Risk-Informed Material Categorization

Brian Kloiber
Oklo Inc.
3190 Coronado Drive, Santa Clara, CA 95054
brian@oklo.com

Abstract

The current method of categorizing nuclear material in the United States is too heavy handed for the current age, and its bluntness is a poison to progress. Material categorization refers to the method of specifying the attractiveness of nuclear material to a bad actor and the level of security, controls, and accounting required for a facility. The U.S. Nuclear Regulatory Commission (NRC) classifies material within Title 10 of the *Code of Federal Regulations* Part 73 using the quantity of nuclear material onsite and the material's enrichment to determine a material category of I, II, or III. This rating has far-reaching regulatory requirements that prescribe certain material-handling procedures, reporting requirements, prescriptive security measures, personnel organization, and more. However, using only mass and enrichment yields an opaque assessment of the material's attractiveness. This method neglects the physical form of the material, which can present significant difficulty in harvesting special nuclear material despite its total mass and enrichment. Further, categorizing materials in this way leads to overprotecting and imposing requirements that stifle development with artificial costs at a time when there is an urgent need for new and expanded capabilities in nuclear power production and nuclear material processing.

Instead of viewing material categorization simply as a two-dimensional measurement of attractiveness to adversaries, it should be risk informed to accurately characterize attractiveness. Incorporating a risk-informed approach considers more than surface-level measurements of the nuclear material and adds operational context. This context includes factors such as proactive friendly actions, the environment that exists around a licensed facility, and the nuclear material's physical form. One of the largest drivers of cost burden is physical security against violent design basis threats. Attempts against hardened locations are conspicuous activities that require thorough planning as well as resourcing restricted materials. This behavior deserves consideration for reducing risk because there may be resources around a facility that would detect and interdict such threats. Therefore, considering operational context analytically can avoid unnecessary cost burdens when it can be shown that the risk-informed method provides an equal level of protection to the mass-and-enrichment material categorization method. By reducing cost barriers, the risk-informed framework expands the opportunity for advancement in the nuclear industry.

Keywords

Material categorization, security, risk-informed

1. Introduction

1.1 Defining adequate levels of protection

In Title 10 of the *Code of Federal Regulations* (10 CFR) Part 73, material categorization is the entry point for most U.S. Nuclear Regulatory Commission (NRC) regulations concerning physical security requirements at a site using nuclear material. In this way, material categorization acts as a measurement of risk and attractiveness for a particular site. The general performance objective of all security regulations administered is to ensure that activities involving special nuclear material do not present an unacceptable level of risk to the public. NRC licensees control risk to the public primarily through physical security controls around regulated activities with special nuclear material.

Protection and security are abstract, qualitative concepts that are difficult to measure because they are contingent upon repelling a predicted adversary. It is important to establish a common definition of protection for the purposes of this article because the intent is to ultimately demonstrate that an alternative risk-informed material categorization framework can provide at least a comparable level of protection to that offered by NRC regulations. For the purposes of discussing levels of protection or security, the terms "protection" and "security" will be in reference to their ability to protect against threats outlined in the following section using all available methods and risk considerations in an environment. To remain in compliance with existing regulations, the risk-informed material categorization will assume that the security mandated by the existing material categorization without risk considerations is "adequate." Then the alternative method will demonstrate how it achieves at least comparable levels of security performance through a broader analysis that includes risk considerations and adjusted physical security controls.

1.2 The threat of radiological sabotage and theft

The context of what threats NRC-regulated activities must protect against is important because it is different from the general concept of corporate security. Outside of the nuclear industry, the intent of physical security is to prevent disruptive behaviors such as violent crimes, capital thefts, vandalism, and intrusion, to name a few. These are very important considerations to deter and protect against for any organization to sustain operations, but they are the responsibility of the business to act in its own interest of being profitable and prosperous. The NRC, on the other hand, regulates to ensure acceptable levels of risk against the threats of radiological sabotage and theft of special nuclear material.

