Scenario for the Safety Assessment of Near Surface Radioactive Waste Disposal in Serpong, Indonesia

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Abstract

Near surface disposal has been practiced for some decades, with a wide variation in sites, types and amounts of wastes, and facility designs employed. Experience has shown that the effective and safe isolation of waste depends on the performance of the overall disposal system, which is formed by three major components or barriers: the site, the disposal facility and the waste form. The objective of radioactive waste disposal is to isolate waste so that it does not result in undue radiation exposure to humans and the environment. In near surface disposal, the disposal facility is located on or below the ground surface, where the protective covering is generally a few meters thick. These facilities are intended to contain low and intermediate level waste without appreciable quantities of long-lived radionuclides.

Safety is the most important aspect in the applications of nuclear technology and the implementation of nuclear activities in Indonesia. This aspect is reflected by a statement in the Act Number 10 Year 1997, that " The Development and use of nuclear energy in Indonesia has to be carried out in such away to assure the safety and health of workers, the public and the protection of the environment".

Serpong are one of the sites for a nuclear research center facility, it is the biggest one in Indonesia. In the future will be developed the first near surface disposal on site of the nuclear research facility in Serpong.

The paper will mainly focus on scenario of the safety assessments of near-surface radioactive waste disposal is often important to evaluate the performance of the disposal system (disposal facility, geosphere and biosphere). It will give detail, how at the present and future conditions, including anticipated and less probable events in order to prevent radionuclide migration to human and environment.

Refer to the geology characteristic and ground water table is enable to place something Near Surface Disposal on unsaturated zone in Serpong site.

Radioactive Waste Treatment

At the present time, the Radioactive Waste Technology Center (RWTC) has capabilities to treat radioactive waste on the form of liquid, spent resin, combustible waste, compactable waste, high active waste and sealed source.

Those radioactive wastes are collected from BATAN facilities as well as from other institute such as; industry, hospital, research institute etc. are represented in table 1.

The above Low and Intermediate level waste emplaced on 100 l, 200 l drum and 350 l, 950 l concrete shell are stored in the interim storage. Radiation doses exposure on the surface of drum and shell should be limited less than 200 mRem/h. The interim storage was designed based on module system that could be expanded. During storage, radioactivity of waste in drum and shell will decrease by decay process.

Near Surface Disposal

The key to the successful performance of Near Surface Disposal facility is the integration of the various phases of activity (i.e. site selection, site design and development, operation and closure) to ensure the most cost-effective achievement of the performance objectives. A systems approach should be used in predicting site performance, the approach should consider both the characteristics of the wastes to be disposed of at the site and the characteristics of the site itself. This performance assessment establishes the basic for design, development and operation, and serves as a guide for selecting specific features and procedures appropriate for that facility.

Site Selection

To carry the works activities in this stage, RWMDC developed a site selection procedure based on consideration of factors such as geologic properties, surface and subsurface hydrology, demographic issues, land use patterns and socioeconomic concerns.

Ideally, the disposal facility should be sited and constructed to minimize the chance that the waste could contaminate surface water or groundwater. The stability of the ground on which the facility structures are to be erected and the movement of water at the site were basically the conditions that must be met. Geologic features such as rock formation as well as the type of soil present in the studied regions are factors that will affect the way water flows on the surface and through the groundwater, which similarly affects the movement of contaminants. The stability of the ground depends largely on the type of rock and soil present therein. Similarly the likelihood of earthquakes, landslides, subsidence and liquefaction were also taken into account.
On the other hand, the movement of water at the site depends on slope, soil and rock type, grain size and whether fractures, faults or karsts features are present.

The site selection were conducted by descriptive, overlay and scoring methods, based on the criteria mentioned above.

Detail and comprehensive description site characteristics of the Serpong Site in Table 2.

Multibarrier system

Purpose of the multibarrier is for retardation of radionuclide release to the human environment as long as possible. Although it would not be relied on as a major barrier, the retardation of radionuclide migration by the surrounding media is an important factor to be considered during the sitting and design of a waste disposal facility.

Unsaturated Zone

Looking at it from a geology characteristic and ground water table enable to place something shallow-land burial in unsaturated zone than will be easier to executed and lower operating costs compared with place in saturated zone.

