the NRC, including in the area of emergency planning. The NRC approved the radiological emergency response plan which included six centers for the emergency response organization. These included the control room, technical support center, and personnel control room within the facility boundary, and a forward command post, executive command post, and state emergency operations center outside the boundary (GAO, 1987). The LPZ was established as 10 miles (FSAR, Rev.7), and a 5-mile plume exposure pathway EPZ and a 30-mile ingestion EPZ were established (NRC, 1980).

Big Rock Point

Big Rock Point was a direct-cycle, forced circulation BWR designed by General Electric and built in Charlevoix County, Michigan. The plant achieved criticality for the first time on September 27,1962 and began commercial operation on March 29, 1963. Big Rock Point was a small reactor (240 MWt, 75 MWe), built to show the feasibility of large-scale nuclear power generation. The reactor produced Cobalt-60 for the medical industry from 1971 to 1982 (NRC, 1996a).

Big Rock Point had an exclusion distance of 0.51 miles, an LPZ of 2.5 miles (NRC, 1996a), and an EPZ of 5 miles. The calculations for the EPZ in "Calculations Relating to the Establishment of Primary Emergency Planning Zone (EPZ) Radius of Five Miles for the Big Rock Point Plant," establish the basis for the 5-mile EPZ (CPC, 1980). The calculation showed that at 5 miles doses under severe meteorological conditions remain below required limits. For this calculation, the dose was integrated over a 24-hour period and represented a maximum dose that could be incurred if the public were not evacuated. In 1997, it was determined that it was no longer economically feasible to continue to operate Big Rock Point, and the reactor was shut down.

La Crosse

La Crosse was a direct-cycle, forced circulation BWR built in Vernon County, Wisconsin and jointly funded by the Dairyland Power Cooperative and the AEC. Built in 1967, the La Crosse was part of an AEC project to demonstrate the peacetime use of nuclear power. As a demonstration plant, it had a low power output of 165 MWt and 50 MWe. In correspondence between NRC and FEMA, dated April 10, 1987, NRC describes that FEMA and the NRC jointly agreed that a 5-mile EPZ for the La Crosse plant was appropriate because the authorized power level was less than 250 MWt.

La Crosse was shut down permanently on April 30, 1987, after it was determined that it was no longer economically feasible to continue operation. Spent fuel from the reactor is currently stored on site in the spent fuel pool, with plans to transfer it into an onsite ISFSI at a later date (NRC, 2010).

N.S. Savannah

In addition to the above small reactors, the process for establishing the EP areas for the N.S. Savannah was also reviewed. The N.S. Savannah is currently docked in the Baltimore Harbor and the reactor is no longer operational. When it was in operation, calculations were performed whenever the ship would port at different locations around the world and effects of a maximum credible accident (MCA) were evaluated. The N.S. Savannah Technical Specifications and Port Operation Criteria, Revision 5 (FAST, 1969) provided the equations and basis to establish a controlled zone, LPZ, dense population zone, two--hour zone and 24-hour zone.

The controlled zone was the area defined by fences, oceanfront, bays, or other barriers either natural or manmade, in which all persons were under the direct control of the ship's personnel and local authorities. In the event of an MCA, evacuation could be affected in a graded fashion so that no member of the public inside the controlled zone would receive an exposure exceeding a 25 rem whole body dose or a 300 rem thyroid dose (FAST, 1969). An LPZ was defined as the area in which it was reasonable to expect that in the event of the occurrence of the MCA total evacuation or protective measures could be carried out in a graded fashion within 24 hours so that no person in the zone would receive more than a 25 rem whole body dose or a 300 rem thyroid dose. This criterion is consistent with the LPZ identified in 10 CFR 100.11. A dense population zone, two--hour zone, and 24-hour zone were also established with each port. Equations were provided in the Port Operation Criteria for the dose calculations along with dose distance curves. The Port Operation Criteria specified that the ship shall not be moored at any location unless calculations showed that the 24-hour zone was completely within the low-population zone (FAST, 1969).

2.2 Fuel Facilities and Material Facilities

The review of fuel and material facilities included NRC guidance documentation, standard review plans, NUREGs, and the Response Technical Manuals (RTMs) for the Paducah (RTM, 1997) and Portsmouth (RTM, 2007) uranium enrichment facilities. For these types of facilities, 10 CFR 70.22 requires that an evaluation showing that the maximum dose to a member of the public offsite due to a release of radioactive materials would not exceed 1 rem effective dose equivalent.

The Paducah Gaseous Diffusion Plant emergency preparedness plan describes the onsite and offsite support expected in response to an emergency at the facility. Onsite emergency response facilities include an Emergency Operations Facility (EOF) and a Central Control Facility used to maintain surveillance and control of operations processes, conduct incident assessment and mitigation, and initially direct protective actions. An onsite Emergency Operations Center (EOC) is also established for coordinating onsite response and mitigation and offsite interface activities. A 2-mile immediate Notification Zone is also described (RTM, 1997).

The Portsmouth Gaseous Diffusion Plant emergency preparedness plan describes the onsite and offsite support expected in response to an emergency at the facility. Onsite emergency response facilities include an EOF, and a Plant Control Facility used to maintain surveillance and control of operations processes, conduct incident assessment and mitigation, and initially direct protective actions. An onsite EOC is also established for coordinating onsite response and mitigation and offsite interface activities. A 2-mile immediate Notification Zone and a 5-mile EPZ are described (RTM, 2007).

