SAND2016-5013C

Classification of Radioactive Waste

John R. Cochran
Sandia National Laboratories
Expert for the U.S. NRC
June 2016
Rev 0

NNSA National Nuclear Security Administration

SAND2016-xxxx PE. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

Sandia National Laboratories

Agenda

- Why we classify radioactive waste
- IAEA Waste Classification System
- U.S. Waste Classification System
- U.S. System for Classifying LLW

Agenda

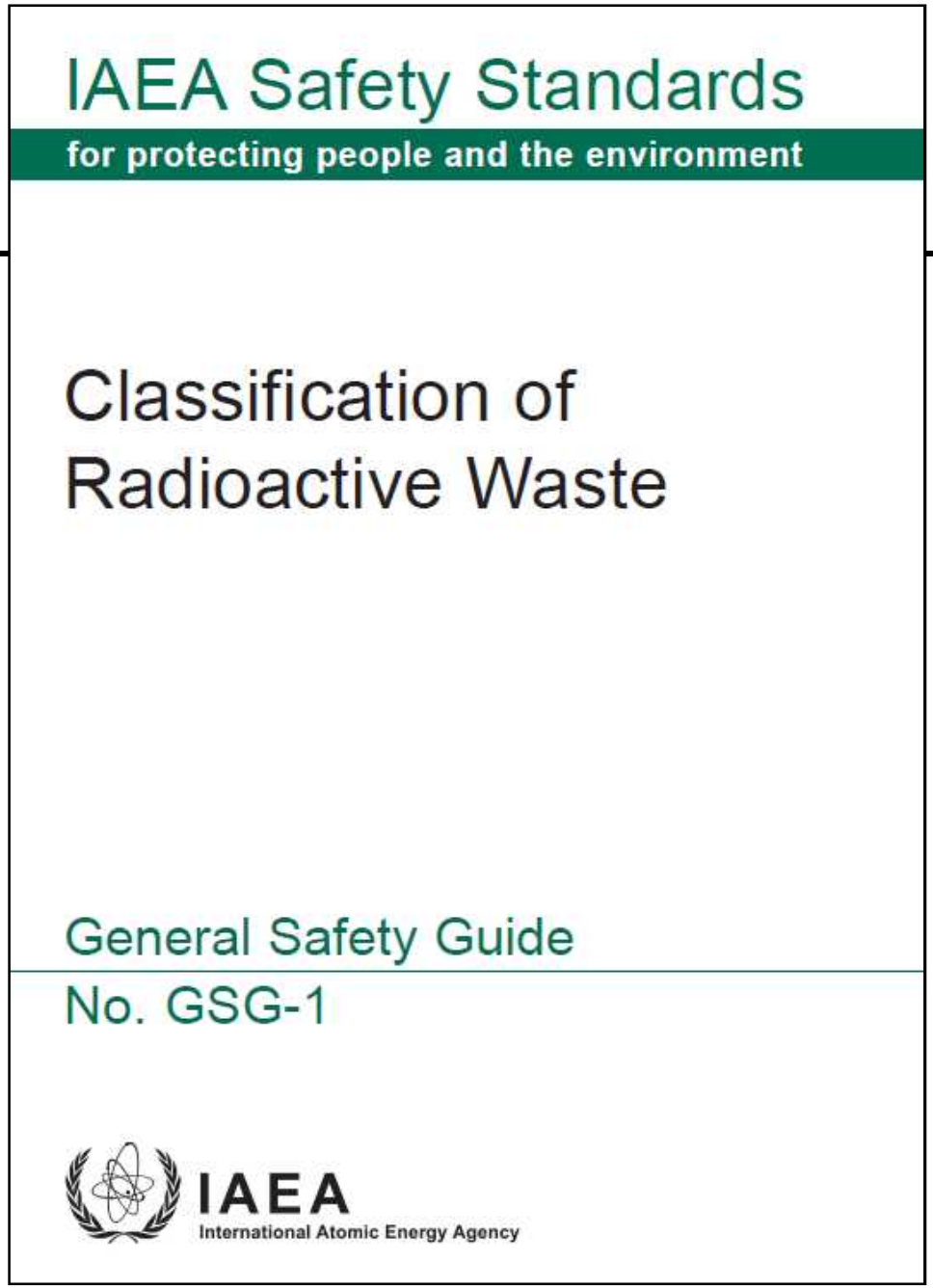
- Why we classify radioactive waste
- IAEA Waste Classification System
- U.S. Waste Classification System
- U.S. System for Classifying LLW

Why Classify Radioactive Waste?