The Serpong site is for planning of shallow-land burial in a place altitude 90-95m above sea level with slope 8-15 % (small erosion). Lithologies in depth 0-9 m are consist of lateritic clay layers with permeability 1.01×10^{-7} – 1.34×10^{-7} m/s (impermeable). Depths of ground water surface are 11 m. Thus, so Serpong site is suitable for shallow-land burial in unsaturated zone.

Scenario Development

One of the key activities in scenario generation methodologies for the development of safety case, is the comprehensive identification of the potentially relevant factors, often termed features, *events and processes* (FEPs), which could directly or indirectly influence the disposal system and the migration and fate of radionuclide within it. These FEPs are usually identified from the disposal system description.

Isolation failure scenarios are very unlikely to occur provided that an appropriate site is selected. Hence, the consequences of these scenarios are considered together with the probability of occurrence of the events that initiate them.

Groundwater scenarios are more likely to arise in the future. Furthermore, a large number of FEPs can contribute to the migration of radioactive substances from the repository, resulting in a much wider spectrum of future evolutions of the system. In order to explore the extent of variations for the groundwater scenarios, assuming independent evolution of the near surface disposal system without significant effects from external factors. The key assumptions of the Base Scenario are summarized below:

- The geological environment remains stable and the present-day geological conditions remain unchanged indefinitely into future. In particular, the mechanical and thermal properties of the rock mass and the hydrological and hydrochemical characteristics that affect mass transport are assumed to be constant;
- The EBS are manufactured and emplaced without any unexpected failures. Each barrier component performs as designed (nuclide containment by the multi barriers system, restriction of nuclide leaching from the waste form and swelling, chemical buffering, colloid filtration and retardation of nuclide migration by the buffer);
- The current surface environment conditions continue throughout the timescale considered in the safety assessment. In particular, the climate and surface water systems do not change;
- The repository is unaffected by future human activities.

Scenario Development Procedure

Scenarios describing possible future evolutions of the near survace disposal system have been developed by following a systematic methodology (ISAM-IAEA, 1999 and Geological disposal in Japan-H12 report). The procedure involved the following steps:

- A comprehensive list of features, events and processes (FEPs), that could potentially affect the performance of the geological disposal systems discussed in Chapter III, was developed by collating a number of FEP lists constructed in earlier projects;
- The implications of the individual FEPs and their relevance to the safety assessment were clarified based on state-of-the-art scientific knowledge;
- A set of FEPs to be considered in the safety assessment was identified, and FEPs that were screened out at this stage were recorded together with the reasons underlying the decisions;
- Scenarios for the safety assessment were developed using the remaining FEPs as building blocks and considering all the important influences among the FEPs. (See figure 1)

Design Scenario

- Site control for 100 years after closure
    - Containers leak after 20 years
    - Containment of radionuclide by engineered barriers
    - Any degradation / damage of the cap can be repaired
    - Some degradation of wastes but not significant release since infiltration through cap is negligible

- Breaching of the cap (100 – 200 years after closure)
    - Suppression of radionuclide release by natural and engineered barriers
    - Degradation of the cap is liable to be initiated by surface damage due to animals or man and than gully erosion in storm events.
    - Infiltration begins once cap is disrupted, most water will percolate through sand around vaults

- Disruption of the vault (200 – 300 years after closure)
    - Suppression of radionuclide release by natural and engineered barrier and restriction of human activity on disposal area
    - At more than 200 years the concrete vaults are liable to be exposed at the surface over a significant fraction of the repository area.
    - Concrete will begin to degrade more rapidly once exposed and the vaults will collapse as more sand is eroded from around them
    - Waste, grout and corroded drums will be exposed and mixed with sand and other materials of the cap
    - Fine radionuclide bearing particulates from the vaults will be distributed in sediment outwash fans around the mound. (See figure 2)

- Exposure pathways
    - Release of gaseous species should be considered from the time of closure
    - Ground water path (percolation to aquifer and well path) initiates when the cap fails (100 – 300 years after closure)
    - External exposure and inhalation over disrupted vaults
    - Soil / grazing path on outwash fans, begin after the vaults are disrupted (>300 years after closure).

