Advanced Reactor Safeguards & Security

Overview of University Advanced Reactor Deployment Activities

Prepared for
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Collin McDowell[1], Azaree Lintereur[1]

[1]Los Alamos National Laboratory

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Prepared by: Collin McDowell, Intelligence Analyst
Azaree Lintereur, R&D Engineer
Los Alamos National Laboratory

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EXECUTIVE SUMMARY

The Advanced Reactor Safeguards and Security (ARSS) program within the Department of Energy Office of Nuclear Energy (DOE-NE) was established to support the domestic deployment of advanced reactors. One particular use case for advanced reactors, a category that includes microreactors, which has gained traction in recent years is siting them on university campuses as research and test reactors (RTRs). This use case would prove the utility and viability of the systems, allow for substantial research into various factors specific to advanced reactors, and educate future generations of nuclear operators. Given the interest in advanced reactor deployments on university campuses, and the relatively short deployment timeframes, due consideration must be given to both the security and material control and accounting (MC&A) approaches that will be required.

This report includes an overview of university advanced RTR deployment activities. This overview was compiled to provide a framework for assessing how current regulations could apply to university sited advanced reactors and identify areas which may require further consideration. Factors such as existing nuclear facilities and nuclear academic programs were also assessed. The compiled information illustrated that several universities are pursuing, or planning to pursue, licenses from the Nuclear Regulatory Commission (NRC) for advanced RTRs. These universities represent a diverse cross section of nuclear programs, and existing nuclear facilities. It should also be noted that there are a variety of advanced reactor technologies being considered, and the activities currently being pursued range from scoping studies to license applications.

The analysis conducted on the current state of play for university advanced RTR deployments, and areas that could benefit from engagement between the NRC and the universities, resulted in a set of recommended regulatory considerations and initial questions that should guide universities' thinking in the early stages of their planning and licensing process. These recommendations include:

- *Identify the optimal licensing approach* – License applications can be pursued under 10 CFR 50 or 10 CFR 52. Each pathway has different associated requirements and timelines.
- *Determine the applicable class of license* – The license class, either a Class 104(c) license or a Class 103 license, will depend heavily on the anticipated use case of the reactor in question.
- *Engage with the NRC throughout the planning and development process* – Early clarification should be sought regarding any regulatory issues that could result in impediments during the licensing process.
- *Perform a general regulatory review* – To ensure that the licensing process is not delayed, universities should engage in a general regulatory review to understand the regulations currently in place. These regulations address a broad swathe of factors, including, but not limited to, construction, security, MC&A, and decommissioning.
- *Perform a tailored regulatory assessment and gap analysis* – Current regulations are primarily tailored to traditional light water reactor (LWR) designs, which means that some specified

requirements for safety and security may not be applicable to the proposed advanced reactors. This gap analysis can be used to identify specific topics where input from the NRC would be required, and to guide identification of regulations that can be met by intent and where the applicant could potentially request an exemption.

- *Identify the exemptions that will be requested* – Exemptions could potentially be required for regulations that were originally written to address LWRs. Early identification of possible exemptions and close collaboration with the NRC during the submittal process will reduce the risk of delays.

- *Obtain guidance on security requirements* – Security requirements for advanced reactors may be different than for traditional RTRs. Universities should develop contingency plans in case the on-site security that has previously been retained is no longer sufficient to meet the regulatory requirements.

- *Develop an MC&A approach* – Different reactor types may require different approaches for MC&A, including integration of different sensors or technology. To ensure there is adequate time to establish the MC&A approach, early planning is recommended.

- *Continually review information* – Information related to regulatory requirements is continually evolving. Regular reviews of available information are recommended to ensure the latest documents are assessed.

- *Prepare for inclusion on the IAEA eligible facilities list* – While IAEA safeguards are not part of domestic safeguards requirements, facilities are included on the eligible facilities list when operating license applications are submitted.

The considerations highlighted above were leveraged to compile a set of recommendations for future activities to support the deployment of advanced RTRs at universities. While there are numerous activities which would benefit the current university projects, several long-term efforts would also be useful to support future advanced reactor deployments. Some recommendations include establishing physical security requirements, assessing cyber security risks, considering MC&A approaches for different types of technologies, and assessing regulatory requirements for facilities at universities that straddle the divide between power and non-power facilities.

1 Introduction

Advanced reactor technologies, including microreactors, are gaining interest among numerous customers for an increasing variety of applications and deployment scenarios. Universities represent a growing subset of users interested in advanced reactors, with several exploring the feasibility of licensing microreactors as research and test reactors (RTRs). Due to some of the nontraditional design aspects of these microreactors, coupled with a use scenario that is not primarily oriented towards power production, there may be unique considerations associated with licensing and deployment.

The Department of Energy Office of Nuclear Energy (DOE-NE) Advanced Reactor Safeguards and Security (ARSS) Program recognized that unique advanced reactor deployment scenarios may require support. As a response, they initiated a scoping study to examine the current landscape of university-led advanced RTR deployment activities. As a framework for this assessment, the research team compiled an overview of these activities. This information was leveraged to guide an evaluation of the regulatory implications for siting advanced RTRs on a domestic university campus. The regulatory review included an assessment of existing and draft NRC regulations and guidance documents, with a particular emphasis on regulations related to security and material control and accounting (MC&A) requirements.

The universities pursuing advanced RTR deployments represent a variety of nuclear academic programs, from those that do not offer nuclear degrees to those that have nuclear engineering departments. They also have a variety of existing nuclear facilities. Further, at this time, there is a wide range of advanced reactor designs and technologies being considered for this use case. As a result of this diverse deployment landscape, there are numerous licensing aspects which should be considered, including requirements specific to domestic safeguards and security. Relevant topics include determining the necessary security measures that will need to be instituted, and developing and implementing appropriate MC&A protocols.

Like traditional light water reactors (LWRs), advanced reactors designed for power production or as RTRs will be licensed by the Nuclear Regulatory Commission (NRC). However, certain design aspects of advanced reactors, including the physical design of the reactor itself, the fuel form used in the reactor, and fuel enrichment levels, may affect the applicable licensing regulations. The regulatory landscape is dominated by regulations tailored to more traditional reactors (i.e. LWRs); as such, the unique attributes of advanced reactors may necessitate specifically targeted regulatory schemes. At present, the NRC is in the process of developing this tailored regulatory guidance. While drafts of these deliberations have been released to the public, they have not yet become part of the legal framework for reactor licensing. Thus, license applicants will need to assess the existing requirements and determine whether their reactors will require certain exemptions, as appropriate.

