Nuclear Safety Issues for the Rare Isotope Accelerator

(High Power Target Category)

Larry Ahle and Jason Boles
Lawrence Livermore National Laboratory
Livermore, CA 94551

Abstract

The intentional production, separation, and reacceleration of radioactive isotopes distinguish the Rare Isotope Accelerator (RIA) from most other accelerator facilities, where radiation and radioactivity are incidental to operation. Therefore, it is not obvious whether the Department of Energy (DOE) will classify the RIA wholly as an accelerator facility or portions thereof as a Hazard Category 2 or 3 nonreactor nuclear facility. This decision, based on the hazard of the facility, will affect the design, construction, operation, and maintenance of the facility; the extent of safety analysis documentation; and the quality assurance requirements for items or services that may affect nuclear safety. If portions of RIA are declared nonreactor nuclear facilities, preliminary calculations for proton beams on calcium oxide and uranium carbide targets show that quantities meeting the definition of a Category 3 nuclear facility can be produced. Additionally, simple hand calculations analyzing Category 2 thresholds, beam currents, and exposure durations, show that the buildup of actinide isotopes over the lifetime of RIA may approach Category 2 levels. The impact of these actinide inventories can be mitigated by a separate Category 2 storage building to accumulate irradiated target systems, thus keeping the target building as Category 3. This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Nuclear Facility or Accelerator Facility?

Is the Rare Isotope Accelerator to be considered a nuclear facility and subject to hazard classification or an accelerator facility? That is the first question to be answered when approaching the safety analysis. In other words, is RIA subject to the requirements of 10 CFR 830, *Nuclear Safety Management* or DOE Order 420.2A, *Safety of Accelerator Facilities*? The scope of 10 CFR 830 is the safety of DOE nuclear facilities, such as reactors or other facilities that involve radioactive and/or fissionable materials in such form and quantity that a nuclear hazard potentially exists to workers, the public, or the environment, but does not include accelerators and their operations. DOE Order 420.2A establishes accelerator-specific safety requirements which, when supplemented by other applicable safety and health requirements, serves to prevent injuries and illnesses associated with DOE or NNSA accelerator operations. Facilities for which DOE Order 5480.23, *Nuclear Safety Analysis Reports*, is applied are excluded from DOE Order 420.2A. 10 CFR 830 is the successor document to DOE Order 5480.23.

RIA could be subject to hazard classification because RIA may have the potential for significant radiological consequences, based on expected radiological inventories and possible release mechanisms. A Category 3 nuclear facility has the potential for significant localized consequences, and a Category 2 nuclear facility has the potential for significant on-site consequences beyond localized consequences. RIA may not be subject to hazard classification because RIA is an accelerator facility, which is specifically excluded from the definition of a nonreactor nuclear facility and, therefore, is outside the scope of 10 CFR 830, including hazard classification. David Pinkston of LLNL, who co-wrote DOE-STD-1027-92, *Hazard Categorization And Accident Analysis Techniques For Compliance With DOE Order 5480.23, Nuclear Safety Analysis Reports*, agrees with this interpretation.

However, the determination of this first question is often based on politics, management issues, and negotiations with DOE and not just hazard analysis. NIF for instance did its safety analysis assuming it was a category 3 nuclear facility while it was believed and confirmed to be a non-nuclear facility. For the Spallation Neutron Source (SNS), currently under construction at Oak Ridge National Laboratory, the decision was made in consultation with DOE to declare the target building a candidate Category 2 facility. The basis for classifying the target building as a candidate Category 2 nuclear facility during high power operation is the following:

- neutronic calculations showing SNS radionuclide inventory exceeding the curie threshold for Category 2 (dominated by Hg-203, Hg-197, and Gd-148), and
- the target material, mercury, will boil at temperatures that could hypothetically be achieved in a fire.

Making this decision will be one of the important early decisions for the RIA project team, and a crucial part of the decision making process will be early contact with the appropriate DOE officials.

Phased Operation and Facility Segmentation

The Spallation Neutron Source may also offer some guidance on how the safety basis of the RIA facility could be managed. The approval of safety documents and authorization to commission and operate the SNS facility is divided into two phases.[1] The first phase is associated with commissioning and low power operation of all SNS facility systems, including the proton accelerator, storage ring, beam stops, and target systems (prior to radioisotope accumulation which transitions the target system into a nuclear facility). The SNS Project Manager is responsible for establishing and approving the safety basis and operations for this phase in accordance with DOE Order 420.2A. The second phase is associated with high power operation of the facility, at which time certain target building systems will transition into a nuclear facility (successively, Category 3 and then Category 2) as the radioisotope inventory accumulates. This transition is planned to occur about six months to one year after project completion. For the SNS Project, Office

[1] Dehmer, P.M., Associate Director of the Office of Science for the Office of Basic Energy Sciences, April 25, 2002, memorandum to R.L. Orbach, Director, Office of Science, subject *ACTION: Approve the Annual Update to Appendix A of the Project Execution Plan (PEP) for the Spallation Neutron Source (SNS) Project*, DOE, Germantown, MD.

of Science has chosen to grant authority to approve safety documents for Category 2 nuclear facilities to the SNS Project Manager.