NUREG 1140, "A Regulatory Analysis on Emergency Preparedness for Fuel Cycle and Other Radioactive Material Licensees," (NRC, 1988) provides a detailed analysis of emergency preparedness for nuclear facilities and was conducted to consider whether additional emergency preparedness requirements should be imposed on certain fuel cycle facilities and other material licensees. The study found that accidents at fuel cycle and other radioactive material licensees pose a very small risk to the public. Serious accidents are infrequent and would generally involve relatively small radiation doses to a small number of people located in small areas.

NUREG 1140 discusses the criterion for deciding whether an accident is significant. The criterion is if a release causes a person outside the plant on the plume centerline to receive an effective dose equivalent of more than 1 rem, a thyroid dose of more than 5 rem, or an intake of soluble uranium exceeding 2 mg (NRC, 1988). One rem whole body or 5 rem thyroid are at the lower end of the EPA PAGs. The NUREG 1140 study identified 64 licensees authorized to possess quantities of radioactive materials for which an accident release could cause doses exceeding 1 rem effective dose equivalent, 5 rem thyroid, or intake of 2 mg of soluble uranium. The study explains that the approach was conservative because some of these licensees do not actually possess all the materials authorized by the license (NRC, 1988). It was found that for most of these licensees the degree of hazard is small and that the maximum doses for even the most severe postulated accidents are only a few rem. The areas within which people should take protective actions (less than a square mile for most licensees) typically contain a small population.

The review of NUREG 1140 supported the SMR review because the study was developed to identify accidents that might result in radiation doses to the public exceeding EPA PAGs. Doses were calculated using a slightly modified version of the CRAC2 (now MACCS version 4.0) computer code (NRC, 1988). CRAC2 did not calculate radioactive decay for material held up in a building before release. A separate correction factor was developed to account for radioactive decay before release to the atmosphere. The rupture of a heated 14-ton cylinder of UF_6 at a fuel cycle facility was determined the most hazardous to people offsite. The analysis found that under typical conditions, transient effects might occur as far away as 1 mile. The 1-mile evacuation area suggested for the rupture of a 14-ton cylinder of UF_6 was determined appropriate for protection against both uranium and UF_6.

Fuel fabrication plants generally receive UF_6 enriched in the uranium-235 isotope, convert it into highly refractory uranium oxides, form the uranium oxides into pellets, and load the pellets into metal-clad fuel elements for shipment to nuclear power plants. In most cases the uranium-235 is enriched to less than 5 percent, but at several plants the enrichment exceeds 93 percent (NRC, 1988). NUREG 1140 describes that using reasonable assumptions, coupled with conservative model input parameters, effective dose equivalents of 1.5 to 2.6 rem were calculated at 100 m and compared to the EPA PAGs of 1 to 5 rem. For the release of 540 kg of low-enriched UF_6, lethal intakes offsite do not seem plausible (NRC, 1988), and there would be no observable effects at 400 m for typical meteorology. In keeping with policy on nuclear power plant emergency preparedness, avoiding fatalities and serious health effects for worst case and protective action guide doses for more probable events, a response distance of roughly 400 m was recommended (NRC, 1988).

The extensive review of fuel cycle facilities and other material licensees conducted for NUREG 1140 was based on tools in use at the time, including the CRAC2 model. The assumptions used were conservative and a risk informed approach was not applied.

2.3 Independent Spent Fuel Storage Installations (ISFSI)

An independent spent fuel storage installation (ISFSI) is a facility for interim storage of spent nuclear fuel; solid, reactor-related, greater than Class C waste; and other associated radioactive materials. ISFSIs include those facilities located at an operating reactor sites and those at an away-from-reactor location. Generally, the away-from-reactor locations are at the site of a decommissioned reactor, and the only facility present at the former reactor site is the storage pad of the ISFSI.

A general license allows a nuclear power plant licensee to store spent fuel in NRC approved spent fuel casks at a site that is licensed to operate a power reactor under 10 CFR 50. The NRC reviews dry spent fuel storage casks and, if technically adequate, a Certificate of Compliance is issued for 20 years. The analysis considers earthquakes and tornados and a review of the security, quality assurance, training and radiation protection programs. ISFSIs that are co-located with an operating reactor site may share the emergency plan with the licensed reactor; however, the impacts of the ISFSI operation must be assessed to ensure that there is no decrease in overall effectiveness of the emergency plan.

Regulatory Guide 3.48, "Standard Format and Content for the Safety Analysis Report for an Independent Spent Fuel Storage Installation" (NRC, 1989) provides an outline and specific guidance regarding the information to be included in an applicant's safety analysis report (SAR). NUREG-1567, "Standard Review Plan for Spent Fuel Dry Storage Facilities," is intended to ensure the quality and uniformity of the NRC staff reviews and addresses emergency planning which must comply with 10 CFR 72.32(a) (NRC, 2000). An emergency plan must include information on the 12 items identified in the regulation. These 12 items are very consistent with the 16 planning standards in 10 CFR 50.47(b).

For a monitored retrievable storage (MRS) or an ISFSI that may process or repackage spent fuel, the emergency plan must comply with 10 CFR 72.32(b). From 10 CFR 72.106, the regulatory requirement for the controlled area for an ISFSI or MRS is:

> "Any individual located on or beyond the nearest boundary of the controlled area shall not receive a dose greater than 5 rem to the whole body or any organ from any design basis accident. The minimum distance from the spent fuel or high-level radioactive waste handling and storage facilities to the nearest boundary of the controlled area shall be at least 100 meters."

2.4 Research and Test Reactors (RTRs)

NRC Regulatory Guide 2.6, "Emergency Planning for Research and Test Reactors," (NRC, 1983) provides the regulatory background, NRC staff position, and acceptance criteria for complying with applicable requirements. Regulatory Guide 2.6 states that the requirements in ANSI/ANS 15.16, "Emergency Planning for Research Reactors," are generally acceptable to NRC staff for complying with the requirements in 10 CFR 50.54 and Appendix E, "Emergency Planning and Preparedness for Production and Utilization Facilities," of 10 CFR Part 50 that are related to research and test reactors (NRC, 1983).