The overview of university advanced RTR deployment activities, combined with the regulatory assessment, was used as the basis for high-level recommendations geared towards steps that universities considering advanced RTRs could take at the outset of their planning and licensing activities. Recommendations were also made for future ARSS activities that could be undertaken to support and guide thinking by vendors and universities alike on MC&A approaches and the development of security measures during the planning and subsequent licensing process.

2 University Advanced Reactor Activities

There are numerous universities that have existing RTRs; these facilities provide important educational and research platforms. As interest in advanced reactor technology increases, universities are exploring the possibility of siting advanced RTRs at campuses. To assess the status of these deployments, an overview of university advanced RTR activities was compiled, discussed in Section 2.2. For the first phase of the assessment background information was summarized, as discussed below.

2.1 Background

The existing NRC licensed RTRs, and information on the nuclear related academics (e.g., department, degrees offered, etc.) offered by these universities was compiled during phase one of this project. All information was obtained through publicly available sources (e.g., NRC website, research center websites, etc.). This assessment formed the foundation for identifying areas of support that may be required as universities prepare for advanced RTR deployments.

There are currently 23 NRC licensed research reactors sited on college campuses [1]. These reactors encompass a variety of designs, including Training, Research, Isotopes, General Atomics (TRIGA), Pool, Lockheed, Argonaut, Heavy Water Reflected (HWR), PULSTAR, critical assembly, and Aerojet-General Nucleonics (AGN). In addition to the different designs there is also a range of power levels amongst university research reactors. It should be highlighted that the existing RTRs use more traditional fuel forms, rather than any advanced fuel types. A summary of the universities that have licensed research reactors at the time this report was written is provided in Table 1.

Table 1. Current universities with research reactors and their associated designs and power levels.

University	Reactor	Power Level
Idaho State University	AGN-201 #103	0.005 kW
Kansas State University	TRIGA	1.25 MW
Massachusetts Institute of Technology	HWR	6 MW
Missouri University of Science and Technology	Pool	200 kW
North Carolina State University	PULSTAR	1 MW

Ohio State University	Pool	500 kW
Oregon State University	TRIGA Mark II	1.1 MW
Penn State University	TRIGA	1.1 MW
Purdue University	Lockheed	12 kW
Reed College	TRIGA Mark I	250 kW
Rensselaer Polytechnic Institute	Critical Assembly	0.1 kW
Texas A&M University	AGN-201M #106	0.005 kW
Texas A&M University	TRIGA	1 MW
University of California-Davis	TRIGA	2 MW
University of California-Irvine	TRIGA Mark I	250 kW
University of Florida	Argonaut	100 kW
University of Maryland	TRIGA	250 kW
University of Massachusetts-Lowell	General Electric (GE) Pool	1 MW
University of Missouri	Tank	10 MW
University of New Mexico	AGN-201M #112	0.005 kW

University of Texas-Austin	TRIGA Mark II	1.1 MW
University of Utah	TRIGA Mark I	100 kW
University of Wisconsin-Madison	TRIGA	1 MW
Washington State University	TRIGA	1 MW

Some key aspects of the information presented in Table 1 should be highlighted for consideration when planning future ARSS activities. First, both universities with nuclear programs (e.g., Kansas State University, University of Florida) and universities with nuclear departments (e.g., Penn State University, Texas A&M University) are represented amongst the list of locations that have existing research reactors. Additionally, some research reactors are located at universities that do not have dedicated nuclear engineering academic programs (e.g., Reed College, University of California-Irvine). Conversely, for completeness, it should be noted that there are numerous universities that provide nuclear academic offerings and do not have a nuclear reactor. The various academic programs, and nuclear resources, could affect the efforts that will be most beneficial for supporting licensing and siting advanced reactors at universities. Further, the different levels of nuclear capabilities should be considered if educational materials are developed. The delivery options may be influenced by the different nuclear academic structures, for example, if there is a nuclear curriculum with elective courses versus select nuclear classes. Finally, as is evident from Table 1, it should not be assumed that only universities with nuclear academic programs will be interested in advanced nuclear reactors.

2.2 Advanced Reactor Deployment Activities

In addition to existing research reactors, the available information related to advanced reactor activity at universities was also compiled. While there is significant academic research being performed related to advanced reactors, the primary focus of this report is activity specifically associated with siting an advanced RTR deployment on a domestic university campus.

The areas of consideration for this assessment included:

- Current nuclear facilities and capabilities
- Advanced reactor deployment activities
    - Reactor design
    - Intended use
    - Status (phase in the planning/development/deployment cycle)
    - License application timeline
    - Physical protection planning and approach
    - Material control and accounting (MC&A) planning and approach

- The forms of support related to understanding, developing, and/or implementing physical protection and MC&A procedures which would be useful:
    - Workshops
    - Short courses
    - Technical papers
    - One-on-one meetings/discussions
    - Others

A summary of these activities is provided in Table 2.

Table 2. Summary of current university advanced RTR activities

University	Advanced Reactor Activities	Reactor Technology	Technology Power Level / Range
Abilene Christian University	• NRC construction permit application submitted	Molten Salt Research Reactor (MSRR)	(up to) 1 MWth (no electricity production)
Massachusetts Institute of Technology	• Design	Molten Salt Test Bed (Loop)	--
Penn State University	• Planning • Memorandum of understanding (MOU) with Westinghouse	Westinghouse eVinci (Microreactor)	200 kWe – 5 MWe
Purdue University	• Scoping Study	None Selected	--
University of Idaho	• Design	Micro Nuclear (Molten Salt Nuclear Battery)	400 kWth
University of Illinois Urbana-Champaign	• NRC preapplication	Ultrasafe Nuclear Corporation Micro Modular Reactor (MMR) (High Temperature Gas Reactor (HTGR))	3.5 - 15 MWe (currently limited to research reactor maximum: 10 MW [2])

As with Table 1, some points deserve special attention. First, there are several universities actively pursuing licensing advanced RTRs. Second, some of these universities currently have a research reactor (e.g., Penn State University), while others do not (e.g., University of Illinois Urbana-Champaign). Third, as was observed with the current RTRs, not all the universities represented in Table 2 have existing nuclear engineering departments or programs (e.g., Abilene Christian University). Fourth, some of these efforts represent consortia, which means that the groups involved may extend beyond the primary university. Fifth, while the current proposed uses are all research reactors or test facilities, it should be noted that different technologies are being pursued. This includes molten salt designs and TRi-structural ISOtropic (TRISO) fueled microreactors. The licenses being pursued at this time will be submitted as 104(c), though there are some differences in the planned approaches for the construction permits. Finally, these activities span a range of developmental stages, from scoping studies to licensing activities.