An additional approach that SNS uses is facility "segmentation." Their use of segmentation allows them to exclude the accelerator building and experimental halls from being subject to the requirements imposed on Category 2 nuclear facilities, so that only the target building is categorized as a candidate nuclear facility. The guidelines for segmentation are provided in DOE-STD-1027-92. In cases where hazards vary greatly in different locations within a facility, the concept of independent facility segments can be applied where facility features preclude bringing hazardous material together or causing harmful interaction from a common severe phenomenon. This concept allows facilities to avoid placing the excessive requirements derived for segments containing Category 3 or 2 amounts of material on co-located segments. In order to utilize segmentation, the independence of facility segments must be demonstrated in the facility's Documented Safety Analysis (DSA) to the extent that hazardous material in one segment could not interact with hazardous materials in other segments during a common severe phenomenon. For example, independence of HVAC and piping must exist in order to demonstrate independence for facility segmentation purposes. For segments that share a common wall, fire rated walls and doors are usually used.

One advantage SNS has over RIA in establishing segmentation is that in normal SNS operations, the radiological inventories are contained in a single location, the target. This is not the case for RIA whose concept is based on the idea of radioactive material leaving the target and transported to different areas of the facility. This may have its biggest impact on whether the experimental areas could be considered accelerator facilities while the target area a Category 2 or 3 nuclear facility.

An Unreviewed Safety Question Procedure Would Be Followed for Beam-Target Configurations Not in the Documented Safety Analysis

Included in the DSA is a systematic identification of the hazards and an evaluation of normal, abnormal, and accident conditions associated with the facility. Based on these hazard and accident analyses, hazard controls are derived to ensure adequate protection of workers, the public, and the environment. However, due to the expected flexibility of RIA, it would be difficult to analyze all possible beam-target configurations. If DOE declares RIA a nuclear facility subject to 10 CFR 830, it is expected that the DSA for a RIA facility would include radioisotope inventory calculations only for a few representative beam-target configurations. For beam-target configurations that are not specifically analyzed in the DSA, a DOE-approved Unreviewed Safety Question (USQ) procedure would be established and followed, as required by 10 CFR 830.203 for nuclear facilities.

The USQ process is used to determine the impact of a proposed activity on the facility's DSA. A proposed activity is a temporary or permanent change (e.g., hardware change) in the facility as described in the DSA, a temporary or permanent change in procedures as described in the DSA, a test or experiment not described in the existing DSA, or a potential inadequacy in the DSA. There are specific criteria that are considered to determine the impact of a proposed activity, but the process can be boiled down to the following: does the proposed activity increase the risk of an accident beyond what is accepted in the DSA or reduce the DSA's margin of safety? If the new configuration can be accommodated within the existing safety basis, then the approval of only facility management would be required prior to operation of the new configuration, and DOE approval would not be required. If not, DOE approval is required. The analysis of the proposed change must be done with the same rigor as the analysis in the DSA. Note that the facility's USQ process is subject to annual review and audit by DOE.

Scoping Radioisotope Production Calculations

Since the possibility exists for RIA to be subject to hazard categorization, a preliminary analysis of a few potential beam-target configurations is performed to make an initial estimate of radiological inventory levels in order to determine whether RIA should a Category 2 or 3 facility.

Table 1 lists the required production rates to reach Category 2 inventory limits assuming a one day, seven day, twenty-eight day, one year, and twenty year irradiation time. Only isotopes requiring production rates of less than 10^{16} atoms/second are listed since these are the only ones to contribute significantly to the inventories at RIA given the expected production rates. The rates in table 1 were determined from the limits given in DOE-STD-1027-92 except for ^{32}P, which is from LA-12846-MS, *Specific Activities,* a LANL document referred to by DOE-STD-1027-92 as a more complete list of specific activities.

The first observation is the small number of isotopes left to play a significant role in the categorization, especially for the short irradiation times. Some of the isotopes listed can be disregarded because the Z of the nucleus is significantly greater than 92. Since the highest Z beam and target presently planned for RIA is uranium, the production rates for Z greater than 92 nuclei should be small compared to the production rates listed in the table. Pu and Np are possible exceptions to this especially for the two-step ISOL target. Therefore isotopes of Am, Cm, and Cf can be ignored.

