The Application of a Graded Approach in the Regulation of Research and Test Reactors at the U.S. Nuclear Regulatory Commission

A. Adams, Jr.

U.S. Nuclear Regulatory Commission (NRC), Washington, DC, USA

E-mail contact of main author: alexander.adams@nrc.gov

Abstract. The application of a graded approach is an important aspect of the regulation of research and test reactors given their wide range of power levels, designs and utilization. The U.S. Nuclear Regulatory Commission uses a graded approach in all aspects of research and test reactor regulation. Examples are discussed in the paper.

Key Words: research reactor, graded approach

1. Introduction

The application of a graded approach is a fundamental concept of the International Atomic Energy Agency (IAEA) for maintaining safety at research reactors. For example, IAEA Specific Safety Guide No. SSG-22, "Use of a Graded Approach in the Application of the Safety Requirements for Research Reactors," [1] presents recommendations on the graded approach for research reactors established in the Safety Requirements publication on "Safety of Research Reactors."[2]

A graded approach is also a fundamental concept of the regulation of research and test reactors (also called non-power reactors by the U.S. Nuclear Regulatory Commission (NRC) and research reactors by IAEA) by the NRC. The purpose in applying a graded approach is to equate the degree of scrutiny exercised in the regulatory process to the safety significance of the features or characteristics of the research or test reactor design that is being evaluated. In general, as the risk associated with a reactor increases, the regulatory process becomes more complex. A graded approach has been used by the NRC and its predecessor, the U.S. Atomic Energy Commission from the earliest days of the regulation of research and test reactors in the United States. In general, the regulatory process is more stringent with the progression from low-power research reactors to high-power research reactors to test reactors to power reactors.

2. Reactor Categorization

Research and test reactors regulated by the NRC encompass a multitude of designs and power levels. Thermal power levels and designs range from 5-watt (W) Aerojet-General Nucleonics (AGN) solid homogeneous fueled reactors to a 20-megawatt (MW) heavy water cooled and moderated tank reactor. Table I shows the licensed power level and design of the current operating research and test reactors regulated by NRC. The NRC's application of a graded approach considers several attributes, including the type of reactor, the power level of the reactor, and the purpose of the reactor.

Non-power reactor is defined in Title 10 of the *Code of Federal Regulations* (10 CFR) 50.2, "Definitions," [3] as a research or test reactor licensed under 10 CFR Part 50, "Domestic

Table I: NRC LICENSED RESEARCH AND TEST REACTORS.

Licensee	Location	Reactor Type	Power Level (kW)
Aerotest	San Ramon, CA	TRIGA	250
Armed Forces Radiobiology Research Institute	Bethesda, MD	TRIGA	1,100
Dow Chemical Company	Midland, MI	TRIGA	300
GE-Hitachi	Sunol, CA	Tank	100
Idaho State University	Pocatello, ID	AGN-201	0.005
Kansas State University	Manhattan, KS	TRIGA	250
Massachusetts Institute of Technology	Cambridge, MA	Tank, MTR fuel	5,000
Missouri University of Science and Technology	Rolla, MO	Pool, MTR fuel	200
National Institute of Standards & Technology	Gaithersburg, MD	Tank, MTR fuel Heavy Water	20,000
North Carolina State University	Raleigh, NC	Pulstar	1,000
Ohio State University	Columbus, OH	Pool MTR fuel	500
Oregon State University	Corvallis, OR	TRIGA	1,100
Pennsylvania State University	State College, PA	TRIGA	1,100
Purdue University	West Lafayette, IN	Tank, MTR fuel	1
Reed College	Portland, OR	TRIGA	250
Rensselaer Polytechnic Institute	Troy, NY	Critical Assembly	0.1
Rhode Island Atomic Energy Commission	Narragansett, RI	Pool, MTR fuel	2,000
Texas A&M University	College Station, TX	AGN-201M	0.005
Texas A&M University	College Station, TX	TRIGA	1,000
U.S. Geological Survey	Denver, CO	TRIGA	1,000
University of California/Davis	Sacramento, CA	TRIGA	2,300
University of California/Irvine	Irvine, CA	TRIGA	250
University of Florida	Gainesville, FL	Argonaut	100
University of Maryland	College Park, MD	TRIGA	250
University of Massachusetts/Lowell	Lowell, MA	Pool, MTR fuel	1,000
University of Missouri/Columbia	Columbia, MO	Tank, MTR fuel	10,000
University of New Mexico	Albuquerque, NM	AGN-201M	0.005
University of Texas	Austin, TX	TRIGA	1,100
University of Utah	Salt Lake City, UT	TRIGA	100
University of Wisconsin	Madison, WI	TRIGA	1,000
Washington State University	Pullman, WA	TRIGA	1,000

Licensing of Production and Utilization Facilities," [4] for research and development. The primary attribute that distinguishes between test and research reactors is thermal power level.

