ASSESSING THE SAFETY OF BOREHOLE DISPOSAL OF UNWANTED RADIOACTIVE SEALED SOURCES IN EGYPT

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ABSTRACT

Radioactive sealed sources have been used in Egypt for over 50 years in a wide range of peaceful applications. Oil exploration and medicine are the largest users of radioactive sealed sources (RSSs). At the end of their useful life, the RSSs are defined as disused or unwanted and there are hundreds of unwanted RSSs in Egypt. Currently, the Egyptian Atomic Energy Agency (EAEA) holds unwanted RSSs in long-term storage.

Many of these unwanted sources will not decay to background or dismissal levels in 100 to 300 years and these RSSs are not normally acceptable for disposal in near surface disposal facilities. Such RSSs contain long-lived radionuclides such as ^{241}Am and ^{226}Ra, or high activities of intermediate half-lived nuclides such as ^{137}Cs and ^{90}Sr.

Sandia National Laboratories has recently demonstrated that intermediate-depth disposal in thick arid alluvium provides geologic isolation similar to that provide by a mined geologic repository, but at a faction of the cost. The EAEA, teaming with Sandia National Laboratories is conducting a Preliminary Safety Assessment of an intermediate-depth borehole disposal in thick arid alluvium in Egypt based on experience with Greater Confinement Disposal. The results of the Preliminary Safety Assessment will then be used to decide of Egypt desires to implement such a disposal system.

The Preliminary Safety Assessment will be conduced as part of a phased repository development program using Sandia's iterative Performance Assessment Methodology.

BACKGROUND AND JUSTIFICATION

Radioactive sealed sources have been used in Egypt for over 50 years in a wide range of peaceful applications. Oil exploration and medicine are the largest users RSSs. At the end of their useful life, the RSSs are defined as disused or unwanted. In Egypt, there are hundreds of unwanted RSSs and hundreds of additional RSSs will become unwanted over the next 25 years.

Currently, the EAEA holds unwanted RSSs in long-term storage. Long-term storage of hundreds of unwanted RSSs is undesirable for economical, safety, security and equity reasons. From a systems view, it is far more economical to develop a disposal facility than to pay for security, monitoring, and maintenance of a storage facility for hundreds to thousands of years. From a safety perspective, it may not be possible for a society to maintain control of a storage facility for more than a few hundred years. Examples of a loss of control over RSSs and storage facilities (and the resulting negative health effects) have already occurred in some former Soviet countries. From a security perspective, a centralized storage facility with hundreds of RSSs represents a target for theft. Finally, this generation created the RSSs and this generation benefited from using the RSSs, therefore, this generation should be responsible for safe disposal. It is not fair to burden future generations with the costs of providing long-term storage of unwanted RSSs.

For all these reasons, the sensible path is to eliminate the financial, safety and security mortgages through permanent and safe disposal.

Near Surface Disposal May be Safe for Most Unwanted RSSs

A near surface disposal facility may be safe for the dispose of most of the RSSs currently in storage in Egypt, because most unwanted RSSs in Egypt are short-lived or low-activity. Near surface (trench) facilities employ engineered barriers and active institutional controls to isolate wastes from the human biosphere. Because the near surface is hydrologically and biologically active, such facilities employ engineered barriers and active institutional controls to isolate wastes from the biosphere. Near-surface facilities less than 10 m deep are appropriate for wastes that decay to background or dismissal levels during the period of active institutional control, typically assumed to be 100 to 300 years.

High-Activity Long-Lived RSSs Require Geologic Isolation

There are some unwanted RSSs that have residual levels of radioactivity that is still quite high after 100 to 300 years and such disused radiation sources could pose a potential health hazard to the public for hundreds to thousands of years. Such RSSs contain long-lived radionuclides such as ^{241}Am and ^{226}Ra, or high activities of intermediate half-lived nuclides such as ^{137}Cs and ^{90}Sr. These sources do not decay to background or dismissal levels in 100 to 300 years and these RSSs are not normally acceptable for disposal in near surface facilities.

Deep-mined geologic repositories have long been proposed for such dangerous long-lived RSSs. Deep geologic repositories utilize isolated and stable portions of the lithosphere at depths greater than 300 m to remove radioactive wastes from the biosphere for thousands to millions of years. For these reasons, deep-mined geologic repositories are said to provide “geologic isolation.” Although conceptually simple, development costs for deep mined repositories can exceed $1 B.