NUREG-0849, "Standard Review Plan for the Review and Evaluation of Emergency Plans for Research and Test Reactors," (NRC, 1982) provides ten planning standards corresponding to the guidance criteria in ANSI/ANS 15.16 (ANSI, 2008). These 10 planning standards are similar to the 16 planning standards in Appendix E to 10 CFR Part 50 for commercial nuclear power reactors. With regard to emergency classification, the four emergency classification levels identified in Appendix E to 10 CFR Part 50 (Unusual Event, Alert, Site Area Emergency, and General Emergency) are applicable to RTRs. However, because the potential radiological release from an RTR is highly unlikely and very small, RTRs do not use the General Emergency classification of radiological accidents.

Due to the low power level, small amount of radioactivity in the core, and required safety features, the risk from RTR facilities is small. NUREG-0849 specifies EPZs designed to prevent radiological doses to the general public exceeding the PAGs of 1 rem whole body or 5 rem thyroid and explains that acceptable EPZs are a function of the steady-state thermal power of the reactor. The EPZs range in size from the operations boundary for reactors having power levels less than or equal to 2 megawatts, to 800 meters for reactors up to 50 megawatts. ANSI/ANS 15.16-2008 states that if emergency planning identifies radiological emergencies that result in offsite plume exposures exceeding 1 rem whole body or 5 rem thyroid, then an EPZ shall be identified. The size of the EPZ depends upon the distance at which protective actions are calculated to be warranted. As an alternative to performing calculations, EPZ sizes based on power level may be adopted as provided in ANSI/ANS 15.16-2008, Table 4 below. ANSI/ANS 15.16-2008 states that these EPZ sizes are based on very conservative dose calculations using the Reactor Safety Study, (WASH-1400) source term generally applicable to research reactors.

Table 4: Alternate method for determining the size of an EPZ from ANSI/ANS 15.16-2008

Authorized power level	Acceptable EPZ size
≤ 2 MW	Operations boundary
> 2 MW and ≤ 10 MW	100 m
> 10 MW and ≤ 20 MW	400 m
> 20 MW and ≤ 50 MW	800 m
> 50 MW	Will be determined on a case-by-case basis

2.5 Summary of Existing Approach to Emergency Planning

Review of EP regulations and guidance for existing nuclear facilities shows that the approach to licensing across different facility types is consistent. Early power reactors, RTRs, and other nuclear facilities established the exclusion areas based upon potential exposure to the public from radioactive releases. 10 CFR 100.11 establishes the Exclusion Area and LPZ and references TID-14844 as an analytical approach for these calculations. License applications for each of the types of facilities are subject to review against a Standard Review Plan. The review provided the following information for consideration in developing EP for SMRs:

- Large Power Reactors: An exclusion area is established of such size that an individual located at any point on its boundary for two hours immediately following onset of the postulated fission product release would not receive a total radiation dose to the whole body in excess of 25 rem or a total radiation dose in excess of 300 rem to the thyroid from iodine exposure. The EPZ was established in NUREG 0396 as about 10 miles based on the potential dose to the public (NRC, 1978).
- Small Power Reactors: The EPZs for Fort St. Vrain, Big Rock Point, La Crosse were each established at 5 miles. For the N.S. Savannah, an LPZ was defined as the area in which total evacuation or protective measures could be carried out in a graded fashion within 24 hours so that no person in the zone would receive more than a 25-rem-whole-body dose or a 300-rem-thyroid dose. These are the same dose limits established for the large power reactor exclusion area.
- Fuel and Material Facilities: The criterion for deciding whether an accident is significant is whether a release could cause a person outside the plant on the plume centerline to receive an effective dose equivalent of more than 1 rem or a thyroid dose of more than 5 rem. This is an application of a dose / distance evaluation to assure exposure does not exceed EPA PAGs.
- Independent spent fuel storage installations: The regulatory requirement for the controlled area for an ISFSI is also a dose / distance evaluation where any individual located on or beyond the nearest boundary of the controlled area shall not receive a dose greater than 5 rem to the whole body or any organ from any DBA. This is consistent with the upper bound of the EPA PAGs.
- Research and test reactors: The requirements for RTRs specify that if emergency planning identifies radiological emergencies that result in offsite plume exposures exceeding 1 rem whole body or 5 rem thyroid, then an EPZ shall be identified. This requirement again applies a dose / distance methodology to assure exposure does not exceed EPA PAGs.

As indicated above, there is a consistent application of a dose / distance evaluation to assure that public exposure at the boundary of a facility does not exceed EPA PAGs. For large reactors, this is further expanded into an EPZ of about 10 miles which was based on a spectrum of accidents evaluated in NUREG-0396.

3. APPROACH FOR ESTABLISHING EP REQUIREMENTS FOR SMALL ADVANCED REACTORS

The review of the current and historical approach to licensing reactor facilities and other nuclear facilities, identified that the EPA PAGs are the primary basis in determining the limits of protective action areas. The next element of this scoping study included a review of available information for SMRs to understand elements of SMRs common or similar to the other nuclear facilities reviewed. As a first step, available information regarding the different types of SMRs was reviewed and used to consolidate reactor specific properties. Next, a comparative review was performed to qualitatively assess the effect of applying the 16 planning standards of NUREG 0654/FEMA REP-1, Rev.1 (NRC, 1980) to SMR designs.