- So that wastes with similar characteristics are managed together. For example:
  - For setting and implementing safety standards
  - National planning

Agenda

- Why we classify radioactive waste
- IAEA Waste Classification System
- U.S. Waste Classification System
- U.S. System for Classifying LLW



National Nuclear Security Administration

Sandia National Laboratories

IAEA Classifies Radioactive Waste Based on Long-Term Hazard

- **IAEA's *Classification of Radioactive Wastes* (GSG-1)**
  - **Classifies radioactive waste based on potential for harm to human health, after the assumed time period of institutional controls**
  - **Sometimes referred to as the "post-closure" hazard**
  - **Not the hazard today, but the hazard a few hundred years from now**

IAEA Code of Conduct for Radioactive Sources Classifies Radioactive Sources Based on Current Hazard

- ***Code of Conduct on the Safety and Security of Radioactive Sources***
  - **Classifies radioactive sources based on potential to cause harm to human health, today**
  - **Not appropriate for classifying radioactive waste**
  - **For security measures**
  - **For emergency planning**

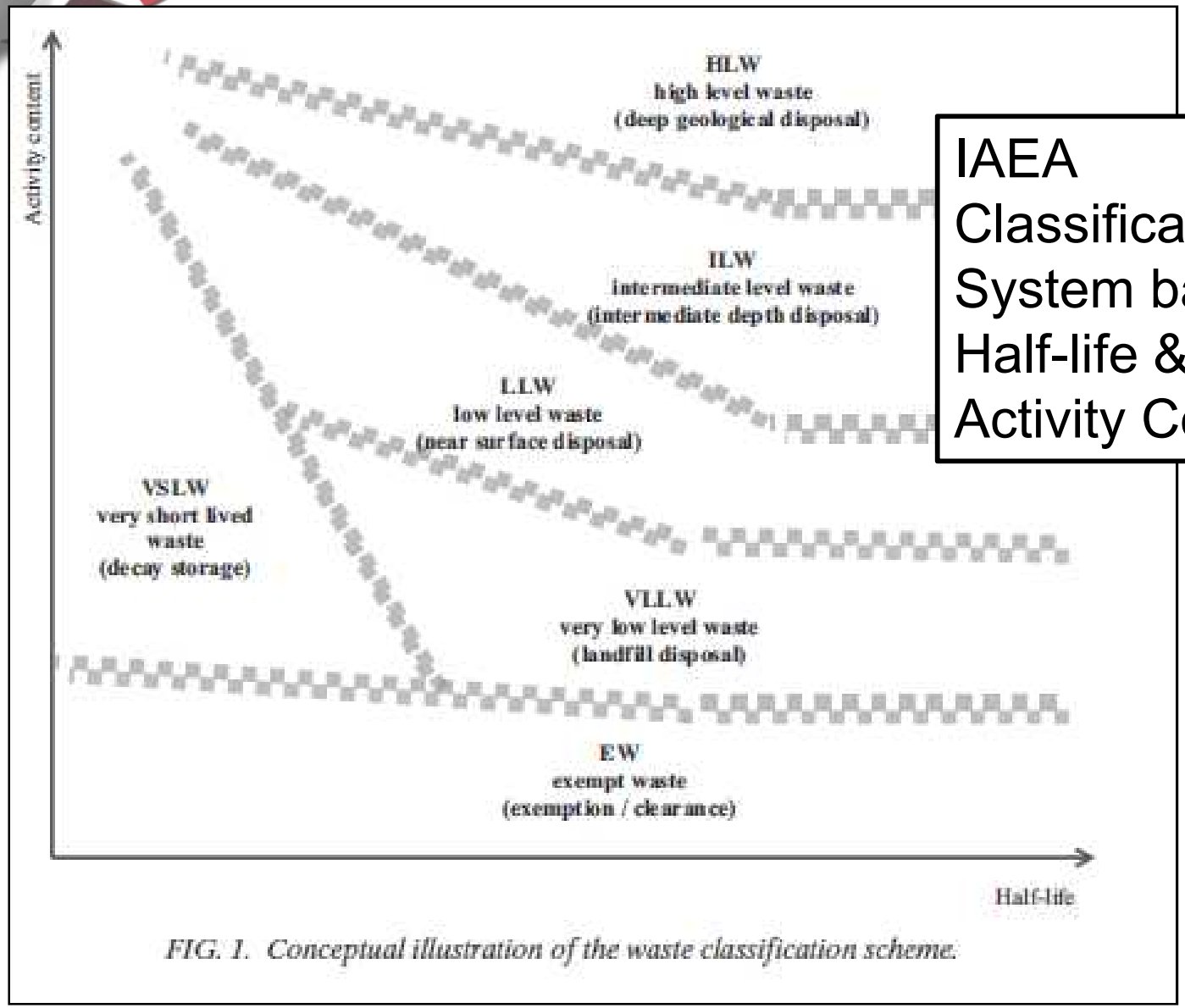


FIG. 1. Conceptual illustration of the waste classification scheme.