Intermediate-Depth Disposal Can Provide Geologic Isolation

Sandia National Laboratories has completed a Safety Assessment [1] to determine if the intermediate depth Greater Confinement Disposal (GCD) boreholes will provide “geologic isolation” of radioactive wastes as independently defined by the U.S. Environmental Protection Agency’s 40 CFR 191 standard. GCD boreholes were used to dispose of unwanted RSSs, other high-specific-activity low-level radioactive wastes and classified transuranic wastes that could not be disposed of elsewhere. The GCD boreholes were about 36 m deep; in which the bottom 15 m was used for waste disposal and the upper 21 m was backfilled with native alluvium. The boreholes are completed in a thick sequence of arid alluvium.

In 2002, after an independent peer review, Sandia’s Safety Assessment was accepted – thus demonstrating that intermediate-depth disposal in <u>thick arid alluvium</u> provides geologic isolation similar to that provide by a mined geologic repository, but at a faction of the cost.

IMPRSS

The Integrated Management Program for Radioactive Sealed Sources (IMPRSS) is a joint project between Sandia National Laboratories, and the Government of Egypt, funded by the U.S. Agency for International Development. The broad objectives of IMPRSS are:

- Greatly reduce threat to human health from mismanaged RSSs.
- Greatly reduce threat to the environment from mismanaged RSSs.
- Develop self-sustaining program in Egypt for the integrated management of radiation sources.

Exploring Intermediate Depth Disposal in Egypt

Utilizing more than a decade of experience with the GCD boreholes, the EAEA and Sandia National Laboratories will assess the safety of disposing of disused RSSs in intermediate-depth boreholes in thick arid alluvium in Egypt. Additionally, the safety assessment will utilize the experiences of the International Atomic Energy Agency (IAEA), AFRA[i] and South Africa in their assessment of intermediate-depth boreholes for the disposal of disused radiation sources.

In summary, Egypt currently stores hundreds of disused RSSs, some of which contain long-lived radionuclides or high activities of intermediate half-lived nuclides requiring isolation for thousands of years, and it has recently been demonstrated that intermediate-depth disposal in thick arid alluvium may isolation long-lived RSSs from the biosphere for thousands of years.

Goal

The goal of this project is to conduct a Preliminary Safety Assessment of an intermediate-depth borehole disposal in thick arid alluvium in Egypt based on experience with Greater Confinement Disposal. The results of the Preliminary Safety Assessment will then be used to decide if the Government of Egypt desires to implement such a disposal system.

Strategy

The strategy is to use an integrated, step-wise Safety Assessment Methodology (SA Methodology) that builds on many years of Greater Confinement Disposal experience in the U.S. and IAEA experience with AFRA. The SA Methodology is described below.

Key Assumptions

- Egypt contains areas of thick arid alluvium.
- The assessment of safety will be specific at an actual inventory, actual disposal system design and actual site or sites in Egypt.
- The waste form will be 0.5 m in diameter, or smaller.
- The inventory of unwanted RSSs will be projected through the year 2029.

PHASES OF DISPOSAL SYSTEM DEVELOPMENT

This work supports decision-making. The decision will be to abandon the concept of intermediate-depth disposal in Egypt, or to proceed with licensing, construction and operation.

For decision-making, the Preliminary Safety Assessment must be specific: specific to an actual site or sites, inventory and disposal system design. Development of a disposal facility for RSSs can be divided into five phases:

1. Pre-Site Selection
2. Site Selection
3. Pre-Operation
4. Construction and Operation, and
5. Closure and Monitoring.

The general process is shown schematically in Figure 1. Although Figure 1 presents a linear process, many activities can proceed in parallel.

Pre-Site Selection Phase

Pre-Site Selection Phase addresses those actions necessary to undertake a site search and to develop a preliminary design. The pre-site selection phase includes three steps:

- Definition of inventory (step PSS1),
- Development of quantitative performance objectives from the disposal regulations (step PSS2) and
- "Mapping" of the licensing process (step PSS3).
- To implement these steps, there will also be project management activities, the management of records and the implementation of a quality assurance program.