Generally, a test reactor (also called a testing facility or testing reactor in the NRC regulations) has a thermal power level in excess of 10 MW. A reactor is also designated a test reactor if it has a thermal power level in excess of 1 MW and certain design features. These design features are (1) a circulating loop through the core to conduct fuel experiments, or (2) a liquid fuel loading, or (3) an experimental facility in the core in excess of 16 square inches in cross section. A research reactor (defined in 10 CFR 170.3, "Definitions" [5]) has a thermal power level of 10 MW or less and is not a testing facility. The only operating test reactor at the National Institute of Standards and Technology is designated a test reactor because of its thermal power level of 20 MW rather than design features.

The application of the graded approach is also dependent on whether a research reactor is considered a commercial or industrial facility. While all current research reactors are licensed as noncommercial, the regulations allow for a commercial research reactor. A research reactor is deemed to be for industrial or commercial purposes 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 other than research and development or education or training. A commercial research reactor would be subject to a more stringent regulatory process similar to a test reactor. The focus on commercial activities requires a more stringent regulatory process than research, education, training, and service activities.

The delineation between low-power and high-power research reactors is at a thermal power level of 2 MW. This is based on decay heat generation and fission product inventory. Depending on the specific reactor design, 2 MW is the power level where an emergency core cooling engineered safety feature could be required to cool the reactor core in the event of a complete loss-of-coolant accident. Air cooling alone may not be sufficient to maintain fuel temperatures below the clad failure safety limit. These reactors also have the ability to induce significant radioactivity into targets, which must be considered during licensing.

The demarcation between a research reactor and a test reactor also contributes to NRC's application of a graded approach. The definition of testing facility appeared in the regulations in 1958. The reason for the 10-MW and 1-MW thermal power levels was not clearly articulated in the historical record. The 10-MW limit appears related to doses from a significant amount of fuel failure. The reduction in power level from 10 MW to 1 MW for liquid fuel, a circulating fuel test loop, or large core water hole represents the additional risk of these activities. In a liquid-fueled reactor, gaseous fission products can readily leave the fuel solution during normal operation. This requires additional complexity in design to contain these gaseous fission products as compared against solid clad fuel where the gaseous fission products are retained in the fuel matrix. A circulating loop through the core for fuel experimentation is a complex experimental facility. The experimental nature of the fuel irradiations could carry a greater risk for the release of fission products than small fueled experiments or other experimental facilities that irradiate nonfuel experiments. Finally, a reactor core with a large water hole in the core presents a greater risk for a large reactivity addition accident than a reactor with small water holes. The 16-square-inch size is thought to be related to either the 4-inch square graphite blocks used in research and test reactors or 3-inch square Materials Testing Reactor-type fuel elements. Dropping the graphite block or fuel element into an operating reactor could result in a large power increase and fuel cladding failure.

3. Atomic Energy Act Requirements

Because of the requirements of the Atomic Energy Act [6], the NRC applies a graded approach in research and test reactor regulation. The Atomic Energy Act is the law passed by the U.S. Congress for the regulation of civilian nuclear technology. For reactors useful in the conduct of research and development activities, the Atomic Energy Act states the Commission is directed to impose only such minimum amount of regulation of the licensee as the Commission finds will permit the Commission to fulfill its obligations under this Act to promote the common defense and security and to protect the health and safety of the public and will permit the conduct of widespread and diverse research and development. The Atomic Energy Act states the term “research and development” means (1) theoretical analysis, exploration, or experimentation or (2) the extension of investigative findings and theories of a scientific or technical nature into practical application for experimental and demonstration purposes, including the experimental production and testing of models, devices, equipment, materials, and processes. This requirement for minimum regulation is applied in all aspects of the regulation of research and test reactors, including licensing processes, regulatory technical requirements and inspections.

