Including Safeguards in the Radioactive Waste Planning Process

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Abstract

When States create or assess their radioactive-waste program, they must be able to examine the entirety of the process, from generation to disposal, for their entire inventory of actual and expected wastes. This integrated approach, ideally done prior to generation of radioactive wastes, will work to ensure a harmonized management approach that does not leave any wastes without a viable disposal pathway. One often-overlooked aspect of this process is the role of State safeguards obligations on wastes containing nuclear materials. For disposal in a non-safeguarded disposal site, the requirements to remove nuclear materials from the safeguards accountancy system may be more stringent than the associated safety case underlying the disposal site. This requires a degree of planning to ensure wastes can be dealt with according to all stakeholder requirements. However, this stringent requirement can be removed by planning to emplace the wastes in a safeguarded disposal site, which has a different set of requirements to be met.

This paper aims to lay out the various pathways that States can use to dispose of waste materials containing nuclear materials, both in safeguarded and non-safeguarded disposal sites. The possible sample space includes wastes classified as exempt-level wastes destined for municipal landfills through to high level wastes requiring geologic isolation; this paper will examine the possible disposal options for each classification of waste. The important factors for each of the branches will be discussed including the physical form of the waste, the concentration of nuclear materials, and the status of safeguards measures applied to the wastes or the steps required to remove those measures. Each of the various pathways identified in this paper has benefits and drawbacks, each with associated economic, political, and scientific hurdles to overcome. Knowledge of the complete range of possible routes that can be employed by a State to safely, securely, and economically manage their waste will assist States to make informed choices for their inventories and start the appropriate consultations with stakeholders

Introduction

Radioactive waste management is a critical issue for many States, as it may pose significant risks to human health and the environment if not properly treated and disposed. Effective management of radioactive waste requires an integrated approach that covers the entire process, from generation to disposal [1]. This approach must ensure a harmonized management approach that leaves no materials declared as waste without a viable disposal pathway. However, one often overlooked aspect of this process is the role of safeguards obligations on wastes containing nuclear materials. Specifically, we are referring to plutonium, uranium enriched in U-235, uranium-233, natural uranium, depleted uranium and thorium as defined in the IAEA statute. [2]

There are typically stringent requirements for removing nuclear materials from a State's safeguards accountancy system that will allow them to be disposed in a non-safeguarded disposal site; this process is referred to as 'termination' of safeguards and requires that the nuclear material be 'practicably irrecoverable' [3]. The requirements for this process are based on different criteria than are typically considered for disposal (i.e., non-proliferation goals vs. safe disposal and protection of human health and the environment), and as such there can be confusion or conflict when termination criteria are compared to disposal criteria. This simple fact is why radioactive waste management requires careful planning to ensure that all stakeholder requirements can be met. The benefit, when done correctly, is that States may be able reduce the cost of disposal. However, the issue can be avoided if the wastes are placed in a safeguarded disposal site, thus retaining safeguards measures on the material and only subject to the waste acceptance criteria (WAC) for the site and not the stringent termination criteria. The balance between these approaches must be weighed in each State and as such, the States must be able to examine their entire inventory of actual and expected wastes to determine the appropriate disposal pathways, ideally prior to the generation of radioactive waste.

To understand the interaction between these two frameworks, a basic understanding of each must be obtained, including how they interact. This paper will provide a short summary of radioactive-waste management principles followed by a discussion of the criteria for termination of safeguards. These will then be combined to provide the possible suite of disposal options for radioactive wastes containing nuclear materials.

Basics of Radioactive Waste Management

The International Atomic Energy Agency (IAEA) has established several principles for radioactive waste management. These principles include (adapted from [4]):

- Responsibility: Radioactive waste generators are responsible for the safe management and disposal of the waste they generate.
- Protection of people and the environment: Minimize the radiation exposure for workers, the public, and the environment now and in the future.
- Justification: The benefits of using nuclear technologies must outweigh the potential risks of generating radioactive waste.
- Optimization: Radioactive waste management practices should be optimized to minimize radiation exposure and waste volumes while ensuring safety.
- Safety: Radioactive waste management practices should be designed and implemented with safety as a primary consideration.
- Compliance with regulations: Radioactive waste management practices should comply with applicable regulations and standards.
- Transparency: Radioactive waste management practices should be transparent and open to public scrutiny.