IAEA Classification System based on Half-life & Activity Content

IAEA Divides Radioactive Waste into 6 Classes based on Half-Live and Activity

- High-level radioactive waste (HLW)
- Intermediate-level radioactive waste (ILW)
- Low-Level radioactive waste (LLW)
- Very Low-level radioactive waste (VLLW)
- Very short-lived radioactive waste (VSLW)
- Exempt waste

It is the Long-Term Hazard, not the Radionuclide

- It is the long-term hazard and not the radionuclide
- For example, Cesium-137 could be in:
  - High-level
  - Intermediate-level
  - Low-Level
  - Very Low-level
  - Exempt waste

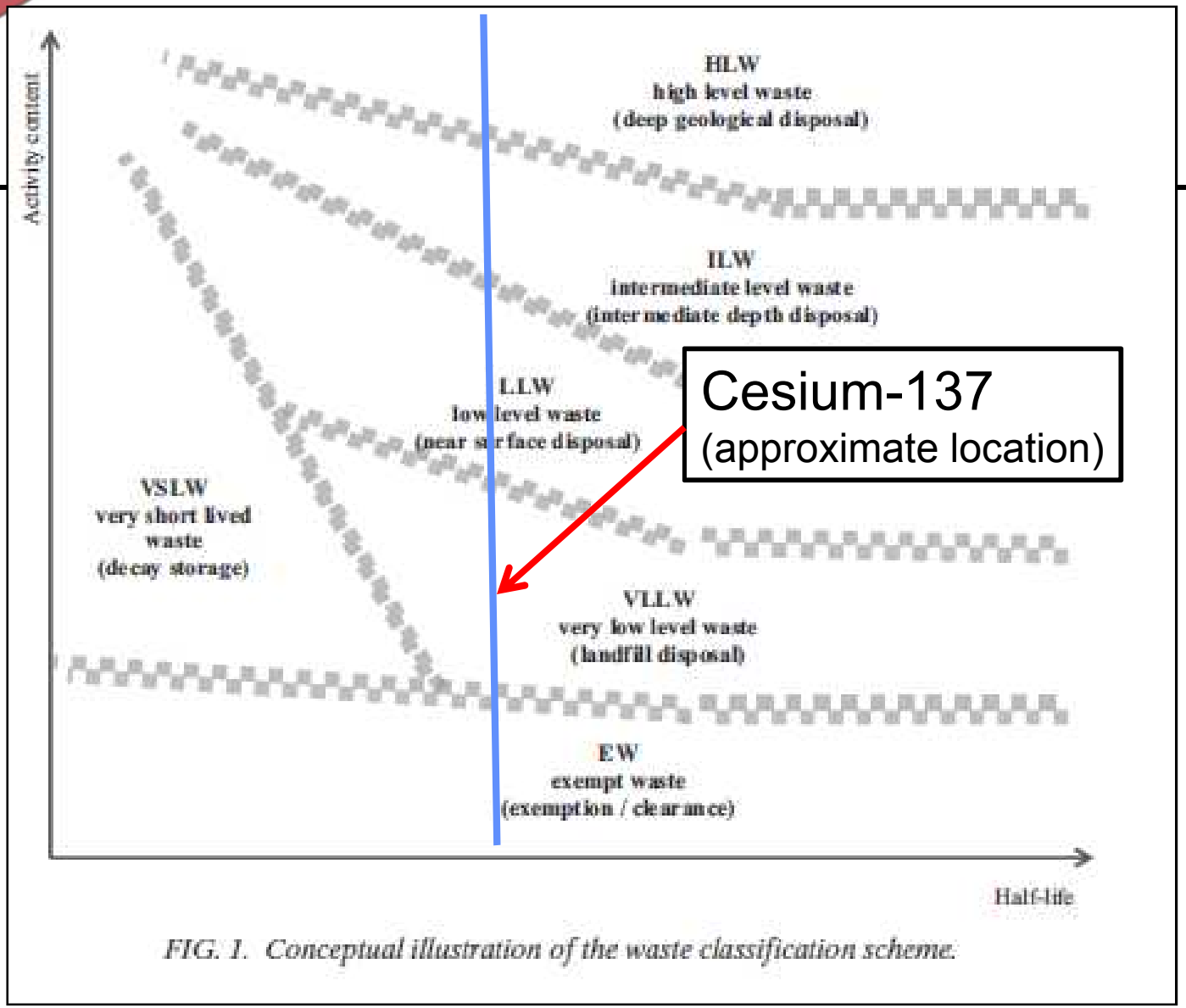


FIG. 1. Conceptual illustration of the waste classification scheme.

The IAEA Does Not Provide Boundaries Between Waste Classes !