4. Graded Approach in the NRC Licensing Process

The licensing process consists of the actions required to issue a license. In general, as the risk associated with a reactor increases, the regulatory process becomes more complex. Examples of the licensing process are the level of regulatory review needed to issue a licensing action and the need for a licensing action to be subjected to a hearing.

The Advisory Committee on Reactor Safeguards (ACRS) is a statutory independent advisory committee to the Commission. The ACRS members are experts in many areas of engineering and science. The regulations require that significant licensing actions are referred to the ACRS for a review and report to the Commission. The regulations in 10 CFR 50.58, “Hearings and report of the Advisory Committee on Reactor Safeguards,” [7] do not require a construction permit or operating license application for a noncommercial research reactor to be referred to the ACRS. However, applications for construction permits or operating licenses for testing facilities and commercial research reactors are required to be referred to the ACRS for review and report. This is an example of the application of a graded approach. Testing facilities and commercial research reactors represent a higher level of risk than noncommercial research reactors and require a higher level of technical review.

Hearings for NRC licensing activities can be held before the Commission or Administrative Judges (either a single judge or a panel). Depending on the licensing action, there could be no hearing, a hearing that is held only if requested by a member of the public who has standing to intervene and a valid contention, or a mandatory hearing. The results of the hearing determine if a licensing action will be approved and if any additional requirements will be placed on the applicant.

The regulations in 10 CFR 50.58 require a mandatory hearing for an application for a construction permit for a testing facility or commercial research reactor. A hearing is not mandatory for the issuance of an operating license for these facilities. For noncommercial research reactors, hearings are not mandatory for either the issuance of a construction permit or operating license. In these cases, the Commission may choose to have a hearing if it determines it is in the public interest or would hold a hearing if a member of the public whose interest may be affected successfully requested a hearing.

The NRC applies a graded approach in license renewal of research and test reactors where the review process becomes more rigorous as the risk of a facility increases. Reactors with a thermal power level of less than 2 MW that are not seeking an increase in licensed power level undergo a streamlined review process.[8] Reactors with a thermal power level of 2 MW or greater or facilities seeking an increase in licensed power level undergo a full license renewal process. The scope of a streamlined license renewal is limited as compared to a full review. For facilities that qualify for a streamlined review, the primary focus of the review is on the sections of the safety analysis report that are most significant to safety. These review areas are reactor design and operation, accident analysis, radiation protection and technical specifications.

5. Graded Approach in the Application of NRC Technical Requirements

As the risk associated with a reactor increases, so do the technical requirements required by regulation. Nuclear power plants are subject to Appendix A to 10 CFR Part 50, "General Design Criteria for Nuclear Power Plants."[9] The General Design Criteria establish minimum requirements for the principal design criteria for water-cooled nuclear power plants. Research and test reactors are not subject to the design criteria of Appendix A. This allows the flexibility for a wide variety of designs, experimental facilities, and programs. The primary regulatory requirements for the design of research and test reactors are maintaining radiation doses to reactor staff and members of the public within acceptable limits during both normal operation and accident conditions. The NRC staff has issued documents which provide guidance on the design and licensing of research and test reactors. The primary document is NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," [10] which presents ways an applicant can use to meet the regulations. Alternatives are also acceptable provided they achieve the same outcomes.

More challenging is the application of a graded approach to the technical evaluation of a specific reactor. However, the reactor design and power level can result in a graded approach in the scope and depth of the licensing review. For example, the complexity of review differs if the reactor core is cooled by forced or natural convection. Increasing power level and the associated increase in fission product inventory can result in the need for engineered safety features. Engineered safety features are active or passive features designed to mitigate the consequences of accidents and to keep radiological exposures to the public and facility staff within acceptable limits. Some examples of engineered safety features are confinements, containments, and emergency core cooling systems. Depending on the reactor design, accident progression and amount of fission products released in the accident analysis, research and test reactors can have confinement systems to control radiological releases to the environment, or more complex containment systems. If decay heat could result in acceptable fuel clad temperatures, an emergency core cooling system would be a required part of the design.