3.1 SMR Properties

Guidance and regulation for existing reactors was reviewed along with draft SMR design information when developing an approach for the establishment of EP considerations for new reactor designs. Because there are many SMRs in the conceptual stage, common design types were binned to see if this would provide insights into potentially common or differing EP requirements. Table 5 presents a binning of SMRs.

Table 5: Small Modular Reactor Binning

Bin	Reactor / Coolant	Manufacturer / Name	Thermal Power, MW	Fuel	Moderator	Coolant	Comment
Thermal	Pressurized Water Reactor	B&W mPower	400	5% enriched UO_2	H_2O	H_2O	Conventional, but Naval Reactor Origins
		GA TRIGA	64	20% enriched UZrH	H_2O	H_2O	Pool-type
		NuScale Pwr	160	5% enriched UO_2	H_2O	H_2O	Like IRIS, natural circulation
		West IRIS	100-335	5% enr. UO_2	H_2O	H_2O	AP-1000 fuel assemblies
	Gas Cooled Thermal Reactor	AREVA ANTARES	600	TRISO	Carbon	Helium	He-Ne secondary cooling
		GT-MHR	600	TRISO	Carbon	Helium	Direct Drive Brayton cycle
		PBMR, Inc PBMR	200	TRISO	Carbon	Helium	6 cm fuel spheres
		NGNP VHTR	300	Coated Particle	Carbon	Helium	Higher temperature
Fast	Sodium Cooled Fast Reactor	Toshiba 4S	30	19% enriched UZr	NA	Sodium	
		GE Hitachi	840	Pu/DU metal	NA	Sodium	Pyroprocessing

	Other Liquid Metal Cooled Fast Reactors	Hyperion PWR Generation HPG Module	70	< 20% enriched UN	NA	Pb-Bi	DOE/SRS demonstration
	Gas Cooled Fast Reactor	ANL STAR GFR	300	UN	NA	Pb-Bi	Replaceable fuel cartridge

Two bins were established representing Thermal and Fast reactors. When neutrons produced by fission are ejected at energies of about 1 MeV, which corresponds to a velocity of about 10,000 miles per second, they are referred to as fast neutrons. The fast systems consist of the liquid metal and gas-cooled reactors, the latter of which can be operated at a temperature high enough to directly drive a gas turbine.

Fast reactors do not have neutron moderator materials found in thermal reactors to maintain the fission chain reaction and require higher enrichment fuels, but because the actinides are fissionable with fast neutrons, fast spectrum systems have the potential to generate less long-lived transuranic waste.

The neutrons are absorbed by either fission capture by another fissionable atom causing further fission, or by non-fission capture by the fuel, coolant, moderator or structural materials. Before the neutrons are absorbed, most lose some of their energy by either elastic or inelastic collisions with atomic nuclei. After many collisions, the neutrons slow down to energies of about 0.025 MeV, which corresponds to the gas molecule velocity due to thermal effects and are then termed thermal neutrons.

The thermal reactors are comprised of the light water systems, consisting of the common boiling and pressurized water reactors, and the gas-cooled prismatic and pebble bed spherical fuel designs. Thermal neutrons have a higher fission cross section for fissioning fissile uranium-235 nuclei and a relatively lower capture cross section for absorbing fertile uranium-238 nuclei, as compared to the faster neutrons originally resulting from fission. Most current reactors have thermal spectrums which allow utilization of low and even natural enrichment fuels.

The binning process provides some confidence in the review approach to assure that different aspects of the SMR designs were considered, but it did not provide any additional insights into potential differences in EP requirements for differing reactor types.

For most of the SMRs, conceptual drawings and graphics are available, but detailed reactor design information is not available for review. Information suggests that these new reactors concepts are implementing inherent passive safety characteristics such as below ground siting, natural circulation decay heat removal, advanced fuel types, and other passive safety systems. Most of the conceptual reactor designs include burying part or all the reactor and reactor pools. This will affect the release height of the source term, which would be at or near ground level, whereas, the source term from large power reactors is typically evaluated at 10 meters. The effects of a ground level release would affect the dispersion of the plume. Buried reactor pools may have longer drainage times and correspondingly longer accident progression times. Detailed design information is needed to understand the effects of these systems with regard to accident frequency, progression, and potential consequences.

3.2 Planning Standards Comparison

The 16 planning standards of NUREG 0654/FEMA REP-1, Rev.1 (NRC, 1980) were reviewed to understand at the planning standard level whether requirements would likely be similar or different based on the reactor size. A summary of the planning standards is provided in Appendix B. The review identified that the 16 planning standards are applicable to SMRs and ONTs, although the application of some of these criteria may be affected by the size of the EPZ and other factors. A detailed review of NUREG-0654 for application to SMRs/ONTs should be completed.

4. EMERGENCY PLANNING ZONE AND COLLOCATION OF FACILITIES

The objective of this scoping study was to describe quantitatively how emergency planning has been considered for existing facilities and use this information to develop an approach for establishing EP requirements for SMRs. An approach is provided below to establish a set of standard EPZ sizes for SMRs based on the source term, reactor design, and operational characteristics.

4.1 Emergency Planning Zone – Plume Exposure Pathway

A central EP issue in the development of small reactors is the required size of the EPZ. The primary contributor to the size of the EPZ will be the projected source term, which is a product of many factors including reactor design, facility power level, fuel material and burn-up, reactor response to off-normal conditions, etc. Accident progression times and other design and operational information for SMRs are not at the detailed stage to support consequence analyses; however, it is possible to establish criteria based on offsite dose to the public, for which compliance may be demonstrated, when the design information becomes available.