It also is apparent that over 20 years inventories of long-lived actinide isotopes, such as ^{227}Ac and ^{228}Th, can build up to the point at which their inventories are of concern. The required production rates for these isotopes fall with time, while the shorter-lived isotopes maintain a relatively constant required production rate. When comparing to the required production rate over twenty years, it is important to consider machine availability and how often a specific configuration is run on RIA. While this will decrease the expected average production rate over 20 years, the required production rate for ^{227}Ac of $3.4x10^{11}$ pps is low enough to cause concern. One possibility to deal with these isotopes is to remove them periodically from the RIA target building area to a co-located storage area. How this would affect the inventories from the ISOL target area and fragmentation line is described below. The storage facility could be designed as a Category 2 facility, but initially operated only as a Category 3 facility. Only at a later time if the inventories warrant would it be operated as a Category 2 facility. All of this would be independent of the RIA facility itself. In short, a separate storage area would provide greater flexibility in handling inventories and keeping the RIA facility below Category 2 limit. We believe this idea has already been somewhat discussed in the RIA community and we strongly endorse this idea.

Table 1. Production Rate (atoms/s) Required for a Category 2 Amount

Isotope	1 day exposure duration	Isotope	7 day exposure duration	Isotope	28 day exposure duration	Isotope	365 day exposure duration	Isotope	7300 day exposure duration
I-131	7.8E+14	I-131	1.4E+14	Ac-227	6.5E+13	Ac-227	5.0E+12	Ac-227	3.4E+11
Ac-225	1.6E+15	Ac-227	2.6E+14	I-131	7.1E+13	Th-228	1.1E+13	Th-228	3.4E+12
Ac-227	1.8E+15	Ac-225	2.7E+14	Po-210	9.9E+13	Po-210	1.5E+13	Cf-252	8.3E+12
Ra-224	2.1E+15	Po-210	3.8E+14	Th-228	1.2E+14	Cf-252	3.5E+13	Po-210	1.3E+13
Ra-223	2.4E+15	Ra-223	4.1E+14	Ac-225	1.2E+14	I-131	6.5E+13	Pu-238	1.6E+13
Po-210	2.6E+15	Th-228	4.8E+14	Ra-223	1.7E+14	Cm-242	7.9E+13	Am-242m	2.4E+13
Ra-225	3.0E+15	Ra-224	4.9E+14	Ra-225	1.9E+14	I-125	9.1E+13	Cm-242	6.2E+13
P-32	3.3E+15	Ra-225	5.0E+14	P-32	2.1E+14	Ac-225	1.1E+14	Am-241	6.4E+13
Th-228	3.4E+15	P-32	5.5E+14	I-125	3.3E+14	Ra-225	1.4E+14	I-131	6.5E+13
I-125	7.8E+15	I-125	1.2E+15	Ra-224	3.7E+14	Ra-223	1.4E+14	I-125	9.0E+13
		Cf-252	1.6E+15	Cf-252	4.1E+14	P-32	1.6E+14	Ac-225	1.1E+14
		Cm-242	2.1E+15	Cm-242	5.6E+14	Pu-238	2.9E+14	Ra-225	1.4E+14
		Bi-210	8.9E+15	Pu-238	3.8E+15	Ra-224	3.7E+14	Ra-223	1.4E+14
				Ru-106	4.6E+15	Am-242m	4.6E+14	P-32	1.6E+14
				S-35	4.6E+15	Ru-106	4.7E+14	Pu-241	1.7E+14
				Bi-210	5.6E+15	S-35	9.7E+14	Pb-210	1.8E+14
				Am-242m	6.0E+15	Na-22	9.9E+14	Na-22	2.3E+14
						Am-241	1.3E+15	Ru-106	2.4E+14
						Pu-241	2.3E+15	Ra-224	3.7E+14
						Pb-210	2.7E+15	S-35	9.2E+14
						Ce-144	5.2E+15	Am-243	1.1E+15
						Te-129m	5.2E+15	Cm-245	1.2E+15
						Bi-210	5.5E+15	Sr-90	2.1E+15
						Te-127m	6.2E+15	Cs-134	2.2E+15
						Cs-134	7.7E+15	Ce-144	3.1E+15
								Pu-239	3.6E+15
								Ti-44	4.8E+15
								Eu-154	5.2E+15
								Te-129m	5.2E+15
								Bi-210	5.5E+15
								Te-127m	5.6E+15
								Eu-152	7.5E+15
								Co-60	7.6E+15
								Cs-137	8.7E+15

Conclusion

The question of whether the RIA facility will be classified as a nuclear facility or as an accelerator facility only cannot be determined from analysis alone due to the allowances of the regulations and the approach that the DOE Office of Science has taken with SNS. Simplistic scoping calculations for proton beams on various targets indicate that the RIA facility is most likely to be a Category 3 nuclear facility, but could produce Category 2 quantities of radioisotopes over the lifetime of the facility. The use of segmentation can be used to limit the Category 2 requirements to only the storage building, leaving the target building and, possibly, the experimental hall classified as Category 3, and the driver linac as an accelerator facility.