- **"2.3.Quantitative values of allowable activity content for each significant radionuclide will be specified *on the basis of safety assessments for individual disposal sites* (which is outside the scope of this Safety Guide).**
- **IAEA provides general criteria for setting numerical limits on the boundaries (next slides)**

IAEA roadmap for their classification system

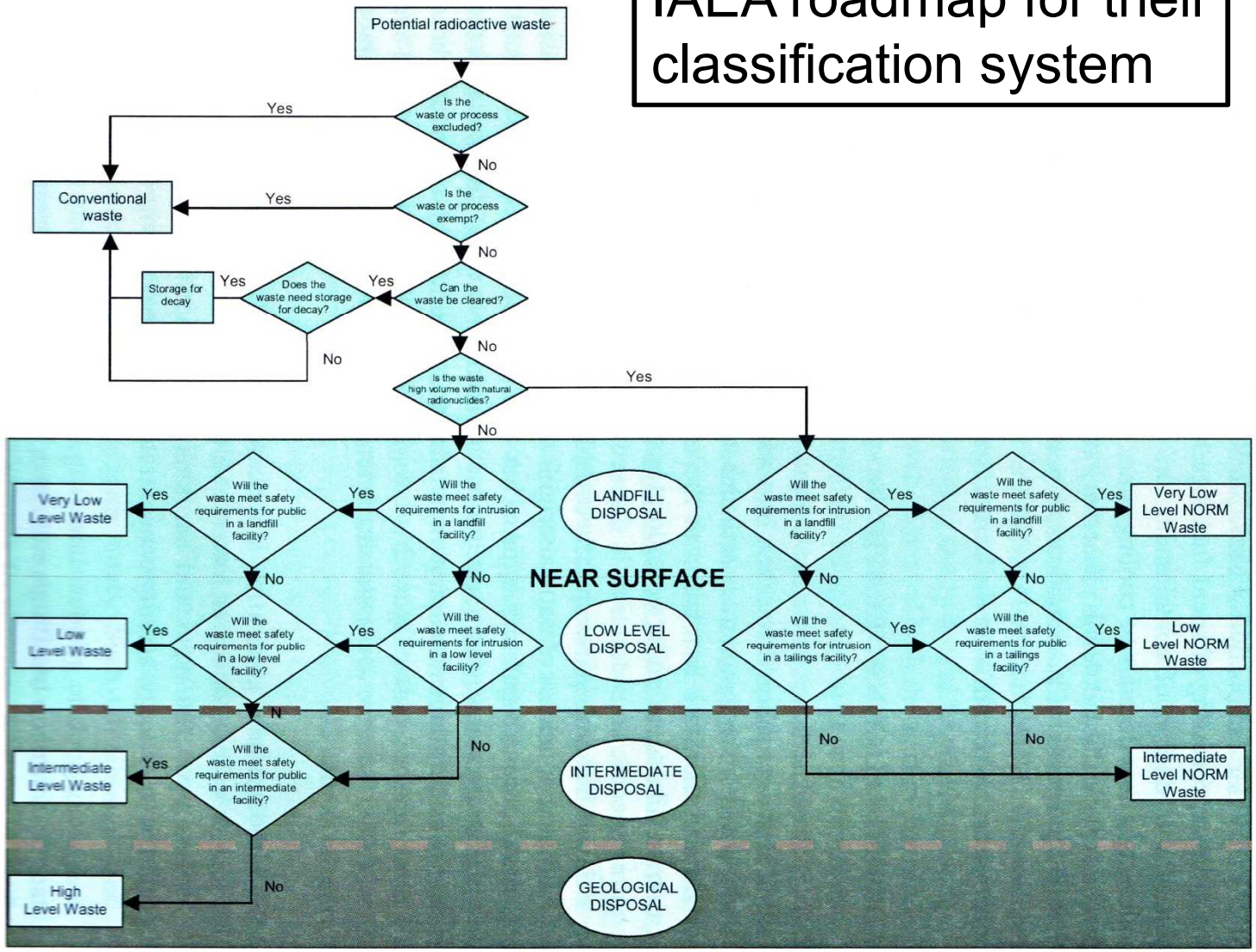


FIG. 2. An illustration of the use of the classification scheme.