Without diverging into an esoteric discussion over the measurements of dose rates or material attractiveness of a fissile fuel, a basic summary of sabotage and theft sufficiently explains how each endangers the public. Radiological sabotage involves releasing and dispersing radioactive material. For example, this can be done by severely damaging fuel in a nuclear reactor while compromising the multiple systems around it, such as the reactor vessel, or by using radioactive waste as an ingredient in a dirty bomb. The options are numerous, but the result is the same: an attacker intentionally spreads radioactive material outside of its intended location of use and exposes the public to excessive levels of radiation. Theft can be related to radiological sabotage in that it may involve an adversary obtaining material for a dirty bomb. However, the core threat of theft is the illicit possession of highly enriched material that could accelerate the production of a nuclear weapon.

2 Existing material categorization

2.1 Kilograms and enrichment

At its foundation, the NRC's material categorization framework works with two inputs: the mass of special nuclear material and the material's enrichment in specific isotopes useful for fission. Table 2-1 shows the NRC's material categorization for grading various amounts of specific isotopes. The most restricted are isotopes of plutonium and uranium-233 because of their especially attractive use in nuclear weapons. Uranium-235, while valuable in nuclear weapons as well, is often diluted with uranium-238 and has a high level of technical difficulty associated with enriching it to the high concentrations needed for use in a weapon. The licensed activities that the NRC regulates with special nuclear material dictate the amount and type of material that a facility uses and therefore the category of the facility.

Table 2-1: The NRC's current material categorization[1]

Isotopes	Cat. I	Cat. II	Cat. III
Uranium, enriched to ≥ 20% U-235	≥ 5 kg	≥ 1 kg < 5 kg	≥ 15 g < 1 kg
Uranium, enriched to ≥ 10 and < 20% U-235	N/A	≥ 10 kg	≥ 1 kg < 10 kg
Uranium, enriched to greater than natural occurrence and < 10% U-235	N/A	N/A	≥ 10 kg
Plutonium and U-233	≥ 2.5 kg	≥ 0.5 kg < 2.5 kg	≥ 15 g < 0.5 kg

2.2 Level of protection

A facility's material categorization category places the entire site into a regulatory space that specifies both the postulated threat it must defend against and how it must protect against that threat. The regulatory requirements for site security include specific measures such as minimum numbers of armed guards, orientation of barriers, levels of illumination, and testing schedules for monitoring equipment, to name a few. Among the three levels of material categorization, however, the level of prescribed security varies significantly.

At the lowest level of material categorization and protection, a category III facility, the expectation is to monitor for unauthorized access or theft and notify authorities accordingly. The level of requirements is scant in comparison to those for the other two categories. Crossing the threshold into category II, the requirements elevate to background checks for established access control programs, searches, and response organizations. Further up into category I, the level of protection grows with greater detection, armaments for guards, and barrier isolation.

The existing material categorization framework is rigid and administered rather bluntly after bucketing material by mass and enrichment. Such a rigid framework provides clear requirements but comes at a significant cost to both the facility and the facility's customers. Overall, there is a notable jump moving from category III to either II or I. The difference in material creates a very fine line, but a change on the margin opens the question of whether there should be flexibility in the rating to properly account for the risk to the nuclear material in use. Instead of punishing activities on the wrong side of a margin and

[1] The regulations in 10 CFR 73.2 also include definitions for a formula quantity of material that accounts for masses and enrichment of mixtures including uranium-233, uranium-235, and plutonium, but for clarity, they are not included in this table.

limiting innovation, there is an opportunity to provide flexibility and incentivize progress in industries involved in the use of nuclear material.

Besides the counterproductive result of step-function security requirements based on only two measurements, there is another oversight that results from the security measures that existing NRC material categorization requires. Required physical security control measures are reactive in nature and assume that licensed sites exist in a vacuum that an adversary will inevitably attack with significant and sophisticated force. While this approach is robust against a specified threat, the scope is narrow to a specific threat and invites complacency with no incentive to have awareness of incipient threats before they occur. There are multiple areas for improvement to this approach both in providing better security and in the opportunity to allow informed decision making by licensees to reduce their regulatory burden.