Possible alternative scenarios

- Vary rapid failure of cap and vaults, e.g. due to human intrusion
- Long term survival of system, e.g. if cap remains stable
- Altered climate scenario, i.e. increase rainfall and infiltration, plus wider agricultural pathways.
- Human intrusion more active exploitation of the vaults to recover metals and aggregates.
  (See table 3)

Identification and classification of relevant FEPs matrix

One of the key activities in scenario generation methodologies for the development of a safety case, is the comprehensive identification of the potentially relevant factors, often termed *features, events and processes* (FEPs), which could directly or indirectly influence the disposal system and the migration and fate of radionuclide within it. These FEPs are usually identified from the disposal system description. When the list is complete, the relative important of each FEP is reviewed, often using expert judgement. This review and judgement process result in the screening of FEPs into those, which can be ruled out, and those, which need to be considered further in the safety assessment analysis. The screening of a FEP can be supported by calculations. A FEP can, therefore, be ruled out on either quantitative or qualitative criteria both.

The resultant list of FEP is used together with the system description to formulate calculation cases of scenarios. This requires a description of relationship between the features, events and processes. Judgements on which of the scenarios should be analyzed in the safety assessment are than made. This choice will be influenced by the purpose of the assessment.

Having defined the near surface disposal systems of interest, together with their safety functions and potential detrimental factors, a comprehensive list of relevant FEPs has been developed by review and collation of:

- A number of generic FEP lists (ISAM-IAEA 1999);
- Other relevant studies (Geological Disposal in Japan from H12 report)

The resulting comprehensive list of FEPs is shown in bellows. The individual FEPs are classified according to the relevant disposal system components and to the category of phenomena to which they are relevant. The resulting matrix structure proved useful in reducing the possibility of overlooking potentially important FEPs. (See table 4.)

Description and screening out of FEPs

Descriptions of all FEPs in the comprehensive list have been compiled based on state-of-theart scientific knowledge, including the relevance of each FEP to the disposal system safety functions.

Based on the comprehensive list, a subset of FEPs to be considered in the main safety assessment calculations has been identified by applying the following screening criteria:

- FEPs that are unlikely to affect the safety of near surface disposal if an appropriate geological environment is selected;
- FEPs that can be avoided by appropriate design and construction of a repository and by engineering measures;
- FEPs whose probability of occurrence is extremely low;
- FEPs other than those listed above whose probability of occurrence or consequences are judged to be insignificant based on current knowledge.

The main safety assessment calculations address groundwater scenarios only (the Base Scenario and perturbation scenarios), since these are considered by far the most likely for a suitably sited and designed repository. FEPs not associated with groundwater scenarios are considered to be either avoidable by suitable site selection and design, or of extremely low probability.

FEPs that are screened out have been recorded, together with the reasons for the screening decision, in order to ensure traceability and transparency of the assessment. Some of the screened FEPs have the potential to generate isolation failure scenarios, which are addressed by less formal.

Conclusion

The most comprehensive efforts to develop a comprehensive FEP list, is probably the database developed by the OECD Nuclear Energy Agency (NEA). NEA also provides a good summary of experiences with FEP lists, database and scenario development as applied to geological disposal system.

Based on OECD/NEA above mentioned the Atomic Energy Commission of Japan AEC decided that the focus of strategies for high-level waste management should be placed on geological disposal, the AEC's Advisory Committee on Radioactive Waste Management (ACRWM) later endorsed the concept, based on a multibarrier system, thus providing the basis for geological disposal in Japan

The main focus of scenario generation of activities within the ISAM-IAEA program is those related to near-surface disposal system. However, considerable international effort has been made with the development of FEP database and the generation of scenarios for geological disposal system, based on OECD/NEA above mentioned.

One of the key activities in scenario generation methodologies for the development of a safety case, is the comprehensive identification of the potentially relevant factors, often termed *features, events and processes* (FEPs), which could directly or indirectly influence the disposal system and the migration and fate of radionuclide within it. These FEPs are usually identified from the disposal system description.

The objective of radioactive waste disposal is to isolate waste so that it does not result in undue radiation exposure to humans and the environment, both well occur for geological disposal system and near-surface disposal system.

In near surface disposal, the disposal facility is located on or below the ground surface, where the protective covering is generally a few meters thick. These facilities are intended to contain low and intermediate level waste without appreciable quantities of long-lived radionuclides.