The inventory (step PSS1), in part, defines the level of protectiveness that the site must provide. For example, an inventory of only ^{60}Co requires the site and the waste form to delay release of the ^{60}Co for at least 50 years (for at least ten half-lives of cobalt). On the other hand, the site and waste form must delay released for at least 4,320 years if there are significant quantities of ^{241}Am from oil and gas well logging.[ii] The inventory must also be known to define the properties of the waste form (e.g., half-life, solubility, retardation coefficients, dose conversion factors, and heat generation).

There are four components of the inventory:

- Existing, unwanted RSSs already held by the EAEA
- Existing RSSs that are in use, but may become unwanted over the next 25 years
- Existing RSSs in use at the EAEA that may become unwanted over the next 25 years
- New RSSs that will be imported, and then become unwanted over the next 25 years;

Preliminary information indicates that the inventory of unwanted RSSs already held in storage by the EAEA includes ~ 40,000 GBq of ^{137}Cs, ~ 45 GBq of ^{241}Am and ~ 250 GBq of ^{226}Ra. Over the next 25 years, significant additional unwanted RSSs will be transferred to the EAEA for storage and disposal.

In the second step of the Pre-Site Selection Phase, disposal regulations will be interpreted to quantitatively define the performance objectives (step PSS2) for the disposal system. An example of a quantitative performance objective might be: the combined concentration of anthropogenic ^{226}Ra and ^{228}Ra should not exceed 185 mBq/L in the groundwater at the boundary of the disposal system for 10,000 years.

Regulations for disposal of radioactive wastes typically set requirements for the (1) maximum all pathways dose to the member of the public, (2) actions necessary to protect against inadvertent human intrusion, (3) long-term disposal system stability, (4) operational safety, (5) monitoring and (6) quality assurance. Many U.S. standards also set limits on the specific activities of certain radionuclides in groundwater.