While the initial objective of this work was to focus on microreactor deployments on campuses, based on the information summarized in Table 2 it is suggested that future projects consider advanced reactors in general. While the currently selected technologies are within the defined power range for microreactors (less than 20 MWth), there are some universities that have not yet selected a technology, and they should not be excluded from future support if they ultimately chose a reactor design that can produce power greater than 20 MWth.

These points lead to the following observations. The outcome(s) of the current university efforts to obtain licenses for advanced RTRs will provide information for several different advanced reactor types, including liquid fueled molten salt reactors and TRISO fueled reactors. This information should be leveraged to inform future licensing endeavors, both for these reactor types and, more broadly, for advanced reactors in general. Also, due to the different stages of these activities, universities currently undertaking the licensing process, or considering future license applications, should observe what insights can be obtained from other applications. In addition to the RTR license applications, there may also be relevant information associated with applications for advanced power reactors. While there are differences in the licensing process between research and power reactors, as further discussed in Section 3, there will likely be information that can be leveraged, particularly related to exemptions.

Due to the differences in reactor technologies being considered for university deployments, specific recommendations are not made here. However, general recommendations based on an overview of the regulations are provided in Section 3. These recommendations were developed to support universities early in the planning process, and to guide some of the initial questions and considerations which should be addressed during preliminary regulatory assessments.

3 Regulatory Considerations

In addition to compiling information related to the current pursuit of advanced reactor technology by universities, the research team analyzed the existing state of nuclear regulations to highlight areas of opportunity and concern for advanced reactor deployments at universities. Given the unique reactor technologies that universities are pursuing, and the fact that they are not planning to use their reactors for profit, advanced reactors at universities will be categorized as research reactors or test facilities [3] and may be subject to different regulations than power reactors during the licensing process and over the operational lifespan of the reactor.

A meticulous, point-by-point overview of the entire licensing process is beyond the scope of this effort. As such, the assessment in this report contains a summary of the regulations that will be most pertinent to the particular situation of university sited advanced RTRs[1], and provides high-level general recommendations. The research team divided this assessment into several key areas, including general licensing regulations, security regulations, and MC&A regulations. Each of these areas will be of particular importance to universities throughout the process of licensing, installing, and operating their reactors. A more detailed regulation overview can be found in Appendix A.

3.1 Domestic Licensing

The NRC licenses (and regulates) the civilian uses of nuclear energy in the United States. The NRC regulations can be found in Title 10 of the Code of Federal Regulations (10 CFR). The regulations governing domestic licensing of production and utilization facilities are included in Title 10 Part 50 (10 CFR 50). Detailed in 10 CFR 50 are the standards that will need to be followed for applicants to receive licenses, construction permits, safety and environmental protection certifications, and regulatory approval. It also specifies the information that an applicant will need to provide to the NRC as part of the application process and provides details as to the classification of a reactor as determined by its specific function.

As part of the license application process a determination will need to be made regarding the specific class of the proposed advanced reactors. Two classes of reactors are described in the 10 CFR 50 guidelines. Commercial and industrial reactors require Class 103 licenses, while medical therapy and research and development (R&D) facilities require Class 104 licenses. It is likely that most of the advanced reactors being proposed for university deployment as RTRs will pursue Class 104(c) licenses. This class of license specifically covers production or utilization facilities which are "useful in the conduct of research and development activities of the types specified in Section 31 of (the Atomic Energy Act)" and which are not commercial or industrial facilities.

The distinction is an important one; 10 CFR 50.41(b) states that the NRC, with regards to Class 104 reactors, should "be guided by the (consideration that)… the (NRC) will permit the conduct of widespread and diverse research and development."[2] Class 103 reactors, on the other hand, have an additional restriction added to them, which states that the commission will consider whether or not the licensed activities serve

[1] Parties interested in understanding the totality of the applicable regulations should consult 10 CFR 50, 10 CFR 70, 10 CFR 73, 10 CFR 74, and 10 CFR 75.
[2] 10 CFR 50.41(b)

a "useful purpose proportionate to the quantities of special nuclear material or source material to be utilized."[3]

The question of whether a research reactor will be labeled as a Class 103 or Class 104 reactor will depend in part on the final use case. As described in 10 CFR 50.22, applications will need to be filed for Class 103 licenses, even for reactors that can be used for research and development, if "the facility is to be used so that more than 50 percent of the annual cost of owning and operating the facility is devoted to the production of materials, products, or energy for sale or commercial distribution, or to the sale of services."[4] In other words, if there is a scenario where an advanced RTR generates electricity which is then sold, it could potentially change the classification of the reactor facility. Thus, if the university decides to expand a reactor's uses to incorporate profitable activities, the university could potentially need to apply for a Class 103 license. Further, as the NRC's backgrounder on research reactors states, "a research reactor's key output is the radiation it produces, not the very minor amount of heat energy produced" [1].[5] Thus, if the eventual use case for an advanced reactor sought by a university includes power or heat generation, this definition may not apply.

Universities should also be aware that the determination if a reactor falls into the category of "research reactor" or "testing facility" depends in part on the operating power of the reactor system. The definitions for a testing facility are provided in 10 CFR 50.2 which clearly delineates the difference between research reactors and testing facilities. Testing facilities are defined as Class 104 reactors that operate at power levels above 10 MW *or* a Class 104 reactor operating at levels in excess of 1 MW if the reactor incorporates any of the following characteristics: a circulating loop through the core that the applicant intends to perform experiments on, liquid fuel loading, or an experimental facility in the core in excess of 16 square inches in cross-section.[6] While this will not likely affect whether or not the reactor can receive a Class 104 license, if the designation is not considered early in the application process there could be delays. Early communication with the NRC regarding this distinction is recommended.

Additional details regarding general licensing considerations, and the required information, can be found in Appendix A. Some of the general licensing requirements address security and MC&A requirements, but there are also security and MC&A specific regulations which will need to be considered for advanced reactors that are cited on college campuses. Some of these considerations are highlighted in Section 3.2 and Section 3.3.

3.2 Security

Current regulations have strict security measures that need to be taken by the owners and operators of utilization and production facilities. However, there are some physical security requirements that are different for RTRs compared to power reactors. For example, rather than having a dedicated security force that is armed and trained according to the specifications enshrined in 10 CFR 73, universities have been able to rely on campus security and local police forces to serve as the RTR's security presence. These types

[3] 10 CFR 50.42
[4] 10 CFR 50.22
[5] https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/research-reactors-bg.html#reactors
[6] 10 CFR 50.2

of details will need to be confirmed for advanced RTRs. However, before specific security issues related to the advanced reactors sought by universities can be addressed, some questions will need to be considered.