For research and test reactor accident analysis, the NRC uses the concept of a maximum hypothetical accident (MHA). The MHA is a limiting postulated fission product release accident with a radiological consequence that exceeds those of any fission product release accident considered to be credible. The NRC staff usually applies a standard MHA which is dependent on reactor design. A graded approach is applied to the MHA. For example, as discussed in Chapter 13 of NUREG-1537, for plate fuel type reactors with low power levels that cannot result in fuel melt, the MHA is the stripping of cladding from a specified fraction of the fuel plates with the resulting release of fission products. For higher-powered plate reactors, the MHA is the melt of a specified fraction of the fuel plates in the core which results in a larger release of fission products.

In the area of emergency planning, the application of a graded approach is readily apparent. The requirements for emergency planning are found in Appendix E to 10 CFR Part 50, "Emergency Planning and Preparedness for Production and Utilization Facilities."[11] Appendix E states that the potential radiological hazards to the public associated with the operation of research and test reactors involve considerations different than those associated with nuclear power reactors. Consequently, the size of Emergency Planning Zones and the degree of compliance with the requirements of Appendix E will be determined on a case-by-case basis. NUREG-0849, the "Standard Review Plan for the Review and Evaluation of Emergency Plans for Research and Test Reactors" [12] is used by the NRC staff in the review of research and test reactor emergency plans. This document categorizes reactors by their thermal power levels. These levels are less than or equal to 100 W, greater than 100 W but less than 100 kilowatts (kW), greater than or equal to 100 kW to equal to or less than 2 MW, and greater than 2 MW. The emergency planning requirements are presented for each category of reactor. For example, a reactor with a power level of 100 W does not need to have the capability of the emergency organization to function around the clock for a protracted period of time, while reactors with a power level greater than 2 MW need to have this capability.

A graded approach is also taken in the area of reactor siting. The graded approach allows more flexibility to the siting of research reactors than test or power reactors. However, this siting flexibility does come with a restriction. The allowed radiation dose to members of the public from the major bounding accident evaluated for siting at research reactors is significantly less than for accidents at test or power reactors. The accident dose limits for research reactors are the same as the limits for normal operation given in 10 CFR Part 20, "Standards for Protection Against Radiation."[13] Power reactors and test reactors are sited under the requirements in 10 CFR Part 100, "Reactor Site Criteria."[14] Research reactors do not have specific siting regulations. The guidance in NUREG-1537 is used. That is why the majority of NRC licensed research reactors are on college campuses, with a number located in engineering buildings.

The NRC environmental regulations in 10 CFR Part 51, "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions," [15] reflect a graded approach. The issuance of a construction permit, operating license, or renewal of an operating license for a test reactor are require an environmental impact statement. These actions for research reactors involve the development of an environmental assessment. An environmental assessment usually contains less detail than an environmental statement and is used to support either a finding of no significant impact and a decision not to prepare an environmental impact statement or leads to a decision to prepare an environmental impact statement.

6. Graded Approach in Security

For research and test reactors, the graded approach in the area of security is primarily based on the type and amount of nuclear material that licensees possess. The regulations in 10 CFR 73.67, "Licensee Fixed Site In-Transit Requirements for the Physical Protection of

Special Nuclear Material of Moderate and Low Strategic Significance," [16] reflect a graded approach towards security requirements. Additional requirements apply as the amount of special nuclear material possessed increases from low to moderate strategic significance.

7. Graded Approach in the NRC Inspection Program

The research and test reactor inspection program [17] also follows a graded approach with three classes of reactors. This graded approach is in recognition of the increase in risk with increasing power level. Class 1 reactors have a thermal power level at or above 2 MW; Class 2 reactors have a thermal power level below 2 MW; and Class 3 reactors are permanently shut down. The period of time to carry out the inspection program and the depth of the inspection varies with reactor class. For example, normally the Class 1 inspection program is carried out over 1 year. The inspector will be on site for 2 weeks during the year. The Class 2 inspection program is over 2 years with the inspector on site 1 week per year. Inspection frequency can be increased for facilities with performance issues or in response to events. Inspectors normally examine a greater number of records for a particular inspection area at a Class 1 reactor than at a Class 2 reactor. The inspection areas are similar for Classes 1 and 2 reactors. Class 3 reactors are normally inspected once every 3 years with the inspection lasting a week or less. This timing and scope of this inspection is tailored to decommissioning activities that are under way.