Looking at it from a geology characteristic and ground water table enable to place something Near Surface Disposal in unsaturated zone than will be easier to executed and lower operating costs compared with place in saturated zone. The Serpong site is for planning of shallow-land burial in a place altitude 90-95m above sea level with slope 8-15 % (small erosion). Lithologies in depth 0-9 m are consist of lateritic clay layers with permeability $1.01x10^{-7}$ – $1.34x10^{-7}$ m/s (impermeable). Depths of ground water surface are 11 m. Thus, so Serpong site is suitable for shallow-land burial in unsaturated zone. See table 4.2.3-9 and Figure 4.2.5-14 bellow.

Refer to geological disposal in Japan (H12 reports) and ISAM-IAEA methodologies could be applied a model scenarios for the safety assessment of near-surface radioactive waste disposal facility in Serpong site.

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Table 1:
The Existing and Management of Low and Intermediate Level of Radioactive Waste in Indonesia

No.	Source of Waste	Type of Waste	Major Radionuclides	Activity Level (Dose Rate)	Quantity of Waste	Management Process
1.	**BATAN Nuclear** Research Center	Liquid	^{60}Co, ^{137}Cs, ^{65}Zn, ^{109}Cd, ^{54}Mn, ^{95}Zr	10^{-6} - 10^{-2} Ci m^{-3}	224 m^3 year^{-1}	Evaporation, Cemented and Interim Storage
		Spent Resin	^{60}Co, ^{137}Cs, ^{131}I	1 Ci m^{-3}	2100 l year^{-1}	Cemented and Interim Storage
		Solid Waste	^{137}Cs, ^{131}I, ^{125}I,	Max. 25 mRem hour^{-1}	1184 drums	Compacted, Cemented and Interim Storage
			^{60}Co, ^{235}U, ^{238}U	Max. 200 mRem hour^{-1}	32 shell	
	Reflector TRIGA Mark II reactor	Solid Waste	^{60}Co, ^{65}Zn	Up to ~ 10^2 R hour^{-1}	~ 1 m^3	Interim Storage
2.	**Nuclear Application**					
	Nuclear Medicine	Spent sealed source	^{137}Cs ^{226}Ra ^{60}Co	400 - 1300 Ci 25 mCi 1000 Ci	9 pieces 6 pieces 5 pieces	Interim Storage Interim Storage Interim Storage
	Industrial Application (Oil & Mining, Paper, Cigar industries)	Sealed source	^{60}Co, ^{137}Cs, ^{90}Sr, Am-Be, ^{85}Kr	22.125 Ci	37 pieces	Conditioning and Interim Storage
	Lightning Protection Device	Solid Waste	^{226}Ra, ^{241}Am	0.72 mCi/piece	809 pieces	Conditioning and Interim Storage

Table 2: Description of site characteristics

No.	Parameters	Serpong Site
1.	Accessibility	Near or on-site of waste source (nuclear research center) and treatment facility, wide ± 2.0 Ha
2.	Geomorphology	One morphology unit : • volcanic foot undulatory plain
3.	Lithology	Sandy silt and tuffaceous sandstone
4.	Stratigraphy	Horizontal bedding
5.	Geological structure	None
6.	Seismicity	Scale II-IV MMI, 0.001-0.032 g (cm/sec^2), far from Euro-Asia plate tectonic
7.	Volcanism	No volcano, ash fall from far volcano
8.	Surface water	Subparalel pattern of drainage, 800 m from Cisadane river
9.	Groundwater	Subparalel pattern Depth of water table 11-17 m Porosity Permeability $1.01x10^{-7}$ to $1.34x10^{-7}$ m/sec Flow velocity: • ground water: 0.0037 m/day • Darcy : 0.011 m/day • Radionuclide : 0.0006 – $7.42.10^{-6}$ m/day (Tritium)
10.	Topography	90 – 95 m above sea level Slope 8-15 %
11.	Climate	Precipitation 2377 mm/y Humidity 60-70 % Atmospheric pressure 759-760 mmHg Temperature 23°C-34°C Free from twister
12.	Natural resources	No mineral resources, natural resources: land, and groundwater
13.	Land Use	Open land on site of the nuclear research center area
14.	Population	Far from population (± 5 km), Amount 5,424 person Density 1.726 person/km^2 (1990)
15.	Land ownership	100% government (BATAN)

Table 3:

Scenarios Used in Safety Assessment Analysis of Near Surface Radioactive Waste Disposal Systems in Serpong Site

SCENARIO TYPE	SCENARIO CHOSEN		STATUS
	EVENTS	DISCOUNTED EVENTS	
• Normal scenario during institutional control	• Barriers: natural degradation, infiltration, leaching, advection, diffusion, dissolution, migration. • Far field: denudation • Biosphere: water well, irrigation, farming	Warfare, terrorism, anarchy, earthquake	Ongoing assessment
• Normal scenario post institutional control	• Cap looses function, ground water infiltration, leaching, advection, dispersion into aquifer, • Well drilling scenario		
• Normal scenario during operational phase	• Waste container accident leading to airborne release • Gas pathway • Fire leading to dust and plume		
• Human intrusion after end of institutional control	• Road / house construction disruption scenarios • Residential scenarios leading to exhausted waste • Farming scenario leading to food consumption.		

Table 4: FEP matrix

Processes and Conditions	Materials and Characteristics				
	Cement matrix	**Drums / Shell**	**Backfill / Buffer (Bentonite sand)**	**Engineer Barrier (Reinforced concrete)**	**Natural barrier (Lateritic Clay)**
Mechanical	• Cement mechanical properties • Cement compression • Cement degradation processes • Volume changes • Mechanical loads imposed	• Containers mechanical properties • Containers degradation processes • Containers compression • Containers collapse • Volume changes • Containers breaching • Expansion due to corrosion • Containers sinking • Containers movement • Mechanical loads imposed	• Backfill/buffer mechanical properties • Backfill/buffer compression • Backfill/buffer swelling pressure • Backfill/buffer deformation • Backfill/buffer extrusion	• Components mechanical properties • Components compression • Components swelling • Components deformation • Components extrusion • Engineer barrier degradation • Engineer barrier collapse • Engineer barrier subsidence • Mechanical loads imposed by the surrounding Geology	• Host sediment Mechanical properties • Host sediment compression • Host sediment deformation
Hydrogeological / Hydraulic			• Backfill/buffer hydrological properties • Saturation of backfill/buffer • Hydraulic flow in backfill/buffer	• Components hydrological properties • Resaturation/desaturation of components • Hydraulic flow in components • Components degradation	• Host sediment Hydrological properties Recharge to host sediment Hydraulic flow in host sediment
Chemical / Geochemical	• Cement Chemical properties • Cement degradation processes • Porewater chemistry around cement • Cement dissolution • Colloid formation • Cement alteration	• Containers Chemical properties • Containers degradation processes • Porewater chemistry in containers • Interaction of containers • Corrosion • Colloid formation •	• Backfill/buffer chemical properties • Porewater chemistry in backfill/buffer • Interaction of backfill/buffer with groundwater chemistry • Colloid formation • Backfill/buffer chemical alteration • Backfill/buffer degradation processes	• Components chemical properties • Interaction of components with groundwater chemistry • Colloid formation • Components chemical alteration • Engineer barrier degradation	Host sediment chemical properties • Interaction of host sediment with groundwater chemistry Colloid formation Host sediment chemical alteration
Biological / Biochemical	• Microbial activity • Effect of organic materials	• Microbial activity • Effect of organic materials	• Microbial activity • Effect of organic materials	• Microbial activity • Effect of organic materials	Microbial activity Effect of organic materials
Thermal	• Thermal properties • Cement temperature • Cement thermal expansion • Decay heat generation	• Containers thermal properties • Containers temperature • Containers thermal expansion	• Backfill/buffer thermal properties • Backfill/buffer Temperature • Backfill/buffer thermal expansion	• Components thermal properties • Temperature of components • Components thermal expansion	Host sediment Thermal properties Host sediment Temperature Host sediment thermal expansion
Gas Sources	• Gas generation and effects	• Gas generation and effects	• Gas generation and effects	• Gas generation and effects	Gas generation and effects
Radiation Effects	• Radioactive decay ingrowths • Porewater radiolysis • Cement radiation damage	• Radioactive decay ingrowths • Porewater radiolysis • Containers radiation damage	• Radioactive decay ingrowths • Porewater radiolysis • Backfill/buffer radiation damage	• Radioactive decay ingrowths • Porewater radiolysis • Components radiation damage	Radioactive decay ingrowths Porewater radiolysis Host sediment radiation damage
Mass Transport	• Cement mass transport properties • Radionuclide release from cement	• Mass transport properties in corrosion of containers • Containers geometry and pore structure • Radionuclide migration path within	• Backfill/buffer mass transport properties • Backfill/buffer geometry and pore structure • Radionuclide migration path within backfill/buffer • Advection / dispersion	• Components mass transport properties • Components geometry and pore structure • Radionuclide migration path within components	• Host sediment mass transport properties • Host sediment geometry and pore structure • Radionuclide migration path