Based on the discussion above, and as was highlighted in Section 3.1, the first question is whether or not the proposed reactors will be classified as research reactors or power reactors by the NRC. Additionally, given the characteristics of the advanced reactors under consideration, they could potentially be classified as testing facilities. As previously stated, reactors are classified as testing facilities rather than research reactors if they have certain characteristics. Given the fact that several currently pursued reactors could have an operating power that is greater than 10 MW, or incorporate characteristics like liquid fuel loading, they could potentially be classified as testing facilities, which could impact the security plans that will need to be put into place. If security plans are determined according to a graded scale that accounts for the operating power of the reactor or the fuel type used, as stated on the NRC backgrounder for non-power facilities, accounting for the difference between a research reactor and a testing facility will be necessary. There are other nuances which will need to be considered when developing a security plan for advanced RTRs. For instance, for planning purposes RTRs must address potential threat scenarios when it comes to security; further, microreactors must address maximum hypothetical accidents (MHAs) and not design-basis accidents (DBAs). These types of distinctions will be relevant when designing security approaches.

Current regulations for reactor security are written in 10 CFR 50.34 and 10 CFR 73; 10 CFR 50.34 includes the requirement to include a security plan with any application for an operating license. This includes a plan to ensure the physical security of the facility, cybersecurity of the facility, and that security personnel are trained and qualified under the standards of Appendix B to 10 CFR 73. Additional details regarding the security requirements of nuclear facilities are provided in 10 CFR 73. The regulations are put into place specifically to protect against radiological sabotage and the theft or diversion of strategic special nuclear material. A high-level overview of the topics found in these regulations is included in Appendix A.

Another possible factor that could come into play when considering security requirements for advanced RTRs is a proposed regulation specifically targeting advanced reactors, under which their security requirements will be graded based on a risk-informed, performance-based assessment of the facility in question. Drafts of this proposed regulation, known as 10 CFR 53, "Licensing and Regulation of Advanced Nuclear Reactors", state that facilities for which "the loss of engineered systems for decay heat removal and possible breaches in physical structures surrounding the reactor, spent fuel, and other inventories of radioactive materials" would result in offsite doses below a certain threshold will not be subject to the security regulations in 10 CFR 73.55 or 10 CFR 73.100, and will be subjected instead to an as-yet-undefined set of security regulations [4].[7] This could potentially affect the proposed RTRs, depending on their technical specifications.

It should be noted, however, that the new regulations have not yet been put into the Code of Federal Regulations, and as such, speculation on their future effect on advanced reactors should be balanced with a working knowledge of which regulations will be relevant to the deployment of reactors by universities. For example, while 10 CFR 53 was developed for advanced reactors, it is specific to power reactors. At this time, it is not clear that 10 CFR 53 will apply to RTRs. Since the current university siting plans are for

[7] Rulemaking: Proposed Rule: Preliminary Rule Language for the Part 53 Rulemaking: Subparts A, B, C, D, E, and F -"Requirements for Operation"-10 CFR 53.820 and 53.830, and Part 73, "Physical Protection of Plants and Materials"-73.100, 73.110, and 73.120, Document Date June 2, 2021 (ADAMS Accession No. ML21148A062)

RTRs and not for power reactors, non-power production utilization facility requirements may form the basis for security regulations. Given these considerations, the guidance for medical isotope production facilities could be relevant and should be considered when establishing security plans for university sited advanced RTRs.

Some of the considerations highlighted above could lead to additional questions. For example, as previously observed, the question of whether off-site security forces will be required for advanced microreactors and small modular reactors deployed at universities as RTRs will need to be answered. If off-site security forces will be permissible, permissible response times will need to be defined. In addition, training requirements for responders will need to be determined to address design differences that could influence how the response is conducted. These include, but are not limited to, the different materials that will be present and the physical siting of the reactor in question, which will dictate the appropriate response. These factors may result in the need for specialized trainings for responders.

Efforts to detail specific security requirements based on existing systems are complicated by the fact that 10 CFR 73 includes a condition that information regarding the various security plans of a facility not be divulged to unauthorized parties. Thus, the questions and considerations outlined above will need to be further explored by applicants to understand their applicability to advanced reactors. Additional considerations are highlighted in Section 3.4, and more regulatory details can be found in Appendix A.

3.3 Material Control and Accounting

MC&A will be another area which will need to be addressed by universities interested in pursuing advanced reactor deployments. The reactor designs currently being considered for university siting will use novel fuel forms, including liquid fuel (i.e. a molten salt reactor (MSR) design) and TRISO particles.

The NRC requires licensees to have an MC&A program which provides control and accounting of nuclear material, and ensures that the licensed nuclear material is being used in a safe and secure manner. MC&A program requirements are well established for LWRs, but not for advanced reactors. The specific regulatory requirements, and the technology and procedures necessary to meet the requirements need to be established. There are also design specific parameters which will affect MC&A programs. These parameters include the different fuel forms and higher enrichment levels (e.g., high assay low enriched uranium (HALEU)) which will be required for many of the advanced reactor designs. The fuel enrichment, burnup, and anticipated plutonium production will all contribute to the MC&A requirements. Further, the fact that these fuel forms and their enrichment levels vary from those used in traditional reactors will mean that novel MC&A procedures may be needed to ensure the universities can meet their obligations under U.S. regulations.

Additionally, fundamental nuclear material control (FNMC) plans could be required for the advanced reactor facilities. The implementation of an MC&A program should be considered early in the planning process to ensure that requirements can be met, and design modifications and delays minimized. Currently, the ability for advanced reactors to receive exemptions from creating FNMC plans has not been determined. It is likely that FNMC plans will be required for some reactor designs. As such, universities should work to develop FNMC plan outlines and approaches in the near term to support license applications and provide an initial gap analysis.

The specific regulations that govern the need to establish MC&A procedures can be found in 10 CFR 50.78, 10 CFR 74, and 10 CFR 75. It should be noted that 10 CFR 50.78 covers the need for the licensee applicant to fill out an International Atomic Energy Agency (IAEA) Design Information Questionnaire (DIQ) as part of the license applicant process. The DIQ will contain facility information and require a facility attachment to be included. This is an important part of preparing for inclusion on the Eligible Facilities List (EFL). The EFL is a list that is submitted to the IAEA containing all nuclear facilities in the U.S. that are not associated with activities of direct national security significance to the U.S. While not all facilities in the U.S. will be selected by the IAEA after placement on the EFL, it is possible that advanced reactors located at universities could be seen by the IAEA as useful testing grounds to refine methods for carrying out international safeguards inspections and verification measures on reactors incorporating non-traditional fuel forms.