Overall, the principles of radioactive-waste management aim to ensure that radioactive waste is managed and disposed of safely and responsibly, in a way that protects people and the environment from potential radiation hazards. This approach is therefore tied directly to the disposal location of the waste. The IAEA classifies radioactive waste based on its physical characteristics and the necessary separation from the biosphere to meet these safety principles. Typically, all of the actions involving a waste package (treatment, immobilization, packaging) are considered when classifying the waste materials. General Safety Guide GSG-1 “Classification of Radioactive Waste” [5] gives the following categories of radioactive waste, which are summarized below:

- Exempt waste (EW): Waste that meets the criteria for clearance, exemption or exclusion from regulatory control for radiation protection purposes.[i]
- Very short-lived waste (VSLW): Waste that can be stored for decay and cleared from regulatory control, typically encompassing isotopes for research and medical purposes.
- Very low-level waste (VLLW): Waste that does not meet the criteria of EW, but that does not need a high level of containment and isolation and is suitable for near surface disposal in landfill type facilities with limited regulatory control.
- Low-level waste (LLW): Waste that is above clearance levels, but with limited amounts of long-lived radionuclides and is suitable for disposal in engineered near surface facilities.
- Intermediate-level waste (ILW): Waste that, because of its total activity or long lived radionuclide content, requires a greater degree of containment, isolation, and disposal at greater depths, of the order of tens of metres to a few hundred metres.
- High-level waste (HLW): Waste with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process or waste with large amounts of long lived radionuclides that require disposal in deep, stable geological formations usually several hundred metres or more below the surface.

For the purposes of this paper, we will be mainly looking at the following categories: Exempt Wastes; Very-Low-Level and Low-Level Waste; Intermediate-Level and High-Level Waste. This simplification is based on the disposal options present. For EW general landfill facilities are suitable; for VLLW and LLW, materials are sent to near surface disposal facilities; and ILW and HLW are sent to underground disposal facilities of varying depths. While there may be practical and economic differences between VLLW and LLW and ILW and HLW disposal facilities, for the purposes of this paper they will be considered together.

Wastes containing nuclear materials will typically fall into one of these three groups based on the concentration of the radionuclides in the waste materials. The specific limits for each group are typically established in national regulation and their disposability will be set forth in the associated disposal facility’s WAC. The limits in the WAC can vary from site to site as they are based on the specific safety assessment for the disposal site in question.

Radioactive wastes will typically be subjected to various treatments to change their physical form or reduce their hazardous characteristics, immobilized if necessary, and packaged for disposal [1]. The end result is a conditioned and packaged waste form suitable for disposal. This process can range from very simple (containerization of raw wastes) to elaborate (vitrification of liquid radioactive wastes). However, every step in the process will move the waste form closer towards a final form that will meet the WAC and can be placed in the disposal site.

Termination of Safeguards

The State is allowed, under specific circumstances, to terminate safeguards on nuclear material, subject to IAEA approval. For States under a Comprehensive Safeguards Agreement, these conditions can be found in paragraphs 11-13 and 35 of the model text [3]. The reasons for termination range from nuclear loss, to extreme dilution, to use in non-nuclear applications. From a waste-management perspective, when a State is producing conditioned waste forms the applicable language is found in paragraph 11 that States that safeguards measures can be terminated when the nuclear material is practicably irrecoverable. This standard of practicably irrecoverable is controlled by two related quantities: the physical characteristics of the waste form and the concentration of nuclear material in the waste form.