A technology neutral, dose specific criteria could be applied, using the EPA PAG of 1 rem as a threshold, to establish a set of standard EPZ distances for SMRs. The EPA PAG is the projected dose over the early phase of the accident (4 days from the start of release). Table 2-1 of the EPA PAG provides projected dose guidelines that can be used for the projected dose during the early phase of the accident. The EPA PAGs and Protective Actions for the Early Phase of a Radiological Incident are provided in Table 6. The EPZ category is determined from the lower PAG values of 1 rem total effective dose equivalent (TEDE).

Table 6: 2017 EPA PAGs and Protective Actions for the Early Phase of a Radiological Incident[7]

Protective Action Recommendation	PAG	Comments
Sheltering-in-place or evacuation of the public[8]	PAG: 1 to 5 rem (10-50 mSv) projected dose over four days	Evacuation (or, for some situations, sheltering-in-place) should be initiated when projected dose is 1 rem (10 mSV)

When trying to determine an EPZ category for a SMR or ONT, analysts should assume normal activity for the population surrounding the site. No type of protective action should be applied, i.e. sheltering-in-place, or evacuation.

There are areas within consequence analyses where uncertainty enters the system, such as site characteristics (e.g., building wake, terrain effects, weather, etc.), source term, release timing, etc. The uncertainty makes it inappropriate to establish a precise boundary of an EPZ based solely on a 1 rem dose threshold, and such an approach would imply that consequence results are more precise than should be interpreted. An approach that uses a minimum size EPZ based upon the dose threshold appears reasonable.

7 Table does not reflect EPA guidance regarding the supplemental administration of prophylactic drugs such as KI.

8 Should begin at 1 rem (10 mSv) if advantageous except when practical or safety considerations warrant using 5 rem (50 mSv); take whichever action (or combination of actions) that results in the lowest exposure for the majority of the population. Sheltering-in-place may begin at lower levels if advantageous.

Current emergency planning largely follows the guidance in Supplement 3 to NUREG-0654/FEMA REP-1, Rev.1, which suggests an initial protective action for LWRs include immediate evacuation of about 2 miles around the plant and about 5 miles downwind from the plant, unless other conditions make evacuation dangerous (NRC, 1996b). The 2- and 5-mile distances, and the 10-mile EPZ, have become standard values in emergency planning. Therefore, an approach is suggested to use the EPA PAGs as threshold criteria and 2-mile, 5-mile, and 10-mile distances, to establish four (4) EPZ categories for SMRs. An analysis of the projected dose would be needed at the site boundary and at each of the predesignated distances, within defined probability levels.

The suggested EPZ categories include:

- Category I: If the projected dose is less than 1 rem at the site boundary, no EPZ is required.
- Category II: If the projected dose is greater than or equal to 1 rem at the site boundary and is less than 1 rem at 2 miles, then the EPZ will be established as 2 miles.
- Category III: If the projected dose is greater than or equal to 1 rem at 2 miles and is less than 1 rem at 5 miles, then the EPZ will be established as 5 miles.
- Category IV: If the projected dose is greater than or equal to 1 rem at 5 miles then the EPZ will be established as 10 miles.

The above approach provides standard sizes for an SMR's EPZ based on the projected source term and reactor specific design. EPZ Categories I through IV are summarized in Table 7.

Table 7: EPZ Categories

EPZ Category	Dose Limits*	EPZ Size
Category I	Projected dose (TEDE) < 1 rem at the site boundary	No offsite EPZ required
Category II	Dose ≥1 rem at the site boundary and < 1 rem at 2 miles	Establish a 2-mile EPZ
Category III	Dose ≥ 1 rem at 2 miles and < 1 rem at 5 miles	Establish a 5-mile EPZ
Category IV	Dose ≥ 1 rem at 5 miles	Establish a 10-mile EPZ

*Dose limits may also include a CDE to the thyroid for each category.

Use of the EPA PAG values provide a defensible basis for using a dose / distance criterion. The PAGs would be used for planning purposes, not to be regarded as dose limits, because situations could occur where impediments to evacuation exist (EPA, 1992). Therefore, consistent with the development of EPZs for large power reactors, the dimensions in Table 7 should be considered as 'about 2 miles' and 'about 5 miles.' The actual dimensions of the EPZ should consider local features to define the EPZ boundary, such as rivers/waterways, roadways, jurisdictional boundaries, population areas, etc.

4.2 Emergency Planning Zone – Ingestion Pathway

The source terms for SMRs are smaller and may, following the above process, have a smaller plume exposure pathway EPZ or no EPZ if the offsite projected dose would not exceed the EPA PAG. It may be expected that the ingestion pathway EPZ would be correspondingly smaller. The ingestion pathway EPZ for large reactors is established as 50 miles where potential exposure would be from ingestion of contaminated water or foods. The duration of the ingestion exposure could range from hours to months and represents a longer-term problem (NRC, 1980).

Determination of the size of a SMR ingestion pathway EPZ may involve a graded approach because the source terms are smaller and ingestion represents a longer-term problem. There has been considerable experience with the expedient large-scale quarantine of foods in the United States in response to contamination outbreaks of E. coli, Salmonella, and bovine spongiform encephalopathy (mad cow disease), etc.. The successful quarantine and removal from public access of contaminated products in response to outbreaks suggests that an ad hoc approach may be appropriate in response to an accident with a release to the environment. Analyses would be expected to demonstrate that SMRs determined to warrant smaller plume exposure pathway EPZs (based on Table 1) would also warrant a smaller ingestion pathway EPZs. For SMRs where the EPZ is determined to be 5 miles or less, it is likely that the size of an ingestion pathway area would be small enough to be manageable on an ad hoc basis.

4.3 Collocation of Facilities

A key benefit of the SMR concept is the ability to manufacture and then construct modules when there is a need for additional capacity. The commercial benefits to this approach are understood; however, detailed SMR design information is not available to fully define the effects this may have on EP. Collocating provides the potential that SMRs of the same type may be located together or with large reactors, at industrial facilities, with different SMR types, or any combination of the above.