Some MC&A relevant recommendations are provided in Section 3.4, and further regulatory considerations can be found in Appendix A.

3.4 Recommendations

The regulations discussed above provide an overview of some of the topics which will need to be considered for advanced RTRs. It is important to reiterate that these regulations were established for LWRs, and they may not be universally applicable to advanced reactors. Further, there will likely be differences in what regulations are identified as being relevant based on the specific advanced reactor designs. Thus, there is not a specific set of safeguards and security recommendations for university deployments of advanced reactors that can be made at this time. However, as a general recommendation, there are some topics which should be considered early in the planning process.

The following list provides some high-level information to help guide initial safeguards and security considerations. These recommendations are derived from the licensing and regulatory topics previously discussed. Some of these topics are also highlighted for relevance as part of future ARSS project planning.

General

- *Identify the licensing approach that will be pursued.* A license application can be under 10 CFR 50 or 10 CFR 52. The primary difference is that 10 CFR 50 is a two-part approach, which consists of a construction permit followed by an operating license. The 10 CFR 52 approach combines the two steps, and the application is for a combined operating license. Either option can be used for Class 103 or Class 104 licenses. However, the 10 CFR 50 approach is more common.
- *Determine what class license will be applicable.* At the moment, it appears that most universities will seek out a Class 104(c) license, since their reactors will be used primarily to advance research and development as described in Section 31 of the Atomic Energy Act. However, the requirements associated with a Class 104(c) license should be considered to ensure that the intended use will be within the license parameters. Further, over the course of the reactor's lifetime, it may be determined that the reactor could serve ancillary benefits (e.g. providing power to nearby communities for profit or selling medical isotopes to hospitals). Before diverging from the original R&D-focused use case, universities should engage with the NRC in order to understand the point at which an application for a new license would be necessary.

- *Engage with the NRC throughout the planning and development process*. Universities should engage with the NRC throughout the planning process to discuss issues where they are unsure about their responsibilities during the licensing process. Early clarification should also be sought regarding any regulatory issues that could potentially result in impediments during the licensing process.
- *Perform a general regulatory review*. There are regulations specific to all phases of reactor deployment and operation. These regulations extend from construction to security to decommissioning. The current regulations are specific to LWRs; however, draft regulations have been developed for specifically for advanced reactors.
    - Different types of guidance documents (e.g. regulatory basis documents, NUREGs, etc.) have also been published to support licensing of advanced reactors. These documents are not law, but they can provide supplementary information that may not be captured in the regulations.
    - It is important to note that not all the drafts, or regulatory basis documents, have become regulations. However, they should still be reviewed for context and to understand some of the different approaches, regulations, and suggestions which have been considered by the NRC. The applicability of these new regulations and/or guidelines to advanced RTRs will need to be determined, but until these determinations have been made, they should still be assessed as part of a regulatory overview. A subset of these documents is listed in Appendix A for reference.
- *Perform a tailored regulatory assessment and gap analysis.* A structured gap analyses should be conducted to determine which regulations are applicable to particular reactors. Given the fact that current regulations are primarily oriented towards traditional LWR designs, some of the specified requirements for safety and security will not be applicable to the proposed advanced reactors. These gap-analyses will need to be individually tailored to each university's planned reactor, due to the variance in reactor types, power levels, and use cases. Some considerations which should be addressed in the gap analysis are:
    - The specific reactor design (e.g. physical configuration, coolant, release limits, etc.)
    - The fuel form (e.g. liquid, solid, cladding, etc.)
    - The fuel enrichment (e.g. LEU, HALEU)
    - Refueling (e.g. online refueling, core replacement, etc.)
    - The amount of SNM that will be on site (core amount, fresh fuel, depleted fuel)
    - Any other features which are unique to the advanced reactor design

  The gap analysis should be used to identify specific topics where input from the NRC will be required regarding regulatory interpretations and requirements. Further, this analysis can be leveraged to guide identification of regulations that can be met through intent and identify the exemptions that will be requested.
- *Identify the exemptions that will be requested.* The process for requesting exemptions can be found in 10 CFR. In general, exemptions will be required when regulations are not applicable because they were established for LWRs. As part of the exemption granting process, it will need to be confirmed that they are authorized by law, and will not endanger the public. Specific requirements can be found in the main parts of 10 CFR. The exemptions that will be (or likely will be) requested should be identified early in the licensing process and submitted to the NRC.

- *Continually review information.* The design, development, and deployment of advanced reactors is a rapidly advancing field. Thus, the information related to regulatory requirements is continually evolving. Regular reviews of available information are recommended to ensure the latest documents are assessed. It is also suggested to directly ask the NRC for updates on new and expected upcoming documentation. A new resource was recently (April 22nd, 2024) published by the NRC to provide a tool where references for advanced reactor licensing can be found. This guidance tool is the Advanced Reactor Application Guidance Page, which can be found at the website listed in Appendix A.

Physical Protection

- *Obtain guidance on security requirements.* Universities should engage with the NRC to determine the security requirements that they will be responsible for instituting around their advanced RTRs, as the requirements may be different than for traditional RTRs. For example, while on-site security hired by the university as security guards may be sufficient for existing RTRs, there is no guarantee that this will be the case in the future. Universities should develop contingency plans in case the on-site security that has previously been retained is no longer sufficient to meet the regulatory requirements.
- *Specific topics and potential areas for future research activities*. A regulatory gap analysis for physical protection requirements for advanced reactors, and the application of the requirements for RTRs, would provide a useful starting point to guide future research. Some specific scenarios of consideration are:
    - *The use of off-site security forces.* The security forces which will be required for advanced microreactors and small modular reactors, particularly for those deployed as RTRs, will need to be confirmed. If off-site security forces are going to be used, then the permissible response times will need to be defined.
    - *Response force training.* Training requirements for responders will also need to be determined; there are aspects to some of the advanced reactor designs which differ from traditional reactors and could affect how response is conducted, including the different materials which will be present. These factors will dictate the appropriate response and may result in the need for specialized training for the responders. Identifying these scenarios, developing a framework to support the license applications, and determining the necessary trainings will require support.
    - *Barriers/access/etc.* The specific physical security requirements for microreactors and small modular reactors will need to be established. Further, requirements associated with the reactor placement need to be addressed. One area of particular interest would be the placement of these reactors in subterranean settings. Future support should be given to studies which help determine the necessary physical security and placement requirements and assist in developing approaches to meet them.