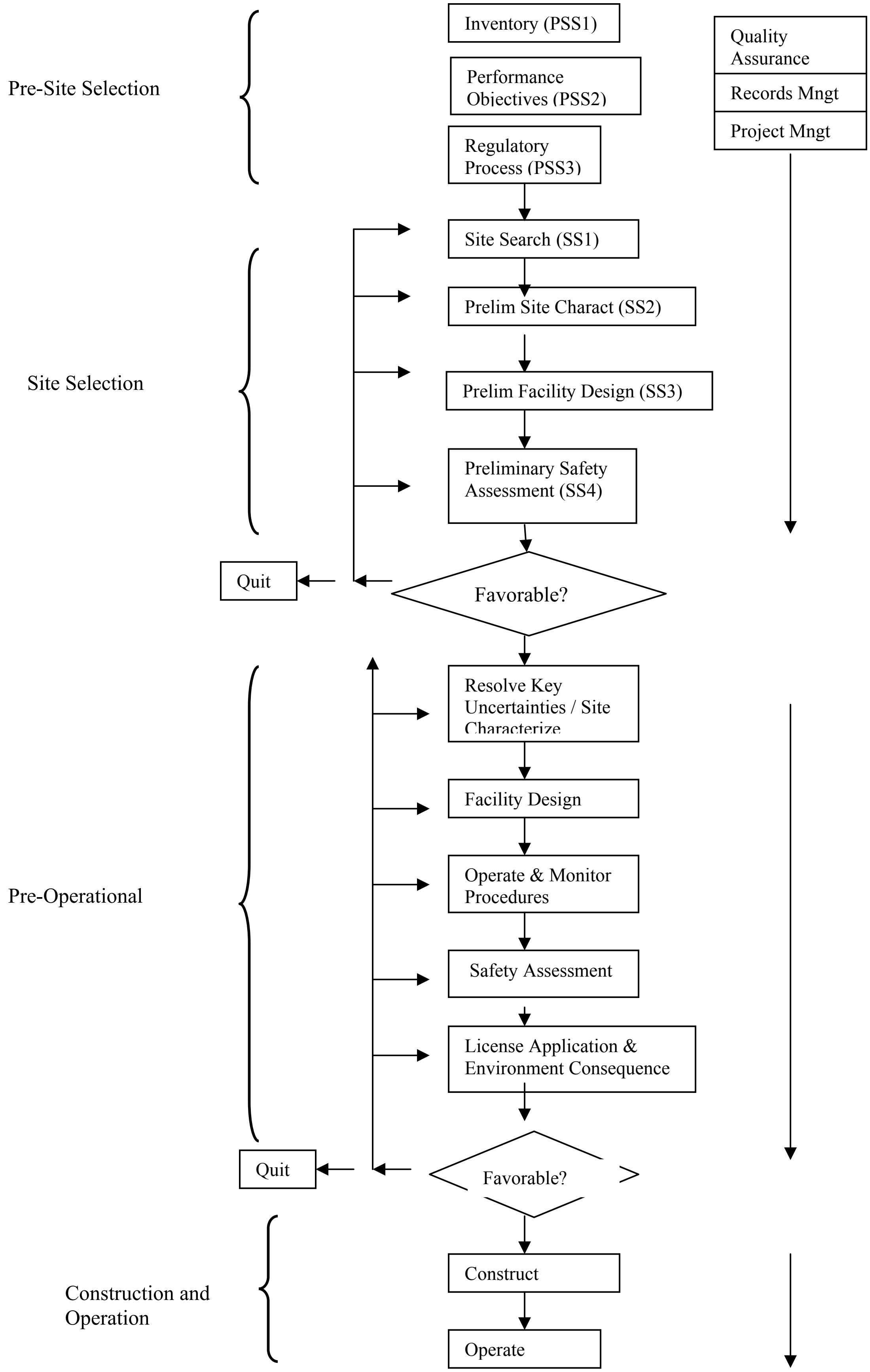

Fig. 1 Steps in the Development of a Disposal Facility

The U.S. Nuclear Regulatory Commission's (NRC's) 10 CFR 61 and the U.S. Environmental Protection Agency's (EPA's) 40 CFR 191 are examples of existing disposal regulations. The NRC's 10 CFR 61.55 defines for the U.S. the boundary between wastes that may be safely disposed in the near surface, and those wastes that require long-term "geologic isolation."

If Egyptian disposal regulations are not defined, assistance will be provided to develop such regulations based on existing U.S. regulations and IAEA guidelines.

Finally, it is necessary to define the licensing process (step PSS3). The licensing process includes the topics the license application must address. An example of the types of information and analysis that needs to be in a license application is provided in the NRC's NUREG-1999, "Standard Format and Content of a License Application for Low-Level Radioactive Waste Disposal Facility." Further information is provided in NUREG-1200 "Standard Review Plan for the review of a license application for a Low-Level Radioactive Waste Disposal Facility, Rev.3." In general, the information needed will include:

- Site description (location, topography, climate, geology, surface water hydrology, vadose zone hydrology, groundwater hydrology, volcanic history, faulting)
- Baseline environmental monitoring program
- Quality Assurance program
- Description of the known and anticipated radioactive inventory
- Waste transportation routes and safety measures
- Site security measures
- Dose/risk assessment to workers from normal operations and accident scenarios
- Waste form engineered barriers, including information on treatment and packaging
- Description of the proposed disposal system (depths, diameters, backfill)
- Safety Assessment (features, events and processes, pathways, models, input parameters, receptors, doses, uncertainties and measures to protect the inadvertent human intruder)
- Long-term stability assessment of the disposal system
- Site Closure Plan (closure design, active and passive controls, long-term monitoring)

At the completion of the Pre-Site Selection phase, there will be a clear and defensible understanding of the inventory of unwanted RSSs, the quantitative performance objectives and the types of information needed for possible licensing.

Site Selection Phase

The Site Selection Phase includes four steps:

1. Site Search (step SS1)
2. Preliminary Site Characterization (step SS2)

3. Preliminary Facility Design (step SS3), and
4. Preliminary Safety Assessment (step SS4).

The results of these steps will be used to decide if an acceptable site or sites are available for licensing.

The first step in this phase is the Site Search (step SS1). For this project, the Site Search criteria are based on the characteristics of the GCD site and the preliminary site selection criteria are:

- Arid climate, < 130 mm per year precipitation
- Thick deposits of sand and gravel (alluvium), > 150 m thick
- Deep water table, > 150 m below land surface
- No potential for surface flooding

The secondary characteristics of GCD disposal site are:

- No dwelling within 1 km
- Land owned by the government
- No volcanic activity in last 1 m years
- No valuable subsurface resources such as oil, gas and gold

Simple geological settings and homogeneous materials are preferable to complex geologic settings and materials, as simple settings and materials are easier and less expensive to characterize, easier and less expensive to model; providing greater confidence in the results of the Preliminary Safety Assessment.