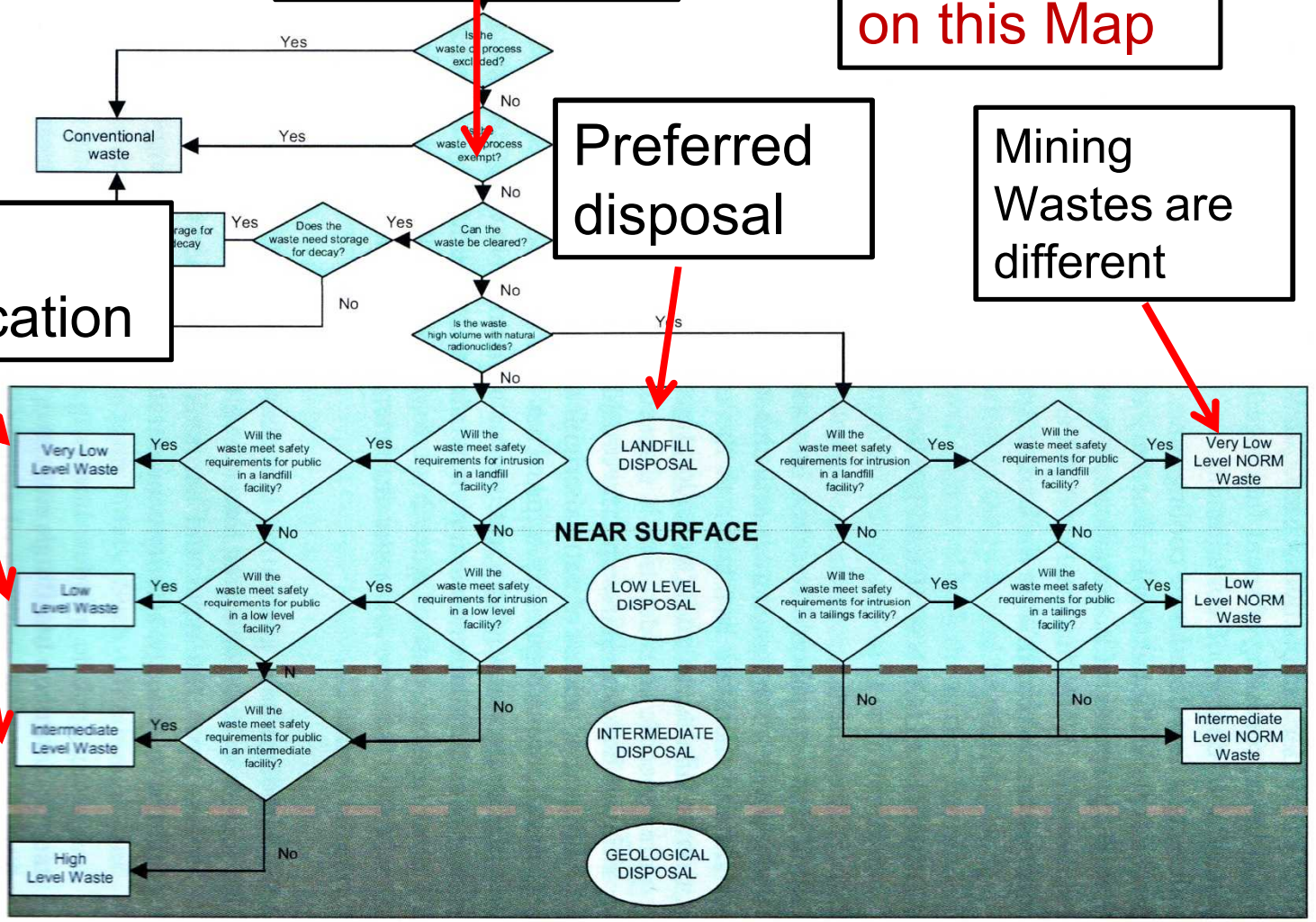
Classification criteria

Important Information on this Map

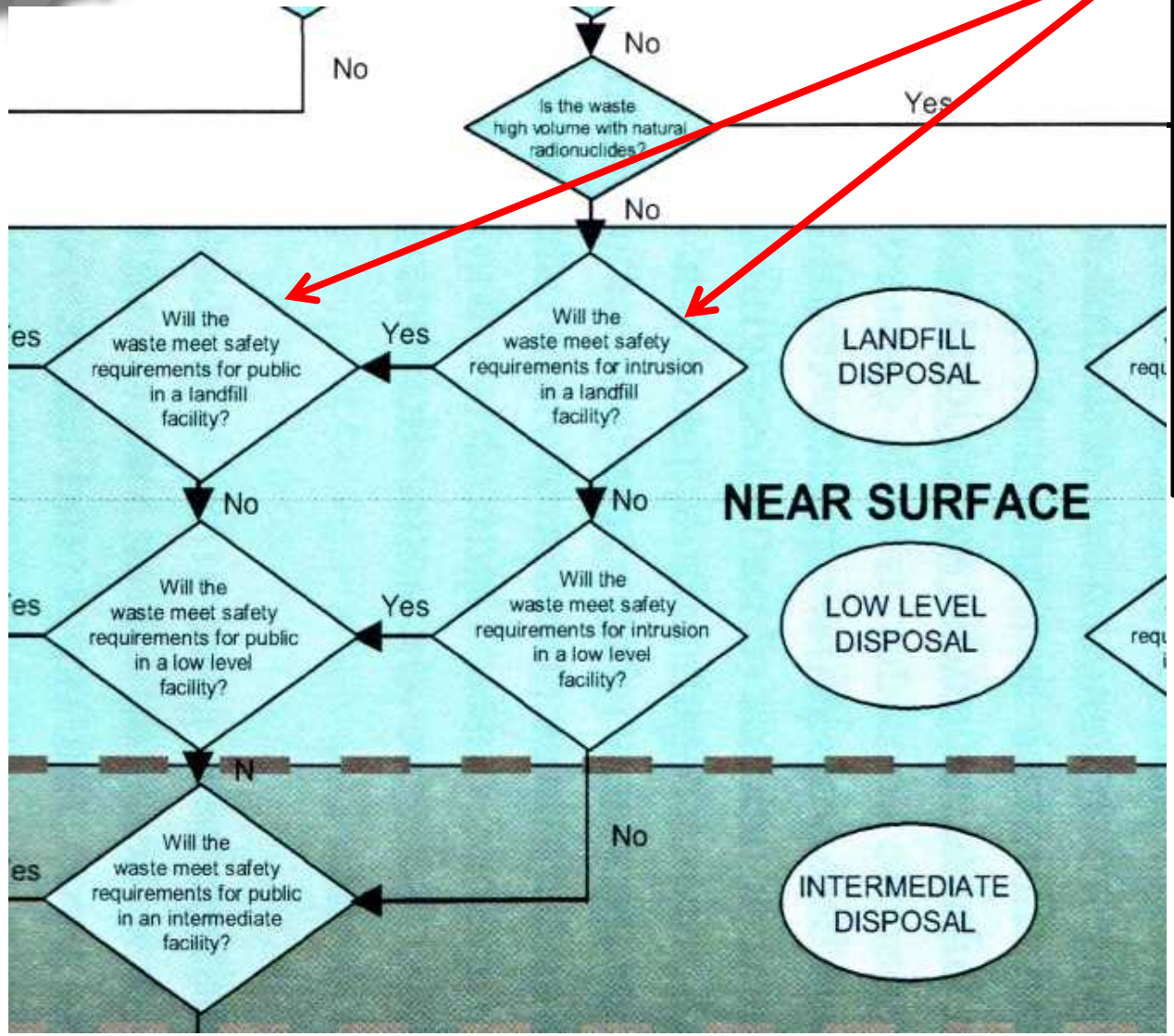
Preferred disposal

Mining Wastes are different

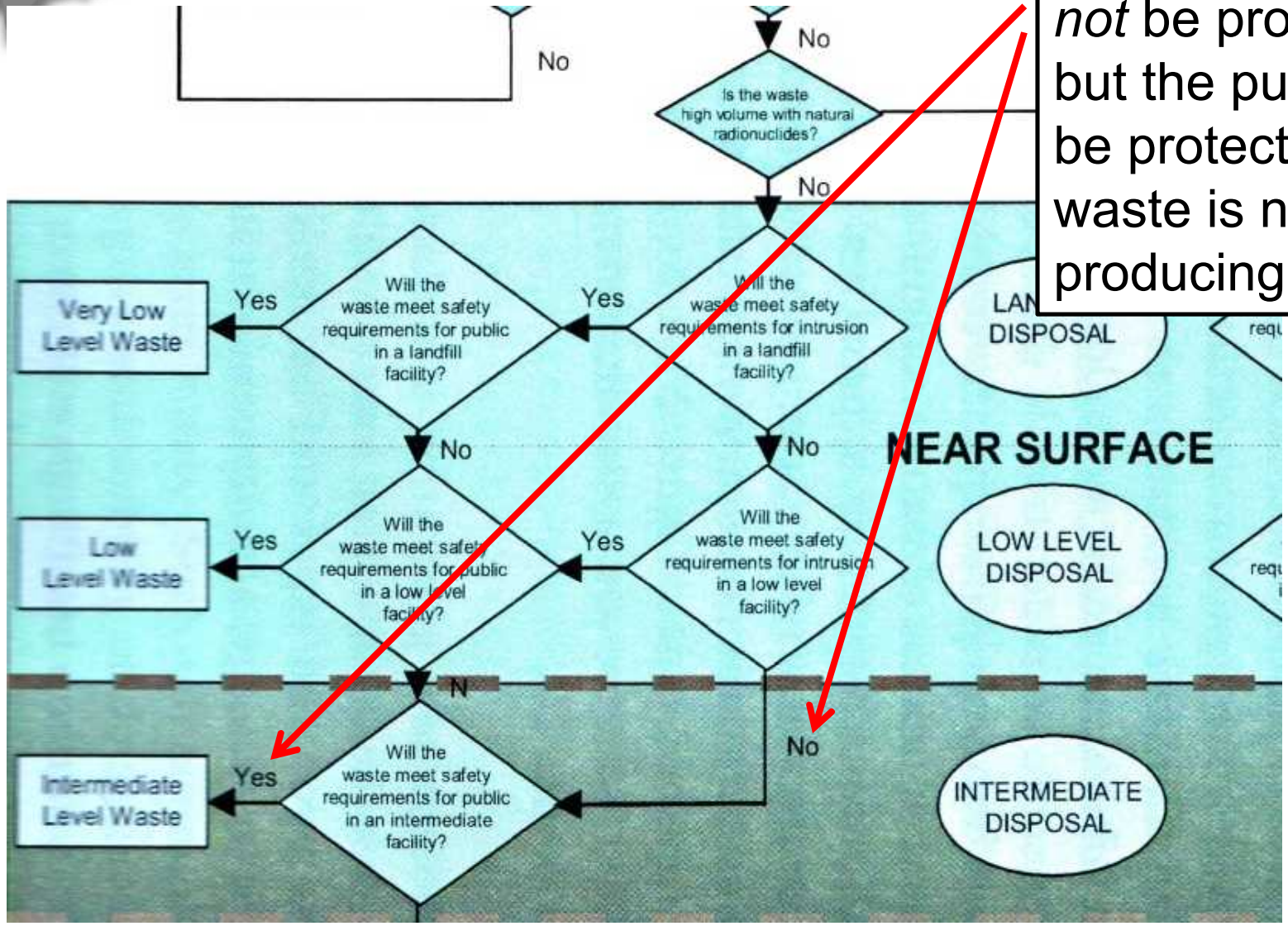
Waste Classification



FOCUS ON SETTING THE BOUNDARY BETWEEN VLLW, LLW AND ILW USING IAEA SYSTEM



IAEA recommends that *protection of intruder* and *protection of member of public* be used to separate VLLW from LLW



If the intruder can *not* be protected, but the public can be protected, and waste is not heat-producing, it is ILW

How IAEA Recommends Separating VLLW from LLW, and LLW from ILW

- The boundary between VLLW and LLW, and the boundary between LLW and ILW is determined by site-specific and country-specific assessments of the ability of the facility to:
  - Protect the inadvertent human intruder
  - Protect the general population
- Will discuss "how to do this" in section on U.S. system

IAEA Recommendations on Defining Human Intruder Exposure Scenarios

- **Inadvertent human intruder exposure scenario(s):**
  - **use present day habits as surrogate for future habits**
  - **specifics must be in the context of country's national regulatory scheme (dose limit for intruder, time of intrusion, nature of intrusion …)**

Notes and Special Cases

- **Difficult to implement a program with 6 categories (for example, Cs-137 might need 4 boundaries!)**