Cyber Security

- *Identify cyber security risks.* Cyber security has become increasingly relevant for the nuclear industry in deployment scenarios currently under consideration. While cyber security requirements may not have direct application for university deployed RTRs, serious consideration should be given to this area.

- *Future research activities.* Depending on how the reactors are operated, studies could examine potential cyber threats and cyber security requirements. The advanced RTR deployments could provide platforms for researchers to gather relevant data and test different approaches.

MC&A

- *Develop an MC&A approach.* The different reactor types may require different approaches for MC&A; measurement methods used for liquid fueled reactors and sealed core microreactors are not likely to be the same. Further, it should also be determined early in the planning or licensing process if an FNMC plan will be required as part of the regulatory documents. In some cases, it is possible that different sensors (or technology in general) will need to be utilized to achieve the MC&A requirements. Thus, to ensure there is adequate time to establish the MC&A approach early planning is recommended.
- *Engage with NRC on MC&A approach.* Early engagement with the NRC on the MC&A requirements, and the planned approach, is recommended. If an FNMC plan is required guidance should be sought on the expected format, and level of information required.
- *Specific topics and potential areas for future research activities*. The different designs, fuel forms, enrichments, coolants, etc., will affect the MC&A approaches which can be implemented. Refueling could also impact MC&A; reactors that will require regular refueling will present additional challenges, including storage of fresh and used fuel. Specific MC&A considerations include:
    - *Inventory requirements*. The inventory requirements and the methods by which inventories are performed will need to be established. Some specific considerations will be related to fuel form which will be heavily impacted by the determination of what can be considered an item. For example, liquid fueled designs will require different approaches to inventory than solid fueled designs. Additionally, minimum mass amounts for "items" could affect the quantities of fuel elements that will need to be grouped. Future activities should address designing inventory approaches and support the development of instrumentation to fulfill any gaps identified.
    - *FNMC plans.* Traditional LWR reactors receive exemptions from FNMC plan submission requirements; the exemptions for advanced reactors have yet to be determined, and it is likely that detailed FNMC plans will be required for some reactor designs. Developing FNMC plan outlines and approaches to support the license applications and provide an initial gap analysis should be considered as a near term activity.
    - *Fuel "ownership"*. The issue of fuel ownership for university RTRs should continue to be monitored. At this time, universities obtain their fuel through fuels support contracts [5]. The availability of novel fuel forms through similar arrangements will affect material storage and total material inventory.
- *Prepare for inclusion on the IAEA eligible facilities list*. While IAEA safeguards are not part of domestic safeguards requirements, it should be recognized that facilities are included on the eligible facilities list when operating license applications are submitted.[8] Placement on the list does not

[8] https://www.nrc.gov/materials/fuel-cycle-fac/intl-safeguards/implementing-iaea-safeguards.html

guarantee selection; in fact, only four facilities in the U.S. have been chosen by the IAEA [6]. However, the IAEA may be particularly interested in these new facilities; as the IAEA works to develop safeguards methods that are appropriate for advanced reactors, reactor facilities might serve as appropriate testing grounds for novel safeguards approaches. Therefore, support for an assessment of how domestic safeguards approaches can be leveraged to address international safeguards requirements should be considered. The results of this assessment could be used to form the basis of a domestic-international safeguards gap study for the different reactor types.

Training

In addition to technical and regulatory considerations, there will be opportunities to support university deployments of advanced reactors through training and education. Specific activities which should be considered in the near-term include:

- *Workshops and short courses.* Workshops and short courses which address different topics, including those highlighted above, should be developed to help universities prepare for and navigate through licensing activities. Specific topics could include designing PPS approaches and developing FNMC plans.
- *Course modules.* Course content should be developed to support student education. Topics should include those which are generally not included in traditional nuclear curricula, such as cyber security. The relatively new state of the field has resulted in an opportunity to create forward-looking material, including in areas like robotics and sensor development. Support for training security and MC&A practitioners should also be considered. As these are niche areas of expertise, there likely will not be sufficient demand to sustain a full set of university courses. However, specialized professional development courses or certificate programs could be considered and pursued. These courses would support both universities planning reactor deployments and vendors throughout the nuclear industry. While there are a variety of courses and training modules related to international safeguards and security, there are limited educational opportunities for domestic safeguards.
- *Faculty exchange.* A faculty/staff exchange program should be explored to establish an opportunity for faculty to work with experts at national laboratories as they prepare for advanced reactor deployments. A reciprocal arrangement should also be considered to support opportunities for national laboratory staff to spend time at the universities while they are navigating the licensing process.

It is worth noting that some of the requirements which may be applicable to advanced reactors have previously been considered in proposed regulations. The NRC Regulatory Basis Document NRC-2014-0118 presents an outline for security and MC&A requirements based on material category, and not use. This framework provides a consistent set of requirements, and may provide a starting point for developing security and MC&A approaches, as well as identifying exemptions. If an applicant can justify that a requirement is met for a specific design, then an exemption is not required (even if the requirement is met in a new way). It is worth reiterating that there could be changes in security and MC&A requirements if universities deploy these advanced reactors for power generation. While this does not appear to be a near-term plan for the universities pursuing advanced RTRs, exploring the implications could be relevant for future deployment scenarios.

Other considerations and areas of support are likely to arise throughout the licensing and deployment process. There should be periodic assessments of the support required, and the associated opportunities for joint research and collaboration.

4 Conclusions

There are numerous universities in the United States that have “traditional” NRC licensed RTRs on their campuses. Recently, however, focus has begun to shift from research reactors using traditional fuel types and designs to advanced reactors. The ARSS Program recognizes that over the past several years there has been increasing interest in deploying advanced reactor technologies, including microreactors, on university campuses. To provide a framework for assessing potential security and MC&A considerations, an overview of the current state of university advanced RTR deployment activities was compiled. Given the relatively short deployment timeframe envisioned by these universities, the importance of this project should not be underestimated.

The NRC licensed RTRs currently in existence on college campuses represent a variety of designs and power levels. In addition, the locations are not solely at universities that have existing nuclear departments and nuclear programs, but include universities that do not offer nuclear degrees. A similar cross-section of academic variation was identified amongst the universities interested in advanced reactor deployments. Further, as with the existing RTRs, there are different advanced reactor technologies being considered. This variety in technology could affect the regulatory requirements related to both security and MC&A.