Using these site selection criteria, the country of Egypt will be searched for candidate disposal sites. Preliminarily, there are three areas that will be searched for possible disposal sites, the Eastern Desert, the Sinia and the Western Desert. Figure 2 provides an image of a site in Western Desert. Within the Western Desert, the El-Kharga depression is one area of interest. The sand-filled structural depression is 220 km long and 40 km wide.

After an appropriate site (or sites) is located, preliminary site characterization (step SS2) is undertaken to provide information for the Preliminary Safety Assessment (step SS4).

Preliminary Site Characterization

A key component of the Preliminary Safety Assessment is the identification of all features, events, and processes (FEPs) that could affect the release of radionuclides. It is necessary to have information about the site (Preliminary Site Characterization data), the wastes, and the regulations to fully assess the FEPs. After the FEPs screening, the development of scenarios, and the identification of transportation codes, the sites physical and chemical characteristics (Preliminary Site Characterization data) are used again to define input parameters for modeling performance.

Fig. 2. Western Desert of Egypt [3]

For a potential disposal site in thick, arid alluvium, the preliminary site characterization can be divided into three areas, (1) site setting, (2) vadose zone and (3) saturated zone. Characteristics of the site setting include:

- Location
- Topography
- Climate
- Geologic history
- Stratigraphy, lithology, and geologic structure of the region and the site, with emphasis on the lithology between the surface and the water table
- Evidence of active faulting at the site and the age of latest movement
- Geologic evidence of volcanism, history of volcanic activity near the site
- Topography of the site showing drainage features, data on the flood history of the region, upstream drainage areas, and precipitation
- History of past and present drilling and mining operations in the vicinity of the site, including groundwater consumption and
- Known occurrences of energy and mineral resources in the area.

Modeling the movement of radionuclides in the vadose zone will require information about the solubilities of the wastes (governed in part by the pore water chemistry in the near field), the advective velocities of the pore water, and the retardation coefficients of the radionuclides in the pore water (governed in part by the pore water chemistry along the flow paths). Geochemical codes may be used to calculate solubilities. To model these processes, information on the following may be necessary:

- Grain size distributions with depth
- Porosity with depth
- Moisture content variations with depth
- Pore water head (tension) variations with depth
- pH
- Eh
- Main dissolved components such as Na, K, Ca, Mg, HCO_3, SO_4, Cl, Si, and TDS
- Trace substances such as Fe, Mn, Br, NO_3, NO_2, NH_4,
- Dissolved gases such as O_2, N_2, CO_2
- Radioactive isotopes for background concentration total U, ^{226}Ra, ^{222}Rn; and
- Other such as dissolved organic carbon colloids and bacteria.

As described in Appendix A of the GCD Safety Assessment, it may be necessary to use environmental isotopes to identify the ages and advective velocities of the pore waters in the vadose zone.

The characteristics of the saturated zone may include:

- Depth to groundwater
- Gradients in the surface of the groundwater
- Porosity
- Groundwater flow rates and transit times
- Location of recharge and discharge area, etc|

If there is no pathway from the wastes to the saturated zone, only minimal characterization of the saturated system will be necessary (e.g., pH, Eh; main dissolved components such as Na, K, Ca, Mg, HCO_3, SO_4, Cl, Si, and TDS).

Finally, site characterization requires a general understanding of past long-term changes in climate, and the effects of those changes on the site setting.

Key parameters - Site characterization can be very complicated, and it is important to remember that for most sites, only a few parameters control the long term movement of radionuclides: source term, solubility's of radionuclides, advective flow rates, retardation coefficients, and the distance to the receptors.

Finally, site characterization efforts must seek information on possible geologic discontinuities, which may serve as fast pathways for radionuclide transport.

The Preliminary Safety Assessment (PSA) (step SS4) uses site-specific information and the proper treatment of uncertainties to project future consequences (e.g., future movement of radioactive waste away from the disposal location to a potential receptor). The process for completing the Preliminary Safety Assessment is described in detail in later.