In practice, there are six waste groups that are used to categorize wastes during discussions surrounding termination of safeguards [6]:

- Unconditioned
- Overpacked, compacted or treated in any manner presenting a moderate additional recovery effort
- Macroencapsulated within a polymeric, cementitious or bitumen-like matrix
- Microencapsulated or incorporated within a polymeric, metallic or cementitious matrix
- Incorporated in a vitrified matrix
- Incorporated in a ceramic matrix

As the physical conformation of the waste moves from unconditioned to ceramic, it is assumed that the waste form will require additional effort, time, and resources to recover the nuclear materials contained therein; for microencapsulated wastes and above, it is assumed that the entire waste form will need to be processed due to the high degree of homogeneity of the waste form. Therefore, the allowable concentration of nuclear material in the terminated waste form will increase as well. It should be noted that the concentrations and physical forms are based only on the ability of the nuclear materials to be recovered and does not consider any additional factors such as disposal location.

Need to Understand All Requirements

With two different classification schemes present that are based on different physical criteria, it can be easy to meet the requirements for one but not the other. For example, a waste form could be created that potentially qualifies for termination of safeguards measures (like a vitrified glass), but which is so radioactive that it would need to be placed in a HLW repository. While this doesn't seem at first to be an issue, it is highly unlikely that a State would develop a HLW repository that is not safeguarded; the most likely waste material to be emplaced is spent fuel which will remain under safeguards. Therefore, there is little incentive to terminate the safeguards on waste glass. Conversely, a State could immobilize demolition wastes in concrete, making a macroencapsulated waste form that contains too much nuclear material to have safeguards measures terminated. In this case the wastes would not be able to be disposed of in a non-safeguarded LLW facility; the State may or may not have a suitable facility for disposal of the material or may have already disposed material that will not be terminated, leaving the State in a potentially uncertain position regarding the future state of the disposal site (e.g., safeguarded vs. non-safeguarded facility).

Another consideration is that the mass of the waste form may not be the same for both sets of requirements. This fundamental disconnect on masses must be carefully managed. Generally, for each waste group (with respect to termination of safeguards) a calculation is made to determine the concentration of nuclear material and consequently the mass of the immobilization matrix is not always counted. For less conditioned wastes, any immobilization matrix is not counted towards the concentration calculation. However, for microencapsulated, vitrified, and ceramic wastes, the immobilizing mass is included in the calculation. In both cases, the mass of any packaging is not included. This is in contrast to the waste classification (with respect to radioactive waste management), where the final classification of the wastes will depend completely on the mass of the final waste package, inclusive. Therefore, if the State's regulation governing LLW States that total activity must be below a defined activity in Bq/g, that will include the entire mass of the waste package.

These fundamental differences can be difficult to manage. States are therefore encouraged to examine their national regulations and disposal goals with respect to the practicably irrecoverable standard by engaging the IAEA at an early stage of development, ideally before any wastes containing safeguarded nuclear materials are generated or conditioned. This best practice of including safeguards in the planning of a new or modified facility or process is known as Safeguards by Design (SBD) [7].

Including Safeguards in the Waste-Planning Process

To ensure that wastes are managed appropriately, States must understand how and when safeguards obligations can be lifted and when they will still apply. This information is critical at the waste planning stage as many long-term decisions will be affected. The inclusion of safeguards in the planning process can be broken down into three broad questions that need to be addressed as early as possible for any waste stream:

1. Should the waste materials stay under safeguards?
2. What type of disposal site is available?
3. What is the balance between waste volume and waste concentration?

High and Intermediate Level Wastes

Applying the questions above question may seem, in the context of waste, to be a simple matter however there is a larger calculus that needs to be evaluated. For waste materials with large quantities of nuclear materials, even with highly durable physical compositions (e.g., glass, ceramic), the waste forms may qualify for termination of their safeguards obligations (due to physical composition and concentration of nuclear materials). However, their radiological characteristics may require that they be isolated from the biosphere in an intermediate depth or deep geological repository (e.g., if they also contain fission products or large amounts of long-lived isotopes). This situation may occur when the wastes do not meet the WAC for LLW and therefore must be disposed of as ILW or HLW. In these cases, States must decide if they are going to establish a separate, non-safeguarded intermediate-depth or deep geological repository.

Some States are looking at establishing a subsurface disposal facility at intermediate depth[ii] for higher activity waste forms, such as activated reactor internals [8]. It is likely that these disposal facilities would not safeguarded. In this case, depending on the WAC for the disposal facility, it may be beneficial to dispose of these "greater than LLW" - ILW waste streams after they have had the safeguards applied to them terminated. This would require that States understand the termination criteria that will govern this process to ensure that the materials will be able to be terminated *and* meet WAC. It also requires a non-safeguarded disposal site that can accept them.