		corrosion of containers	• Diffusion, sorption		within host sediment

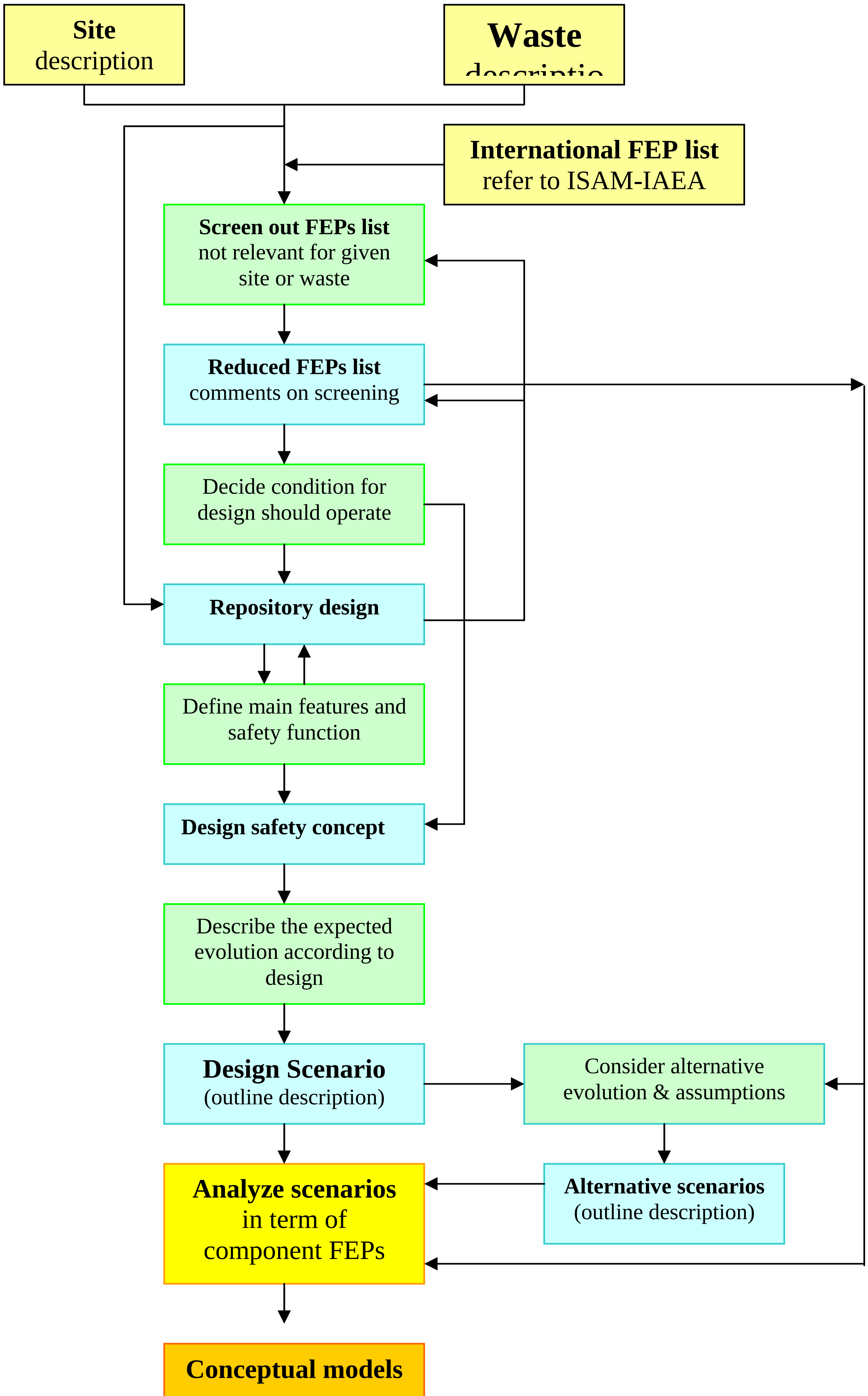

Figure 1
Scenario Development Procedure