3 Risk considerations

3.1 Proactive protection measures

The existing material categorization strategy is reactive in nature, but a proactive approach could better inform the resulting security requirements. Existing NRC material categorization is reactive because it assumes that an attack will successfully be resourced and executed to perfection without any advance indication to the facility. Making this assumption neglects and underestimates the difficulty required for a sophisticated and complicated attack on a facility. Conducting an attack on a nuclear facility would present multiple types of indicators that a general surveillance effort, synchronization with law enforcement, and information sharing with federal agencies could assist in identifying. Applying a proactive approach in a site's defensive strategy provides early indication to modify its security posture, interdict a developing threat, and overall reduce the risk to the facility. With a lower risk to a facility, it can afford to consider a lower tier of security requirements. The indicators of preparation for a sophisticated attack include gathering information to plan, resourcing of sensitive materials, and rehearsal of actions to conduct the attack.

An adversary cannot easily infiltrate and successfully attack a site that uses special nuclear material without significant knowledge of its layout, operations, or potential vulnerabilities. The reason for this is that regardless of the category of their material, all sites employ engineered efforts to prevent access to sensitive areas and actively withhold certain key portions of information related to those protections. Depending on the facility, required programs protect critical information as safeguards or even classified national security information. A proactive approach, which is already the standard for controlled information, would track attempts at assembling information, siphoning information to persons without access, or using information nefariously. Considering the presence and performance of programs that detect patterns of such indicators as an early warning sign of a potential attack is an opportunity to inform the risk to a site. Greater or lesser detection resources can be one of the various risk-informing inputs to adjusting external support to the security of a site and therefore the overall material categorization of the site.

Another indicator available for performance assessment of early detection is the aggregation of the sophisticated equipment needed for a design-basis threat attack on a licensed facility. To use the NRC's description of the design basis threat against nuclear power plants from 10 CFR Part 73, "Physical protection of plants and materials," as an example of the most challenging of threats to a particular site, Section 73.1, "Purpose and scope," defines the attacking force as a group of individuals with military training, automatic handheld weapons, explosives, and specialized equipment used to compromise the safety of a reactor. While the NRC controls specific details of the adversary characteristics assessed as at least safeguards information, the level of information provided in the regulations is sufficient to see that the types of equipment available to postulated attackers are all controlled items monitored by at least the U.S. Government's Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF). The individual physical barriers and layers of physical security between the public and special nuclear material for both radiation protection and general access are significant. Forcibly breaching the layers of protection present for a site demands a considerable aggregation of controlled substances in addition to the firearms that would best support an assault on a facility. The ability to detect these types of illicit activities includes indicators and early notification signs like the planning indicators that risk-informed material categorization can integrate into an assessment of a site's risk.

A final example of an attack indicator is the detection of rehearsal activities. Although often overlooked as an essential activity, rehearsals are essential to the type of successful sophisticated attack required to defeat an engineered physical security system. Conducting a sophisticated attack, as the NRC assesses in force-on-force evaluations, and the main concern of physical security systems, is a significant investment. Successful preparation requires gathering the necessary safeguarded technical information on a site, cultivating the knowledge of how to successfully sabotage a facility, and acquiring the specific illicit equipment to resource an attack. An adversary that uses rehearsals is also indicative of a sophisticated threat, with military training, that would make efforts to maximize its chances of success and minimize its own risks. Therefore, one can expect that there are signs of rehearsals of actions, such as rehearsing breaching techniques against specific barriers employed at a site, constructing site mockups, and practicing attacks specific to the vulnerabilities at a particular site. Like all examples of potential attack indicators, detection capability of rehearsals related to an attack on a protected facility is another form of informing the risk to a particular site and how to categorize material.

3.2 The operational environment

Another type of risk consideration is the operational environment variables that surround a licensed site and form the context of a situation in an area. Operational environment variables include characteristics such as political, military/police, economic, social, information, and infrastructure. These variables and the analysis tool to describe them come from military staff planning tools and schemas outlined in the Army Doctrine Publication 3-0. A common method of analyzing operational variables is to organize them in a grid matrix to evaluate each variable through the lens of the area as a whole, structures, capabilities, organizations, people, and events. The output of such an analysis is a comprehensive aggregation of the existing factors to inform whether a site is in a relatively high-, low-, or normal-risk area based on the operational environment it occupies. Insights from such an analysis can have powerful impacts on risk-informing the material categorization of a licensed site. As a basic example of potential positive factors, certain locations could have tightly knit communities, be near federal installations with a vested interest in monitoring for illegal activities, or have especially prohibitive arms control statutes. On the opposite side, a site may be near a concentration of organized crime, domestic terrorist activity with minimal oversight, or little law enforcement in the immediate area. Both extremes can paint a vastly different picture. A particular site may warrant a category III rating instead of category II to be commensurate with its risk profile, or vice versa.