Many other States are looking at deep geological repositories[iii] for the disposal of spent fuel as well as these higher-activity items. As such, the nuclear materials at these facilities will remain under safeguards even after emplacement and closure of the disposal site. Therefore, the repository will be a safeguarded facility and there is no net benefit, in the long term, to terminating the safeguards obligations on these wastes at an early stage. Much to the contrary, if a safeguarded disposal facility is available for these wastes, it may be in a State's economic favour to increase the concentration of nuclear materials in these waste forms beyond the limits imposed by termination criteria. This will reduce the total footprint of the waste in the disposal site and allow more waste materials to be disposed in the facility. This process is summarized in Figure 1 for these higher-activity wastes.

Low-Level and Very-Low-Level Wastes

Worldwide, the majority of radioactive wastes fall into these categories in terms of volume of waste [9]. There is a common misconception that these wastes are eligible for termination due to their low concentration of nuclear material. However, due to the wide variety of conditioning applied to these wastes as well as the metrics which classify these materials as VLLW or LLW imply that the final forms may or may not be terminable. This category of waste has the potential to create the largest volume of waste without a disposal pathway if not managed correctly.

Recall that while termination criteria are based on a mass concentration (e.g., mg/g), the classification of waste as VLLW or LLW is typically based on an activity concentration (e.g., Bq/g). Furthermore, the waste classification will typically only evaluate the final waste package whereas the safeguards considerations are more focused on the input wastes for lower waste groups, which are more common in VLLW and LLW. This may prove an issue if detailed discussions are not taken soon enough. It is conceivable that a suitably dilute waste form will be created that meets all WAC but is too concentrated to be terminated. If this is not discovered soon enough, the State could inadvertently place the waste in a disposal site, thus potentially altering the regulatory basis of the disposal site. In addition, depending on the State's safety analysis for the disposal site, even VLLW may be meet all WAC but still be too concentrated to have the safeguards on the nuclear materials terminated. This may not be common but it remains a possibility and needs to be managed accordingly

For lower categories of waste (unconditioned, overpacked, and macroencapsulated) commonly found in VLLW and LLW streams, the State and the IAEA can determine if the nuclear materials in the wastes will qualify to have the safeguards on them terminated *prior to any conditioning taking place*. This is a beneficial checkpoint as this prevents wastes from being made that may not be able to be disposed of properly.

For those wastes that are too concentrated to have the safeguards on the nuclear materials contained within them terminated, there is the option to either resubmit the wastes for a more comprehensive waste treatment or to place them in a safeguarded disposal or storage facility. An undesirable outcome is one where a waste form has been created *and emplaced* in a disposal facility prior to confirming that the nuclear materials would qualify to have their safeguards measures terminated. This may require significant work to determine an appropriate path forward that meets all criteria, national legislation, and treaty obligations.

Exempt Wastes[i]

In contrast to the previous waste types, wastes that fall under the category of exempt wastes will *generally* fall under the limits for termination; this generalization will need to be checked and clarified in every State to ensure that this is in fact the case. The classification of waste as exempt means that, regardless of its final location, it will not pose a hazard to human health or the environment. Similarly, they do not typically pose much of a proliferation risk due to their diffuse state.

States should work with the IAEA to ensure there is an appropriate mechanism to terminate any materials that fall under exempt wastes. These wastes may be sent to a municipal landfill directly without any containerization if they are materials such as lightly contaminated soil or rubble. These wastes would be considered as unconditioned wastes and would be subject to a flow restriction by the IAEA in terms of the process for termination of safeguards on the nuclear material in the wastes. If the wastes are containerized, even in something as simple as a polymer bag, the wastes may be considered to be conditioned and the flow restriction would be lifted. For this simple reason, the State needs to consider these safeguards concepts during the initial stages of their waste management programme.