Collocation of facilities may require additional considerations and analyses. Potential SMR collocation policy issues include the need for guidance regarding the effect of collocation on the size of the EPZ, number of control rooms, control room staffing, reactor staff who interact with an interconnected manufacturing or industrial plant, supervisory staff, shift work, and training (SECY 10-0034, 2010). Furthermore, the effects of interconnected SMRs and their integrated safety systems must be considered and defined when developing the source terms for these analyses as required under 10 CFR 100.11(b). For example, should analyses of collocated facilities include analyses of increased probabilities of an accident at that reactor due to other facilities (i.e. oil or gas facility accident affecting a collocated SMR). Detailed design information will be needed in order to fully understand the potential impacts of collocated facilities.

One suggestion for the EPZ size of a site with collocated facilities would establish the size of the EPZ for each specific reactor following the process in Figure 2. Using this approach, considerations of each reactors EPZ size and how potential accidents could affect the site should be made. For example, if an SMR and LWR are collocated and the EPZ for a SMR is encompassed by the EPZ for the LWR, the site EPZ would be the 10-mile LWR EPZ.

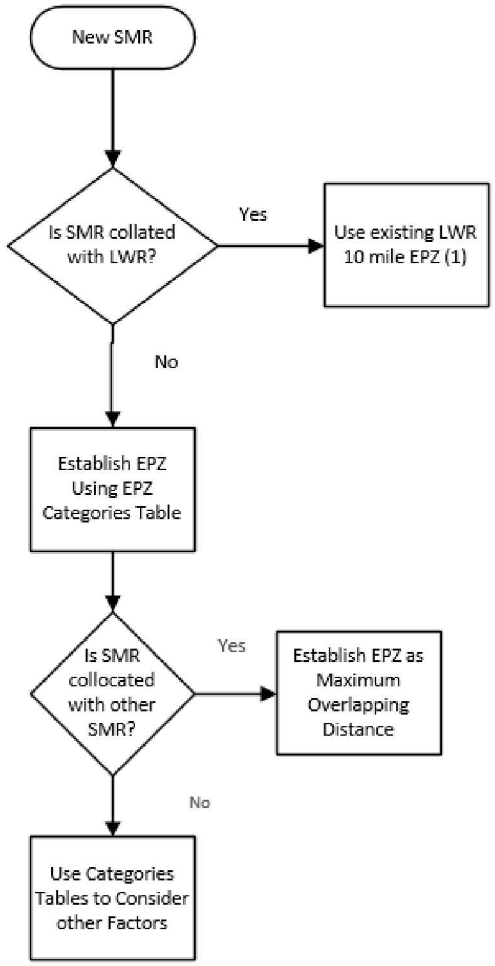

Figure 2: Process to Establish SMR EPZ

Figure 3 identifies an example site with 3 reactors (R1, R2, and R3). R1 and R2 are the same SMR design and are 0.1 miles apart and each is assumed to require a 5-mile EPZ. Because they are 0.1 miles apart, the total east/west distance of the EPZ would be the 5-mile radius of each plus the 0.1 miles for a total of 10.1 miles. Assume that R3 is a different SMR design and requires a 2-mile EPZ. R3 is located 0.1 mile south of R2. Following the process outlined above, the EPZ for R3 is the maximum EPZ size based on the reactors at the site. This process does not assume that protective actions, such as evacuation and sheltering, would be implemented to 5 miles for R3, but the EPZ would be 5 miles.

Multiple modules within one building could conceivably have one EPZ based on the largest consequence determined considering the source terms and design of the integrated systems. Details regarding the emergency planning would need to be coordinated among the facilities, and the actual implementation of protective actions should be based on the dose projections at the time of the emergency. The overlapping of EPZs and use of the larger combined area may be an issue with different reactor owners and in effect requires a larger response planning area than necessary if analyzed individually.

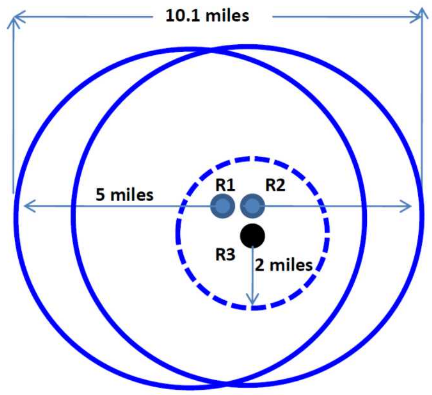

Figure 3: SMR Combined EPZs

5. SUMMARY

The review of the current and historical approach to licensing reactor facilities and other nuclear facilities provides insights into the licensing of nuclear facilities and identifies some common elements in the process. The results of this review are consistent with previous reviews of SMRs and advanced reactor designs conducted by NRC staff for SECY 97-020 and SECY 10-0034. In SECY 97-020 and SECY 10-0034, NRC staff determined that the rationale upon which EP for current reactor designs, which is based on potential consequences from a spectrum of accidents, is appropriate for use as the basis for EP for evolutionary and passive advanced LWR designs (SECY 97-020, 1997; SECY 10-0034, 2010).

This scoping study identified that all the existing nuclear facility types that were reviewed apply a dose / distance approach to establish the boundary of the EPZ (or other planning area) based on the EPA PAGs. A similar technology neutral dose / distance approach could be applied to SMRs using the EPA PAGs as threshold criteria. It is suggested that standard sizes of EPZs be set at 2, 5, or 10 miles based on a dose / distance analysis. No EPZ would be necessary where the projected dose would not exceed EPA PAGs at the site boundary.