3.3 Form of material

The final risk consideration is the physical form of a material and characteristics that can determine how usable a material is in theft or sabotage. Considering the physical form of the material is important because it clarifies an assumption inherent in the existing material categorization table. To illustrate this point, consider a fictional site licensed to possess up to 1 kg of plutonium. According to NRC material categorization standards in Table 2-1, this would be a category II facility. By reading the description of this facility, it sounds like there are whole, concentrated pieces of plutonium onsite totaling 1 kg of solid material, and it would be reasonable to assume that a significant physical security presence, as described by the appropriate regulation, is appropriate. An adversary could steal a solid piece of material for a threat of theft or detonate in an improvised nuclear device to distribute radioactive material. However, these dangers are not the same if the 1 kg of plutonium is in a distributed form and diluted in a larger volume such as a metallic alloy or dissolved in caustic solution at a prohibitively high temperature. The solid physical and diluted forms are clearly not equal. An adversary cannot use a diluted quantity of nuclear material to the same degree as other forms, so dilution is worth considering in a site's risk level. Leveraging this insight when possible provides yet another opportunity to incentivize innovative processing techniques that avoid unnecessary costs to commercial entities.

4 An alternative approach to material categorization

4.1 Framework criteria for success

The previous sections introduced various considerations that can augment the evaluation of the material categorization process currently employed by the NRC. Ultimately, the goal of an approach to material categorization that spurs innovation is to establish a framework for assessing levels of protection commensurate with the risk presented by a particular facility. Assessing a broader evaluation of a facility's risk profile incentivizes licensees to make deliberate choices that reduce their risk to the public because it can avoid costs while maintaining an adequate level of protection. To refresh the idea of measuring the level of protection from the introduction, adequate protection ensures that activities involving special nuclear material do not present an unacceptable level of risk to the public. Existing material categorization establishes that the performance of the physical security measures alone, required by particular masses of isotopes, is an acceptable level of protection. The following section will describe the proposed risk-informed material categorization framework that evaluates protection with four criteria instead of just the lone application of onsite physical security measures. These additional criteria will produce the risk-informed element of an alternative material categorization framework to demonstrate equivalent levels of protection to existing material categorization while using fewer physical security controls.

4.2 Weighted criteria matrix and comparison approach

Determining the level of security controls needed for adequate levels of protection in new and novel nuclear facilities is analogous to military planners evaluating plans for a defensive position in unfamiliar territory. To make an informed decision on the effectiveness of a plan and the proper application of resources, military decision makers select criteria to evaluate the plans based on how each plan scores across the criteria. Each criterion can have a different weight based on its assessed importance to the overall evaluation of the plan. The tool that organizes the plan options, criteria, and weighting factors is a weighted criteria matrix. This tool can adapt to also evaluate different material categorization options based on their physical security controls and risk considerations for an assessment of protection that is commensurate with their presented risk.

The goal is to score and evaluate a material categorization level using the existing method against other levels of existing categorization with risk considerations. After evaluating all options, the analysis can identify whether a lower level of physical protection onsite reduces the overall protection to the public. To objectively assess protection, the risk-informed material categorization framework will define protection as the aggregate scoring of physical security measures in addition to the risk considerations of the operational environment, detection of planning indicators, and material form. Physical security measures come from the existing framework of material categorization used by the NRC, a baseline level of protection to compare against. The remaining criteria expand the evaluation of protection from material categorization and use the risk-informing characteristics defined earlier. Since the existing method of material categorization does not account for risk insights, the framework ranks categorization options in a relative manner. For example, if a site has a net favorable amount of assets in its operational environment for adaptability, then the risk-informed option receives a higher score, but the inverse is also possible by using risk-informed material categorization. If the operational environment is not conducive to protection, the risk-informed material categorization would score lower than the existing material categorization in the criteria of operational environment for its overall protection score.