Conclusions

The waste management process is one populated by the needs of many stakeholders. The public, the State, the regulator, the environment all have requirements that are applied to the wastes and the waste management programme needs to be responsive to them. Safeguards considerations is one of those stakeholders. Just as with any of the other requirements, the failure to consider the impact of safeguards obligations on a waste stream can lead to a waste that does not have a disposal pathway open to it. It is possible that these waste materials either cannot be emplaced in the waste facility envisioned as it is still safeguarded and an appropriate facility does not yet exist. In some cases, the requirements imposed by the process of termination are more strict than those imposed by the long term safety of the waste. States are encouraged to look at all possible disposal pathways, including the creation of safeguarded disposal sites, in order to find the best possible fit between their waste inventory and their disposal options. Above all, States are encouraged to consult with the IAEA early in the development of a waste management process that includes even low levels of nuclear material – a process of collaborative risk management known as safeguards by design (SBD).

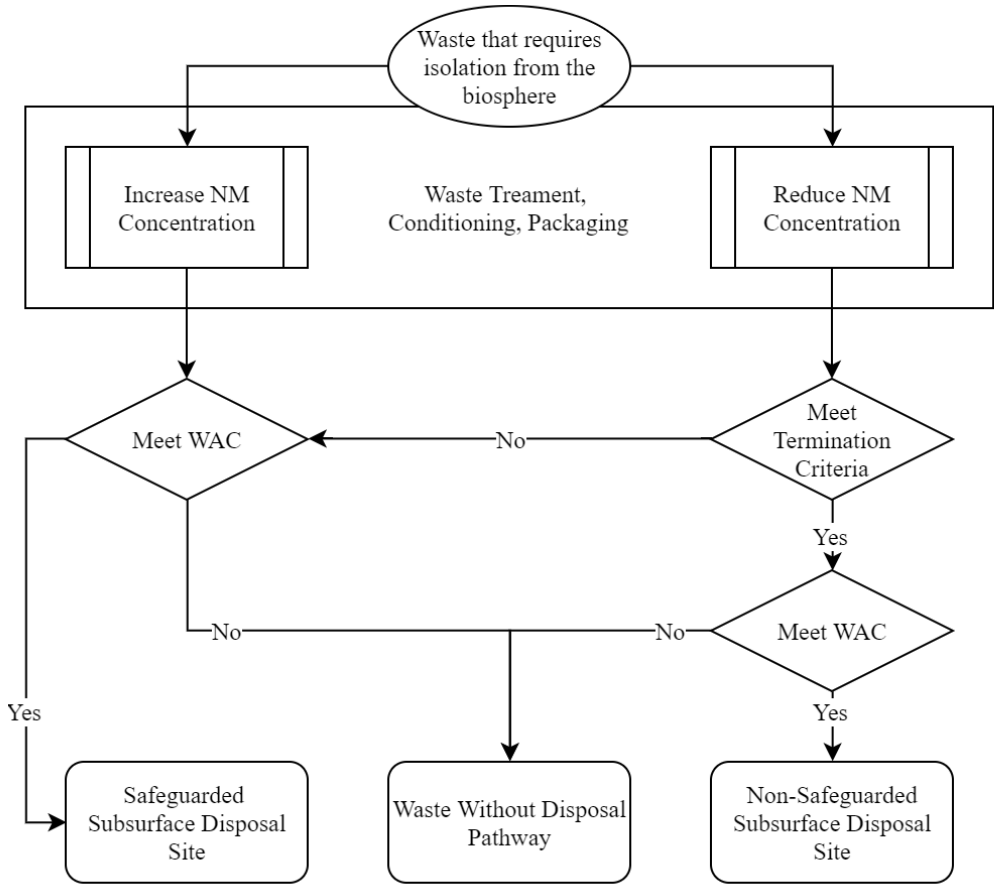

Figure 1 - Simplified decision tree for higher level wastes. These wastes are typically microencapsulated, vitrified, and ceramic waste forms.