8. Other Areas of the Application of a Graded Approach

There are other areas in the regulation of research and test reactors where a graded approach is used such as financial protection requirements, civil penalties, and fees.

For licensees subject to the financial protection requirements in 10 CFR 140, "Financial Protection Requirements and Indemnity Agreements," [18] the amount of financial protection required is based on the thermal power level of the reactor (see 10 CFR 140.11). A research reactor with a thermal power level of 10 kW or less needs to maintain financial protection in the amount of $1 million. The amount increases to $1.5 million for a research reactor with a thermal power level in excess of 10 kW up to 1 MW and increases again to $2.5 million for a research reactor with a thermal power level in excess of 1 MW up to 10 MW.

It is interesting to note that, if a violation of NRC regulatory requirements results in the imposition of a civil penalty, the amount of the civil penalty prescribed by the NRC enforcement manual [19] reflects a graded approach. The base civil penalty for a power reactor is $140,000, a test reactor, $14,000, and a research reactor, $7,000.

The NRC collects fees from various classes of licensees under 10 CFR Part 170, "Fees for Facilities, Materials, Import and Export Licenses, and Other Regulatory Services Under the Atomic Energy Act of 1954, as Amended."[20] Research and test reactors that are subject to fees were assessed a fee of $83,500 in fiscal year 2015. Power reactors were assessed a fee of $5,030,000 for the same period.

9. Summary

The graded approach has been applied to the regulation of research and test reactors from the earliest days of reactor regulation. The application of a graded approach is used in all aspects of NRC's regulation of research and test reactors.

Appendix 1: References

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, "Use of a Graded Approach in the Application of the Safety Requirements for Research Reactors," Safety Standard Series No. SSG-22, Vienna (2012).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, "Safety of Research Reactors," Safety Standard Series No. NS-R-4, Vienna (2005).

[3] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10 *Code of Federal Regulations* (10 CFR) 50.2, "Definitions."

[4] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10 *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities."

[5] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10 *Code of Federal Regulations* (10 CFR) 170.3, "Definitions."

[6] ATOMIC ENERGY ACT (As Amended), Chapter 2 Definitions, Section X. (1954) P.L. 83-703.

[7] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10 *Code of Federal Regulations* (10 CFR) 50.58, "Hearings and report of the Advisory Committee on Reactor Safeguards."

[8] UNITED STATES NUCLEAR REGULATORY COMMISSION, "Interim Staff Guidance on the Streamlined Review Process for License Renewal for Research Reactors," (2009).

[9] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10 *Code of Federal Regulations* (10 CFR) Part 50, Appendix A "General Design Criteria for Nuclear Power Plants."

[10] UNITED STATES NUCLEAR REGULATORY COMMISSION, NUREG-1537, "Guidelines for Preparing and Reviewing Application for the Licensing of Non-Power Reactors."

[11] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10 *Code of Federal Regulations* (10 CFR) Part 50, Appendix E "Emergency Planning and Preparedness for Production and Utilization."

[12] UNITED STATES NUCLEAR REGULATORY COMMISSION, NUREG-0849, "Standard Review Plan for the Review and Evaluation of Emergency Plans for Research and Test Reactors."

[13] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10 *Code of Federal Regulations* (10 CFR) Part 20, "Standards For Protection Against Radiation."

[14] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10 *Code of Federal Regulations* (10 CFR) Part 100, "Reactor Site Criteria."

[15] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10 *Code of Federal Regulations* (10 CFR) Part 51, "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions."

[16] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10 *Code of Federal Regulations* (10 CFR) 73.67, "Licensee Fixed Site In-Transit Requirements for the Physical Protection of Special Nuclear Material of Moderate and Low Strategic Significance."

[17] UNITED STATES NUCLEAR REGULATORY COMMISSION, "NRC Inspection Manual."

[18] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10 Code of Federal Regulations (10 CFR) Part 140, "Financial Protection Requirements and Indemnity Agreements."

[19] UNITED STATES NUCLEAR REGULATORY COMMISSION, "Nuclear Regulatory Commission Enforcement Manual."

[20] UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10 *Code of Federal Regulations* (10 CFR) Part 170, "Fees for Facilities, Materials, Import and Export Licenses, and Other Regulatory Services Under the Atomic Energy Act of 1954, as Amended."