In the examples that follow, each compares three cases. There will be one baseline measure with existing material categorization (i.e., not risk-informed) and two different levels of risk-informed physical security controls; higher scores mean more protection. There are two ranks available for each criterion, representing a binary measure of more or less protection. A higher rank in a criterion will receive a 2 and the lower rank will receive a 1. As a result, when comparing the level of protection for a criterion, such as physical security controls, there will be ties. The purpose of a weighted criteria matrix is to determine relative levels of protection for the analyzed cases, but the scores are not intended to be an absolute measure of protection. For example, we can conclude that option A scoring 10 is more protected than option B scoring 9, but we cannot directly compare these scores to those of a separate analysis or make blanket statements such as that a site would need a score greater than 9 to be sufficiently protected. Each weighted criteria analysis serves to compare alternatives to the baseline level of protection provided by the current material categorization method for a particular site.

4.3 Applications of risk-informed material categorization

The alternative nature of this risk-informed material categorization matrix will show that in some instances, the level of protection from existing NRC material categorization may not be commensurate with the risk to material because it is overlooking certain risk insights. Setting up an example use of this framework requires identifying three cases of material categorization: a base rating, a risk-informed base rating, and a risk-informed reduced rating. The base rating corresponds to the existing material categorization method, the risk-informed base rating is an evaluation of the same category with risk insights, and the risk-informed reduced rating is a lower level of material categorization than the base with risk insights. For the purposes of showing an example of shifting protection requirements on the margins of material categorization, the base rating will represent a category II facility in the existing material categorization method, and the reduced rating will represent a category III facility in the existing material categorization method. Table 4-1 shows the layout of the initial setup for the weighted criteria matrix.

Under the risk-informed material categorization framework, protection is a measure of the four criteria: physical security controls present, the proactive protection measures, operational environment, and material form. These criteria come from the existing material categorization physical security controls in Section 2 and the risk considerations introduced in Section 3. Each criterion in Table 4-1 has a weighting factor in parentheses. To give credit and increased consideration of the importance of existing regulatory requirements and the steep increase of protection between material categories, physical security measures carry a weighting factor of 2. The greater weighting factor represents the accepted protection importance of physical security controls, while the other risk insight criteria carry a weight of 1. Multiplying a protection criterion ranking and its weighting factor yields a score for that criterion. The final column sums all scores of criteria for a total protection score to compare against the other material categorization ratings. Larger numbers for ranks and scores represent better protection ratings. For example, the rank of physical security controls at a category II facility will have a higher rank represented with a 2 because they are more robust than the category III facility, which will receive a rank value of 1. Then both ranks are multiplied by the weighting factors for a criterion score.

Table 4-1: Example risk-informed comparison matrix setup

Material categorization	Physical security (2)	Proactive measures (1)	Operational environment (1)	Material form (1)	Total protection score
Base rating					
Risk-informed base rating					
Risk-informed reduced rating					

4.3.1 Example: Effect of favorable risk insights

The first example will use favorable risk insights in all criteria to demonstrate the maximum potential effect of risk-informed material categorization. Table 4-2 shows the result of a universally favorable integration with government agencies for proactive protection measures, operational environment, and a material form that is not easily accessible. The following is a demonstration for the original "base rating" ranking, scoring, and totaling to show the application of the weighted criteria matrix and the method for generating a total protection score in Table 4-2. For the physical security of the base rating, the two other options are a risk-informed base rating and a risk-informed reduced rating. The physical security for a base rating and a risk-informed base rating are the same, but both are greater than the reduced rating. Therefore, the base and risk-informed base ratings both receive a rank of 2, while the risk-informed reduced rating receives a rank of 1. The physical security score for the base rating is 2 multiplied by the weighting factor of 2 assigned to the physical security criterion, resulting in a total score of 4. In the remaining three risk consideration criteria of proactive protective measures, operational environment, and material form, the base rating rank is 1 because it does not consider these factors. The risk-informed options assess that they are comparatively better, and both receive a 2. All the risk considerations have weights of 1, and the base rating scores 1 multiplied by 1 for each of these three criteria. Lastly, the total protection score for the base rating is the sum of the base rating's scores in all criteria: 4, 1, 1, and 1, for a total of 7.