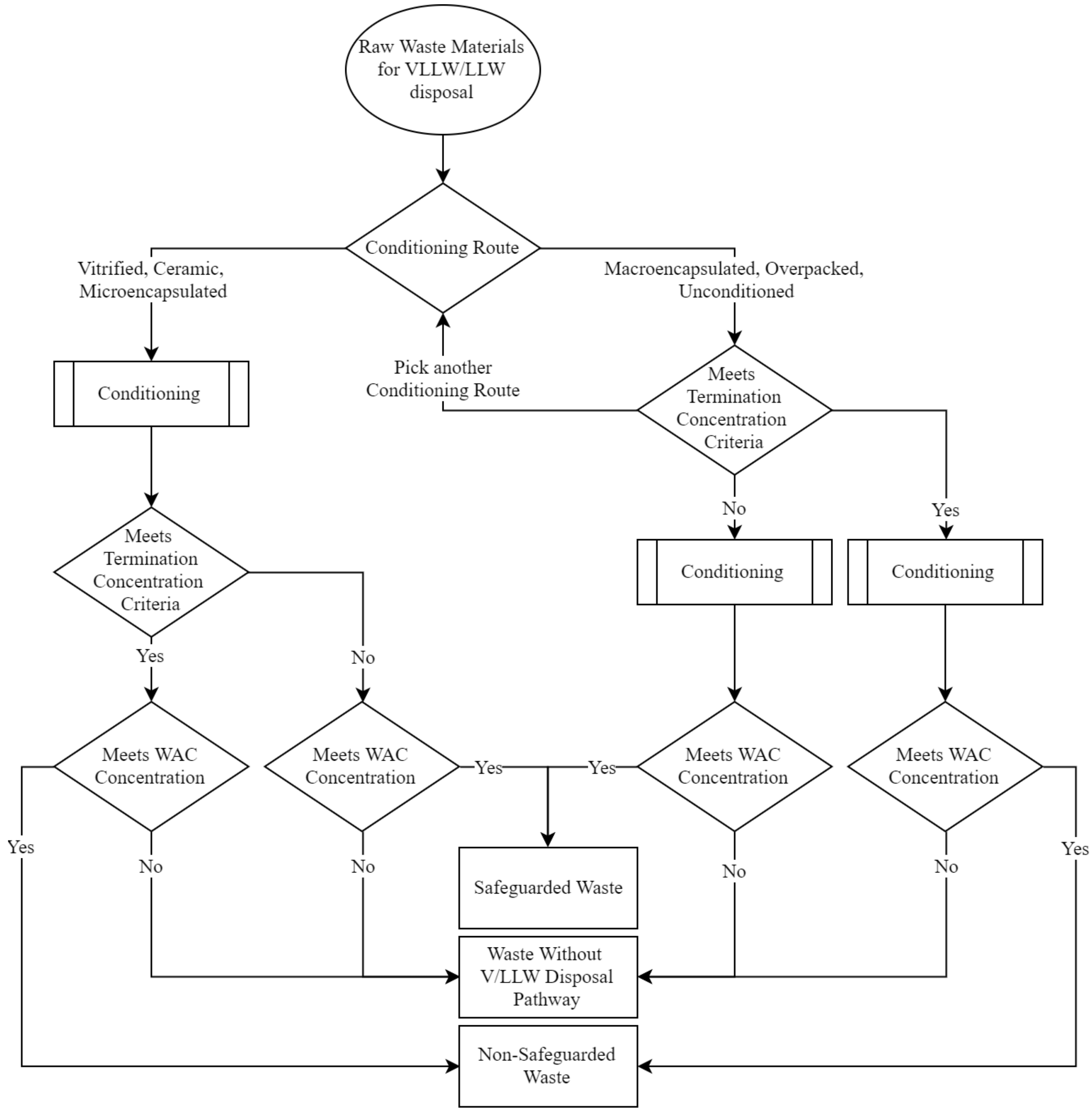

Figure 2 - Simplified decision tree for VLLW and LLW materials. All waste types may be found in V/LLW though microencapsulated, microencapsulated, and overpacked are common.

References

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[i] This term should not be confused with the safeguards specific term "Exempt Material" which is material that has been temporarily removed from safeguards accountancy.
[ii] A disposal facility located 10s of meters below grade
[iii] A disposal facility located 100s of meters below grade in a stable geological formation.