Each type of licensed nuclear facility is subject to review under a specific Standard Review Plan. A comparison to the 16 planning standards in NUREG-0654/FEMA REP-1, Rev.1 showed that most criteria for the planning standards will likely be directly applicable to SMRs, although the application of some of these criteria may be affected by the size of the EPZ and other factors. A detailed review of NUREG-0654 for application to SMRs should be completed.

With regard to the ingestion pathway EPZ, because the source terms are smaller and ingestion represents a longer term problem (NRC, 1980), a graded approach may be appropriate. The successful quarantine and removal from public access of contaminated products in response to food contamination outbreaks suggests that an ad hoc approach may be appropriate in response to an accident with a release to the environment. For SMRs where the EPZ is determined to be 5 miles or less, it is likely that the size of an ingestion pathway area would be small enough to be manageable on an ad hoc basis.

Collocated facilities are a factor in determining the size of the EPZ. Here, an approach is suggested where the size of the EPZ would be the maximum aggregate size of the collocated facilities. If the SMR is collocated with another SMR, then the EPZ for the site is the maximum overlapping EPZ. If the SMR is collocated with an LWR, then the EPZ would be the 10-mile LWR EPZ. If the SMR is a stand-alone unit, then the EPZ is based upon the single unit characteristics. The effect of interconnected SMRs and integrated safety systems must be considered when developing the source terms for these analyses as required under 10 CFR 100.11(b).

This review documented the criteria used in the licensing process and shows that a conservative approach has been used for all types of nuclear facilities. Development of SMR guidance should consider the current state of knowledge and advancements in accident progression and consequence modeling and integrate these in a risk informed manner. Some of the suggestions herein with regard to how issues might be approached in the SMR licensing process may provide ideas for thought in the development of additional or supplemental guidance in selected areas.

There remain some key gaps that must be filled prior to final decisions regarding some EP guidance. Specifically, final design information, source term information, operational plans for fuel cycles, collocation considerations and guidance, and a spectrum of design accidents are needed.

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APPENDIX A. STANDARD REVIEW PLANS

The NRC has developed standard review plans (SRPs) for construction and operating license applications for each nuclear facility and reactor type that it regulates. This makes it possible for the SRP to address the specific features of each type of facility or reactor and their potential impact on safety while still allowing for general safety considerations across all types. A review was conducted of existing SRPs for nuclear facilities, focused on sections pertaining to emergency planning. The list of facility types reviewed includes Light Water Power Reactors, Research and Test Reactors, Fuel Cycle Facilities, and Spent Fuel Dry Storage Facilities. The main content of each is summarized below, along with a discussion of aspects unique to each facility type.

A.1. NUREG-0800 – SRP for Light Water Reactors – Section 13.3 Emergency Planning

The standard review plan for licensing of a light water reactors (NUREG-0800), Section 13.3, "Emergency Planning," is organized based on the 16 emergency planning standards found in 10 CFR 50.47. NUREG 0800 is less descriptive of specific requirements needed to meet the 16 planning standards and more of a summary and listing of supporting documentation regarding specific aspects of the emergency plans. The main document referenced is NUREG-0654/FEMA REP-1, Rev.1, which describes in detail the content of an emergency plan. The guidance for each of the 16 emergency planning standards found in 10 CFR 50.47(b) is provided in NUREG-0654/FEMA REP-1, Rev.1.

Section 13.3 describes the emergency planning information that needs to be included based on what type of application is submitted. For example, when submitting an early site permit (ESP), the applicant need only include proposed features of the emergency plan which will then require further tests or analysis to verify, while an applicant submitting a combined operating license (COL) will be required to have emergency plans which are nearly finalized. Additionally, the SRP provides emergency planning guidance for submitting an application for an additional reactor at an operating reactor site.

Section 13.3 includes a summary of important information that must be contained within an emergency plan presented below:

- The licensee must identify population distribution and physical impediments to evacuation in the 10-mile plume exposure pathway EPZ and project future populations
- Additionally, the licensee must identify population distribution and physical impediments to evacuation in the 50-mile ingestion control pathway EPZ
- An evacuation time estimate (ETE) is required
- An Alert and Notification System is required to notify public
- An emergency response data system (ERDS) is required to notify NRC
- Off-site emergency facilities must include, at the minimum, a Technical Support Center and an Emergency Operations Facility
  - Both must contain a safety parameter display system that can be used to assess the safety condition of the reactor

A.2. NUREG-0849 – SRP for Review and Evaluation of Emergency Plans for Research and Test Reactors

NUREG-0849 is a standard review plan specific to emergency plans for research and test reactors. NUREG-0849 is organized according to the 10 planning standards identified in ANSI/ANS 15.16, which in turn was endorsed by Revision 1 of Regulatory Guide 2.6.

NUREG-0849 divides research and test reactors into three power level categories (> 50W and < 100kW; ≥ 100kW and < 2 MW; and ≥ 2MW) and determines which regulations are applicable to each category. This was based on the fact that the radionuclide inventory is largely dependent on power level and operating history and an accident release cannot exceed the actual inventory.

There are a number of significant differences in emergency planning between research and test reactors and light water reactors, identified in NUREG-0849. They are summarized as follows:

- Any reactor which operates at a power level lower than 100 watts does not need to meet the emergency planning standards, although there are still some minimal requirements
- The Emergency Action Levels (EALs) which are used to define the emergency classes use slightly different dose criteria
    - For example, to declare a general emergency, NUREG-0849 uses a sustained actual or projected dose at the site boundary of 500 mrem/hr, while Appendix A to NUREG-0654 for power reactors uses a dose at the site boundary at any time of 1 rem/hr under actual meteorological conditions
- Emergency classes do not include general emergency for any reactor with a power level below 2 MW and nor generally for higher power research and test reactors as well
- An EPZ is only required if an accident scenario could result in an offsite plume exposure exceeding 1 rem whole body or 5 rem thyroid
- If required, EPZ size can be determined in two ways:
    - Appendix II of NUREG-0849 which relates the EPZ size to authorized power level
    - Individually for each reactor, as long as a sufficient technical basis is provided
- A public address system is required at the reactor site
- Emergency facilities must include, at the minimum, an emergency support center.