Pre-Operational, Construction, Operation and Closure Phases
This article does not address the Pre-Operation, Construction, Operation or Closure phases of a disposal system in Egypt, and this article is not a commitment to implement intermediate-depth disposal.

Regulatory Involvement and Peer Review

Regulatory involvement and peer review may be critical for the success of this program. Such involvement could include a draft Environmental Impact Study. The regulatory process will determine the level of public and political interaction. To facilitate regulatory involvement and peer review, this program will:

- Identify key parties that may include environmental protection agencies, special interest groups and the IAEA.

- Develop and implement an awareness and involvement strategy.

- Organize and prepare material for briefings, working group meetings

PRELIMINARY SAFETY ASSESSMENT METHODOLOGY

The project will use the results of a Preliminary Safety Assessment (PSA) to determine if intermediate-depth borehole disposal in thick arid alluvium will safely isolate radionuclides for thousands of years. The PSA will be developed in context of Egyptian laws governing disposal of radioactive wastes. If such Egyptian laws do not currently exist, the PSA will be conducted in context of IAEA and U.S. guidelines and examples. The PSA is step SS4 in the Site Selection Phase of repository development shown in Fig. 1.

Compliance with most standards or laws is directly verifiable. If the law states that a roadway must be at least 20 m wide, measurements can be taken to verify compliance with the law. However, the PSA for the disposal of unwanted RSSs must demonstrate protection of human health for long time periods in the future. The results of such a safety assessment cannot be directly verified, yet the PSA is the basis for determining if such a system will be protective of human health.

This section overviews the PSA Methodology, which provides confidence in the analysis and results. Fundamental to this methodology is the philosophy that this PSA is not a prediction of how the disposal system will actually perform. Actual performance cannot be assessed or verified. Rather, this PSA provides simulations of a range of plausible outcomes, *which are developed in a manner to provide confidence that the results of the analysis do not overestimate the ability of the disposal system to protect human health.*

Figure 3 schematically describes the PSA Methodology. The basic steps of this PSA Methodology are (1) define performance objectives, (2) assimilate existing site information, (3) develop and screen scenarios, (4) develop models and parameter values, (5) perform consequence analyses, (6) decide if the simulated performance of the site is acceptable, (7) conduct sensitivity analyses if the answer to Step 6 was "no," (8) assess the ability to collect desired data, (9) decide whether to proceed with another iteration of the PSA or to declare the site unacceptable, and (10) collect data and/or modify the site and begin the PSA process again.