In addition to assessing the current university advanced reactor deployment activities a review of the relevant security and MC&A regulations was also performed. The deployment of advanced reactors is a rapidly evolving field, and new regulations are being developed and considered to address the needs of these facilities. These draft and proposed regulations were also reviewed, and their potential impact on advanced reactor licensing was assessed. It should be noted that some of the draft regulations may not apply to advanced RTRs. Thus, further regulatory guidance may be required.

Due to the variety of advanced reactor designs, fuel forms, and current stage of planning and/or licensing activities, specific recommendations were not provided. However, a general overview of safeguards and security related considerations was outlined to provide universities with information to guide initial planning. First and foremost, frequent communication with the NRC is suggested in all stages of the reactor deployment and licensing process, including the earliest stages of planning. Regulatory assessments specific to the different reactor technologies and deployment scenarios are also recommended.

In addition to the general overview provided in the body of this report, a more detailed regulatory overview can be found in Appendix A. There is also an Appendix B which was provided to the ARSS Program directors summarizing additional information which should be considered when planning future research efforts.

Appendix A Regulation Summary

A review of NRC regulations pertaining to research reactors was conducted to assess the current physical protection and MC&A requirements. Regulations which are being proposed, or have particular relevance for advanced reactors, were also considered.

University reactors are categorized as research reactors or test facilities, as opposed to commercial power facilities [3]. These reactors are subject to the same regulatory requirements as power reactors. The primary regulations which are relevant to this assessment are from Title 10 of the Code of Federal Regulations (CFR):

- 10 CFR 50 [7]
- 10 CFR 70 [8]
- 10 CFR 73 [9]
- 10 CFR 74 [10]
- 10 CFR 75 [11]

Additional references and resources which were leveraged include:

- 10 CFR 52 [12]
- 10 CFR 53 [4]
- NUREG-1537 [13]
- Regulatory Basis Document: NRC-2014-0018 [14]
- SECY-23-0021 [15]
- SECY-08-0059 [16]
- Updated NRC Staff Draft White Paper: Analysis of Applicability of NRC Regulations for Non-Light Water Reactors [17]
- NRC Advanced Reactor Application Guidance [18]

These references could prove useful as a starting point for assessing regulatory applicability.

Domestic Licensing

The regulations governing domestic licensing of production and utilization facilities are included in 10 CFR 50). Detailed in 10 CFR 50 are the standards that will need to be followed for applicants to receive licenses, construction permits, safety and environmental protection certifications, and regulatory approval. It also specifies the information that an applicant will need to provide to the NRC as part of the application process and provides details as to the classification of a reactor as determined by its specific function. This section will provide a high-level overview of these regulations, laying out the information which will need to be provided to the NRC to pursue construction permits, operating licenses, or combined licenses.[9] Note that the main points are highlighted here rather than a point-by-point overview of the full set of regulations.

[9] For more detailed information, interested parties should refer to the regulations contained in the footnotes. While the length of these regulations precludes them from inclusion in their entirety in this report, failure to comply with the necessary regulations could lead to a rejection of the application for a permit or license, leading to potential delays in the deployment process.

While this appendix should serve as a guide for aspiring licensees in the planning stages of deployment, the regulations contain all the needed information and should be consulted at every stage in the process.

- The applicant must provide general information regarding the proposed reactor, including, but not limited to:
    - The class of license applied for, the facility use, the period of time for which the license is sought, and a list of other licenses, except operator's licenses, issued or applied for in connection with the proposed facility.[10]
    - Radiological emergency response plans at the state and local level for governmental entities within the plume exposure pathway emergency planning zone.[11]
- A preliminary safety analysis report (for construction permits) which would include:
    - A description and safety assessment of the site upon which the facility will operate and a safety assessment of the site itself.[12]
        - Factors the NRC will take into consideration with regards to the reactor design characteristics and proposed operation include the intended use and power level of the reactor, the material contained within the reactor, whether or not the reactor includes unusual or enhanced safety features, and what safety features and barriers would have to be breached in order to result in an unintended release of radioactive material into the environment.[13]
- A final safety analysis report (for operating licenses) which would include:
    - All information related to the site that has been developed since the preliminary safety analysis, including environmental and meteorological monitoring.[14]
- An extensive set of risk analyses and assessments determining how best to avoid a number of potential accidents. The full list is comprised of six pages of potential accidents and is thus too lengthy to include in this section. However, the detailed list can be found in 10 CFR 50.34(f)(1-3).
- Plans for developing, implementing, and maintaining strategies to mitigate the effects of beyond-design-basis events, as required by 10 CFR 50.155.[15]

Besides the general information outlined above, there are also security and safeguards specific requirements, some of which are provided below.

- An overarching security plan that conforms to the requirements in 10 CFR 73.
    - Depending on whether or not the proposed reactors will be classified as power reactors or non-power reactors, different requirements may be applicable. For both power reactors and non-power reactors, a physical security plan will need to be submitted.[16] For power reactors, the licensee will have to submit a cybersecurity plan and a training and qualification plan for the facility's security personnel.[17]

[10] 10 CFR 50.33(e)
[11] 10 CFR 50.33(g)
[12] 10 CFR 50.34(a)(1)(ii)
[13] 10 CFR 50.34(a)(1)(ii)(A-E)
[14] 10 CFR 50.34(b)(1)
[15] 10 CFR 50.34(i)
[16] 10 CFR 50.34(c)(1), 10 CFR 50.34(c)(2)
[17] 10 CFR 50.34(c)(2)

- A safeguards contingency plan must be submitted that conforms to the requirement in appendix C of 10 CFR 73.[18]
- Assurances that the information in the physical security plan, the safeguards contingency plan, and the cybersecurity plan is not disclosed to unauthorized parties.[19]
- The applicant must submit facility and site information to the NRC under the agreement between the IAEA and the NRC. The facility information must be submitted on IAEA Design Information Questionnaire (DIQ) forms, while the site information must be submitted on DOC/NRC Form AP-1 and associated forms.
    - The required facility information includes:
        - The character, purpose, nominal capacity, and geographic location, as well as a description of the general arrangement of the facility, a map of the site, information on the size of the buildings, and a description of the activities pursued in each building.
        - The form, physical location, and flow of nuclear material, and general layout of important items of any equipment that uses, produces, or processes SNM.
        - A description of the features of the facility related to surveillance and MC&A.
        - A description of existing and proposed MC&A procedures, with a focus on the establishment of material balance areas, flow management, and procedures for physical inventory taking.

In addition to the general information described above, some of which includes security considerations, there are security specific regulations which will also need to be addressed for advanced reactors that are cited on college campuses.