For Serpong site

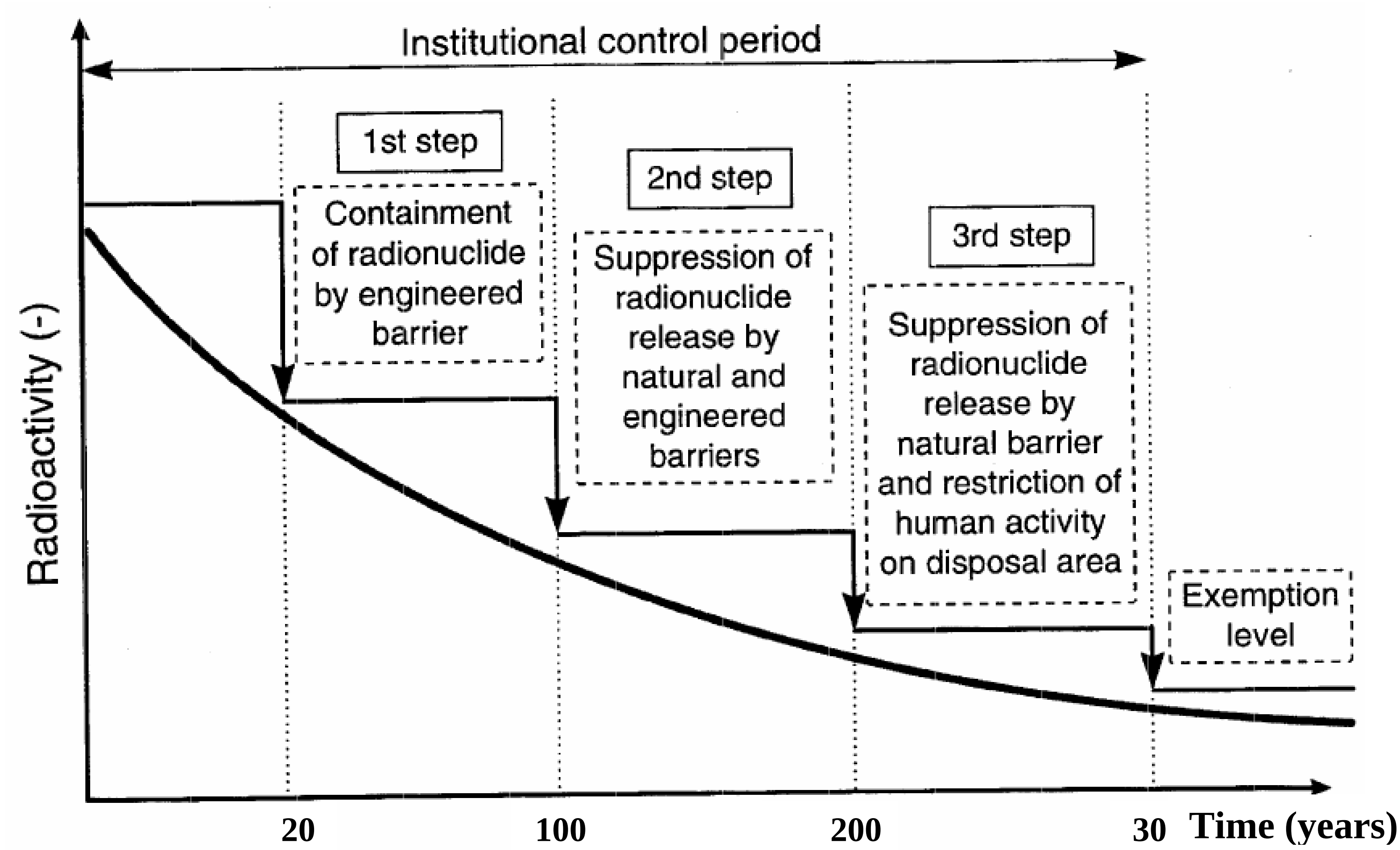

Figure 2: Safety Management Plan for Near Surface Radioactive Waste Disposal on Serpong Site