Comparing the two base rating options, the result from the weighting matrix shows, as would be expected in a fully favorable case, that the site is more protected than is accounted for in existing material categorization. The amount of physical security is equivalent, but there is a positive level of credit from the risk consideration criteria. Therefore, the level of protection in this example is greater than the total level of protection required and existing in the base rating.

Another important result is that the reduced rating shows that despite there being a reduction in physical security controls, there is at least the same assessed value of total protection as the base rating. The risk-informed, reduced material categorization total protection score is 8 and is greater than the protection score of the base rating from the existing material categorization framework. Per the original context of the example, this would mean that a facility initially required to be a category II facility under the existing material categorization would have adequate protection with category III site security measures in this favorable environment.

Table 4-2: Favorable risk-informed material categorization results

Material categorization	Physical security (2)	Proactive measures (1)	Operational environment (1)	Material form (1)	Total protection score
Base rating	2(2)	1(1)	1(1)	1(1)	7
Risk-informed base rating	2(2)	2(1)	2(1)	2(1)	10
Risk-informed reduced rating	1(2)	2(1)	2(1)	2(1)	8

4.3.2 Example: Effect of unfavorable risk insights

As mentioned earlier, risk-informed material categorization can also highlight when the material categorization and physical security controls are less than expected. Consider the example results in Table 4-3. In this example, all risk considerations are negative and present additional risk to the site under consideration. While the base rating of the site is expected to have a score of 10, it is a 7 when accounting for risk considerations. This result indicates that the site is less protected than expected and may warrant either additional external support to adjust its rating of risk considerations or possibly increased physical security controls. Further, in the reduced rating case the score is still lower, illustrating the utility in using this risk-informed approach to identify not only cases in which it may be appropriate to reduce physical security requirements but also cases where it would be inappropriate to do so. Such situations show that it would be prudent for a licensee to adjust their risk profile. All criteria are available to influence but carry different costs that inform decision making. Voluntarily committing to a higher category of physical security controls will come at a significant cost but will improve total protection significantly. Significant changes such as moving from category II to category I protection measures warrant a reevaluation of all risk considerations and potentially have spillover effects to the operational environment and proactive measures with the additional capabilities available. Alternatively, selecting a more favorable site with more proactive measures or using more dilute material forms could prove to be more economical options and again incentivize risk-mitigating actions by licensees deploying innovative nuclear technology.

Table 4-3: Unfavorable risk-informed material categorization results

Material categorization	Physical security (2)	Proactive measures (1)	Operational environment (1)	Material form (1)	Total protection score
Base rating	2(2)	2(1)	2(1)	2(1)	10
Risk-informed base rating	2(2)	1(1)	1(1)	1(1)	7
Risk-informed reduced rating	1(2)	1(1)	1(1)	1(1)	5

5 Conclusion

It is possible to improve upon the NRC's existing method of material categorization with risk-informed considerations. Currently, material categorization only considers the mass and concentration of certain isotopes to direct levels of physical security controls in regulations. Omitting risk considerations overlooks the impact of the robust detection capability of existing federal agencies to identify efforts to prepare a sophisticated attack against a nuclear site and the impact of the specific operational environment of the facility. Additionally, current material categorization assumes all special nuclear material is equally usable for all adversary threat purposes. However, pure metal in solid form is significantly different in attractiveness from special nuclear material dissolved in large volumes of benign material. These valuable risk considerations offer the opportunity to develop a more comprehensive assessment of the threats facing the special nuclear material at a licensed site.

The proposed framework of accounting for risk considerations in risk-informed material categorization is to employ a weighted criteria decision matrix. This approach allows the analyst to capture an objective measure of protection that is acceptable in the NRC's current material categorization. Additionally, the risk-informed framework identifies when there is an incongruence in the amount of protection expected and what is provided. Risk-informed material categorization identifies when a system is physically overprotected, does not require the prescribed level of physical security controls, and incentivizes a more holistic approach to protecting special nuclear material. Correcting an overprotected system with fewer security controls reduces financial burden to the site owner but maintains the overall level of protection specified by the existing material categorization approach. This cost-saving, incentive-boosting effect is possible because risk-informed material categorization accounts for the protective effects of the variables and assets that can exist around any nuclear site. Neglecting risk considerations leads to overprotecting sites, while accounting for them can support broader deployment of nuclear sites with more latitude for innovation.