A.3. NUREG-1520 – SRP for Fuel Cycle Facilities

NUREG-1520 is the standard review plan for fuel cycle facilities, which are used in the conversion, enrichment, and fabrication stages of the fuel cycle. Chapter 8, titled "Emergency Management" provides key information on emergency plans. It is organized according to emergency planning standards found in Regulatory Guide 3.67 which contains the standard format and content of emergency plans (NRC, 1992).

There are a number of significant differences in emergency planning between fuel cycle facilities and reactors, as identified in Chapter 8 of NUREG-0849. They are summarized as follows:

- First, the SRP specifically states that emergency plans may not be required for all fuel cycle facilities
    - The criteria for submittal are found in 10 CFR 70.22
- The site area description must include all structures and water bodies within a 1-mile radius of the site
- Additionally, a general map out to 10 miles is required

- The EALs which are used to define the emergency classes, as found in Appendix A to Reg Guide 3.67, do not include specific dose criteria
- Emergency classes only include alert and site area emergency, because a general emergency is not expected to occur at a fuel cycle facility
- Emergency facilities must include, at the minimum, an emergency operation center and technical support center.

A.4. NUREG-1567 – SRP for Spent Fuel Dry Storage Facilities

NUREG-1567 is the standard review plan for spent fuel dry storage facilities. Section 10.4.5, titled "Emergency Planning" summarizes the requirements, and references Regulatory Guide 3.67 as containing the principle guidance on the content of emergency plans. This means that dry storage facilities must follow the same emergency planning standards as fuel cycle facilities. Section 10.4.5 contains some specific differences in emergency plan requirements for spent fuel dry storage facilities which are summarized as follows:

- Government regulations to observe when completing emergency plans are contained in 10 CFR 72.32 (as opposed to 10 CFR 70.22 for fuel cycle facilities)
- Every accident event in the safety analysis report must be specifically addressed in the emergency plans. Additionally, the facility is required to have the ability to detect accident events not identified in the SAR

APPENDIX B. NUREG-0654 PLANNING STANDARDS SUMMARY

B.1. Emergency Response Planning Standards

Planning Standard	Criteria
A. Assignment of responsibilities	Primary responsibilities for emergency response by the nuclear facility licensee and by State and local organizations within the Emergency Planning Zones have been assigned, the emergency responsibilities of the various supporting organizations have been specifically established, and each principal response organization has staff to respond and to augment its initial response on a continuous basis.
B. On-Site Emergency Organization	On-shift facility licensee responsibilities for emergency response are unambiguously defined, adequate staffing to provide initial facility accident response in key functional areas is always maintained , timely augmentation of response capabilities is available and the interfaces among various onsite response activities and offsite support and response activities are specified.
C. Emergency Response Support and Resources	Arrangements for requesting and effectively using assistance resources have been made, arrangements to accommodate state and local staff at the licensee's near-site Emergency Operations Facility have been made, and other organizations capable of augmenting the planned response have been identified.
D. Emergency Classification	A standard emergency classification and Emergency Action Level (EAL) scheme, the basis of which include facility system and effluent parameters, is in use by the nuclear facility licensee, and state and local response plans call for reliance on information provided by facility licensees for determinations of minimum initial offsite response measures.
E. Notification Methods and Procedures	Procedures have been established for notification, by the licensee, of state and local response organizations and for notification of emergency personnel by all organizations; the content of initial and follow-up messages to response organizations and the public has been established; and means to provide early notification and clear instruction to the populace within the plume exposure pathway EPZ have been established.
F. Emergency Communications	Provisions exist for prompt communications among principal response organizations to emergency personnel and to the public.
G. Public Education and Information	Information is made available to the public on a periodic basis on how they will be notified and what their initial actions should be in an emergency, the principal points of contact with the news media for dissemination of information during an emergency are established in advance, and procedures for coordinated dissemination of information to the public are established.
H. Emergency Facilities and Equipment	Adequate emergency facilities and equipment to support the emergency response are provided and maintained.
I. Accident Assessment	Adequate methods, systems, and equipment for assessing and monitoring actual or potential offsite consequences of a radiological emergency condition are in use.

J. Protective Response	A range of protective actions has been developed for the plume exposure pathway EPZ for emergency workers and the public. Consideration is given to evacuation, sheltering, and, 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.
K. Radiological Exposure Control	Means for controlling radiological exposures in an emergency are established for emergency workers. The means for controlling radiological exposures shall include exposure guidelines consistent with EPA Emergency Worker and Lifesaving Activity Protective Action Guides.
L. Medical and Public Health Support	Arrangements are made for medical services for contaminated injured individuals.
M. Recovery and Reentry	General plans for recovery and reentry are developed.
N. Drill and Exercise Program	Periodic exercises are conducted to evaluate major portions of emergency response capabilities, periodic drills are conducted to develop and maintain key skills, and deficiencies identified as a result of exercises or drills are corrected.
O. Emergency Response Training	Radiological emergency response training is provided to those who may be called on to assist in an emergency.
P. Responsibility for Planning Effort	Responsibilities for plan development and review and for distribution of emergency plans are established, and planners are properly trained.

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