Security

Current regulations have strict security measures that need to be taken by the owners and operators of utilization and production facilities; these regulations are written in 10 CFR 50.34 and 10 CFR 73. As stated previously, 10 CFR 50.34 includes the requirement to include a security plan with any application for an operating license. This includes a plan to ensure physical security of the facility, cybersecurity of the facility, and ensure that security personnel are trained and qualified under the standards of Appendix B to 10 CFR 73.

Additional detail regarding the security requirements of nuclear facilities is provided in 10 CFR 73. The regulations are put into place specifically to protect against radiological sabotage and the theft or diversion of strategic special nuclear material. As a high-level overview, these regulations include the following topics0:

- Physical protection requirements for fixed sites.
    - Facilities need physical protection systems that are capable of detecting attempts to gain unauthorized access or introduce unauthorized material across the boundaries of material access areas or other vital areas.

[18] 10 CFR 50.34(d)
[19] 10 CFR 50.34(e)

    - The physical protection system must:
        - include a physical security organization, physical barriers to deter, detect, and respond to unauthorized parties attempting diversion or sabotage, a system of control for all points of access into the facility and into each vital area, detection aids and alarms, and an NRC-approved safeguards contingency plan to respond to threats, theft, and radiological sabotage of the facility.
        - ensure that only authorized placement and movement of SNM within material access areas takes place.
        - permit only authorized activities and conditions withing protected areas, material access areas, and vital areas.
        - ensure that only authorized removal of SNM from material access areas is possible, as well as ensure that the material is in previously confirmed forms and amounts.
- Access authorization and access control requirements.
    - Individuals who the licensee intends to grant unescorted access to protected or vital areas, individuals who can take actions that could degrade the licensee's operational safety, security, or emergency preparedness, and individuals who are part of the licensee's protective strategy are subject to the access authorization program.
- Criteria for security personnel.
- Guidelines for safeguards contingency plans.
    - The safeguards contingency plan contains five categories of information, each of which contains vital information for licensees planning to detect and respond to security threats.
    - The contingency plan must contain:
        - *background information* concerning perceived dangers, the scope and purpose of the plan, and definitions for the operational and technical aspects of the plan.
        - a generic *planning base* identifying events that will be used to signal the beginning or aggravation of a safeguards contingency event, ensuring that the licensee can detect security threats and respond to them effectively.
        - a *licensee planning base* that includes facility-specific contingency planning, including those aspects related to organizational structure of the facility, the physical layout of the facility, the safeguards systems in place at the facility, a list of available law enforcement agencies, policy constraints and assumptions, and administrative and logistical considerations.
        - a *responsibility matrix* based on events outlined in the generic planning base containing the objectives to be accomplished relative to each identified safeguards contingency event, a tabulation for each event and response entity depicting the assignment of responsibilities for decisions and actions to be taken, and a description of actions associated with each response entity.
        - *implementing procedures* in written form containing specific guidance and operating details identifying actions that will be taken and decisions that will be made.

Note that 10 CFR 73 also includes a requirement that information regarding the various security plans of the facility not be divulged to unauthorized parties. Thus, the questions, considerations, and requirements outlined above will need to be further explored to understand their applicability to advanced RTRs.

Material Control and Accounting

The specific regulations that govern the need to establish MC&A procedures can be found in 10 CFR 50.78, 10 CFR 74, and 10 CFR 75. The MC&A program regulations established by the NRC are based on a requirement that SNM can be tracked and verified. The regulations in 10 CFR 74 specifically address Material Control and Accounting of Special Nuclear Material, and provide a good starting point for developing an MC&A approach. A detailed review of each section of 10 CFR 74 is beyond the scope of this report, but the general topics are provided below for awareness.

- General Provisions.
    - This section provides the purpose and scope of the document. Of significance, specific exemptions are also covered.
- General Reporting and Recordkeeping Requirements.
    - The different reports, and details for record keeping are outlined. Reports include:
        - *Loss or theft*
        - *Unauthorized production of SNM*
        - *Material status*
        - *Transactions*
        - *SNM physical inventory summary* it should be observed that physical inventory for some of the advanced reactor designs may be challenging and could require new methods.
- SNM of Low Strategic Significance
- SNM of Moderate Strategic Significance
- Formula Quantities of Strategic SNM
    - Topics in this section include
        - *Process monitoring*
        - *Item monitoring*
- Enforcement
    - Details of inspections, tests, and violations are covered.

Since most of the currently proposed reactor concepts will use novel fuel forms, including molten salt reactors (MSR) and reactors fueled by TRISO particles, the application of the topics in 10 CFR 74 will need to be determined. In some cases, novel MC&A procedures could be required to ensure the universities can meet their regulatory obligations. Further, as was highlighted previously, FNMC plans may be required for some of the advanced reactor facilities. The FNMC plan describes how a facility will meet their MC&A licensing requirements. Traditional LWR facilities are not required to submit FNMC plans. However, it should not be assumed that the same exception will be granted to all advanced reactor technologies. The information that needs to be included in an FNMC plan for bulk facilities, such as enrichment and fuel fabrication facilities is well established and documented. There are several NUREGs which have been published on FNMC plans requirements (e.g. [19],[20]). But guidance for advanced reactors has not yet been published. The existing NUREGs provide a starting point for establishing the type of information that needs to be included in an FNMC plan, and there have been research efforts that have looked at modifications that could be required/relevant for advanced reactors [21] [22]. These publications should be reviewed as a starting point for MC&A planning, and to identify areas which may require further assessment and research support.

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7 Acronyms and Abbreviations

Acronym	Definition
AGN	Aerojet-General Nucleonics
ANS	American Nuclear Society
CFR	Code of Federal Regulations
DBA	Design Basis Accident
DIQ	Design Information Questionnaire
EFL	Eligible Facilities List
FNMC	Fundamental Nuclear Material Control
GE	General Electric
HALEU	High Assay Low Enriched Uranium
HTGR	High Temperature Gas Reactor
HWR	Heavy Water Reflected
IAEA	International Atomic Energy Agency
LEU	Low Enriched Uranium
LWR	Light Water Reactor
MC&A	Material Control and Accounting
MHA	Maximum Hypothetical Accident
MMR	Micro Modular Reactor
MOU	Memorandum of Understanding
MSR	Molten Salt Reactor
MSRR	Molten Salt Research Reactor
NRC	Nuclear Regulatory Commission
R&D	Research and Development
RTR	Research and Test Reactor
TRIGA	Training, Research, Isotopes, General Atomics
TRISO	TIi-structural ISOtropic
TRTR	The National Organization of Test, Research, and Training Reactors