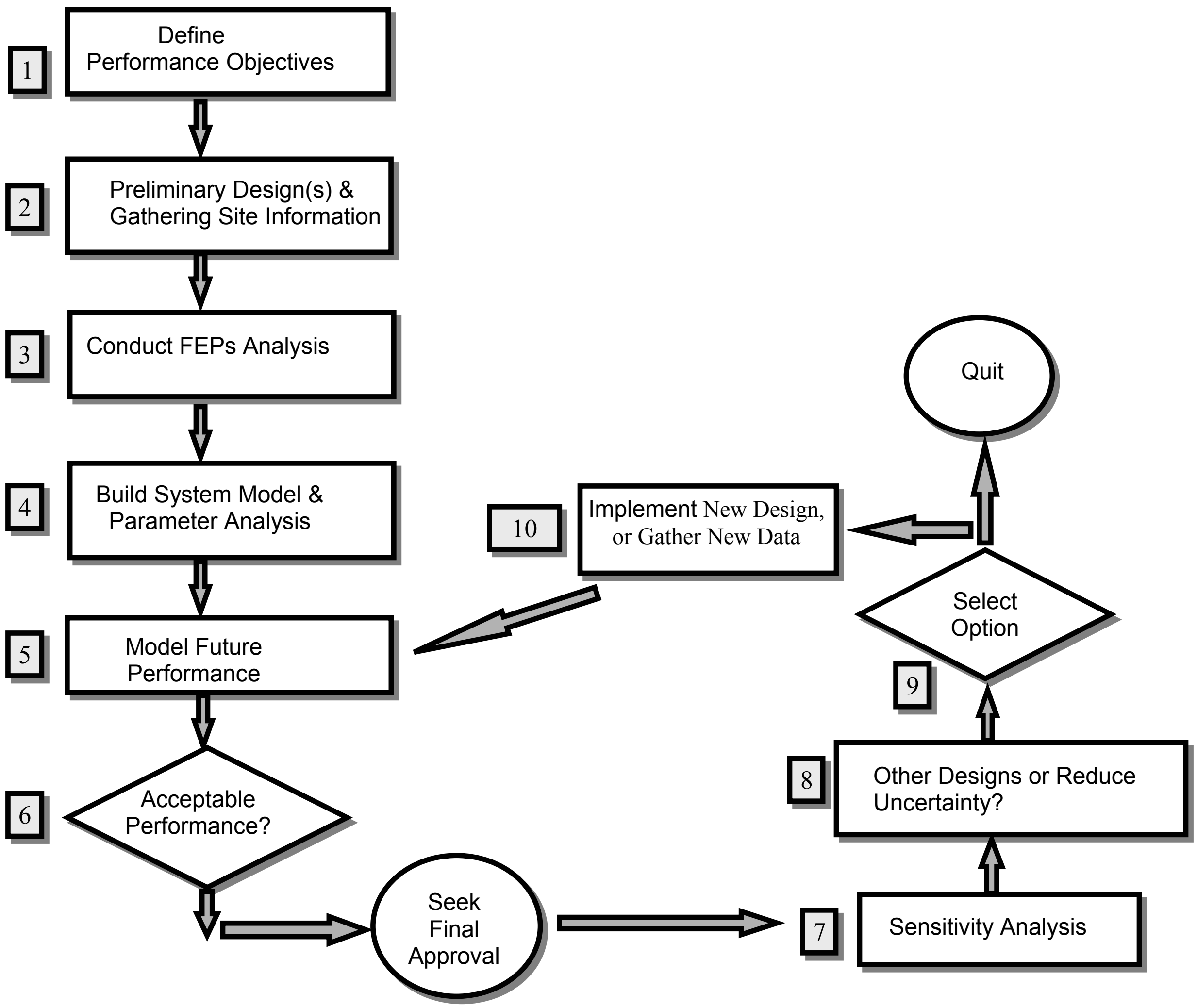

Fig. 3 Preliminary safety assessment methodology

An iterative framework is a very important aspect of this PSA Methodology. The process advocates beginning the SA with simple, defensible models, in which model uncertainty and parameter uncertainty are managed as described below. If compliance is demonstrated, the PSA is complete, if not, sensitivity and data worth analysis are used to guide future activities (e.g., additional site characterization).

In using this methodology it is important to understand both parameter uncertainty and parameter variability. Parameter uncertainty is defined as a lack of knowledge about a given parameter value.

Parameter variability, on the other hand, is heterogeneity in a population.

For this PSA, probability distributions of *effective values* of parameters may be developed and used to represent the parameter values over the spatial and temporal scales defined in the PSA mathematical model. Probability distributions used in this analysis represent both parameter uncertainty and variability.

Unbiased probability distributions may be used to capture uncertainty in the effective values of parameters. *Unbiased*, as used here, is meant to indicate that the distribution chosen for a given parameter is an accurate representation of the current state of knowledge for that parameter. If there is little uncertainty in a parameter's value, the parameter will be described using a narrow range (or even a single value). If, there is significant uncertainty in a parameter's value, then the input parameter is described with a broad distribution that captures that uncertainty.

This methodology is described in greater detail in both [1] and [4].

SUMMARY

The EAEA holds several hundred unwanted RSSs in long-term storage, some of which are long-lived and inappropriate for near surface disposal. Sandia National Laboratories has recently demonstrated that intermediate-depth disposal in thick arid alluvium provides geologic isolation similar to that provide by a mined geologic repository, but at a faction of the cost. The EAEA, teaming with Sandia National Laboratories is conducting a Preliminary Safety Assessment of an intermediate-depth borehole disposal in thick arid alluvium in Egypt based on experience with Greater Confinement Disposal. The results of the Preliminary Safety Assessment will then be used to decide of Egypt desires to implement such a disposal system.

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FOOTNOTES

[i] AFRA is African Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology; AFRA has 26 Member Countries, including Egypt and South Africa.

[ii] Ten half-lives is only for illustration; analysis will be necessary to determine the concentrations of specific radionuclides that will not decay to dismissal levels in 100 to 300 years.