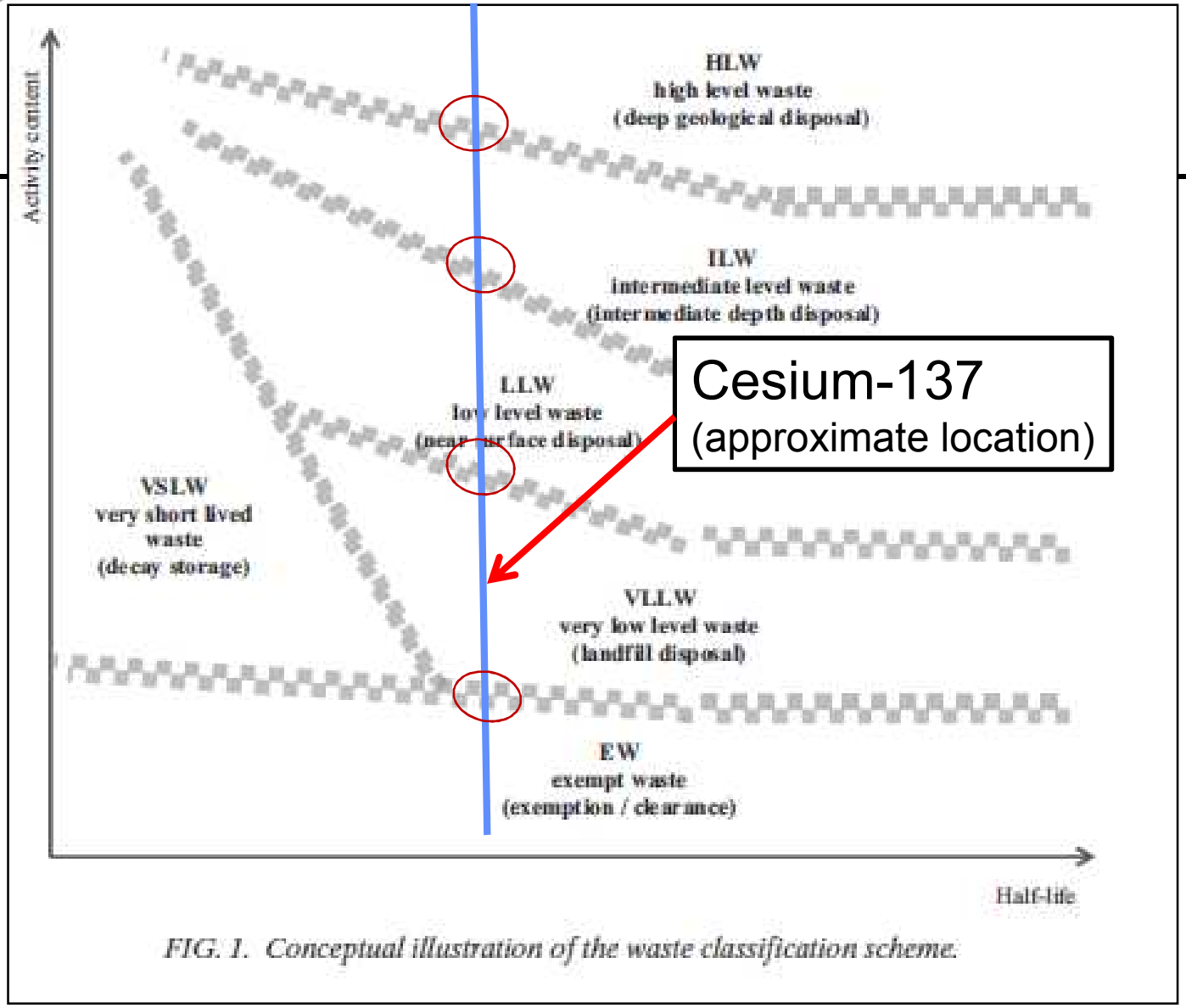


FIG. 1. Conceptual illustration of the waste classification scheme.

Notes and Special Cases

- **Exempt Waste - *Application of the Concepts of Exclusion, Exemption and Clearance*, IAEA Safety Standards Series No. RS-G-1.7, IAEA, Vienna (2004)**
- **Mining wastes with natural radionuclides may be disposed in landfill-type facility (2.18) and held to a less restrictive dose standard (2.25)**
- ***Near-surface* is upper 30 m (2.23)**
- **"In many States it is assumed that institutional controls can be relied upon for a period of up to around 300 years." (2.25)**

Notes and Special Cases

- ***Sealed sources require special considerations*** **– because they are so concentrated (2.32)**
- **Wastes with long-lived alpha (> 400 Bq/g on average), may be held to a higher standard (2.27) (LLW managed as ILW)**
- **High-level radioactive waste –** ***requires special considerations*** **- can not meet requirements for disposal in near-surface, and generates significant quantities of heat (2.2 (6))**

Agenda

- Why we classify radioactive waste
- IAEA Waste Classification System
- U.S. Waste Classification System
- U.S. System for Classifying LLW

U.S. Divides Radioactive Waste into 5 Categories*

- High-level radioactive waste (HLW)
- Spent Nuclear Fuel (SNF)
- Transuranic Waste (TRU waste)
- Low-Level radioactive waste (LLW)
- By-product material ("11e(2)" material)

* U.S. Nuclear Waste Policy Act of 1982

High-Level Radioactive Waste

"(A) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in process and any solid material derived from such liquid that contains fission products in sufficient concentration; and (B) other highly radioactive material that the [Nuclear Regulatory] Commission, consistent with existing law, determines by rule requires permanent isolation."

HLW is defined by origin, not activity

Transuranic Radioactive Waste

- **TRU waste**
- **Waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, with half-lives greater than twenty years, per gram of waste, except for: (1) High-level radioactive wastes; (2) wastes that the Department has determined, with the concurrence of the Administrator, do not need the degree of isolation required by this part; or (3) wastes that the Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61."**
- **Long-lived alpha waste**
- **Looks like LLW, but must be disposed in geologic repository**

Low-Level Radioactive Waste

- **Radioactive material that– (A) is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material as defined in section 11e(2) of the Atomic Energy Act of 1954; and (B) the [Nuclear Regulatory] Commission, consistent with existing law, classifies as low level radioactive waste."**
- **LLW is defined by what it is not**
- **No floor and no ceiling (no numerical boundaries !)**

Observations about U.S. System

- Only TRU waste has a quantitative boundary (100 nCi/g)
- HLW is defined by origin (waste from reprocessing SNF)
- U.S. does not have an exemption level or below-regulatory-concern level
- LLW has no floor and no ceiling (LLW can be screaming hot)

Agenda

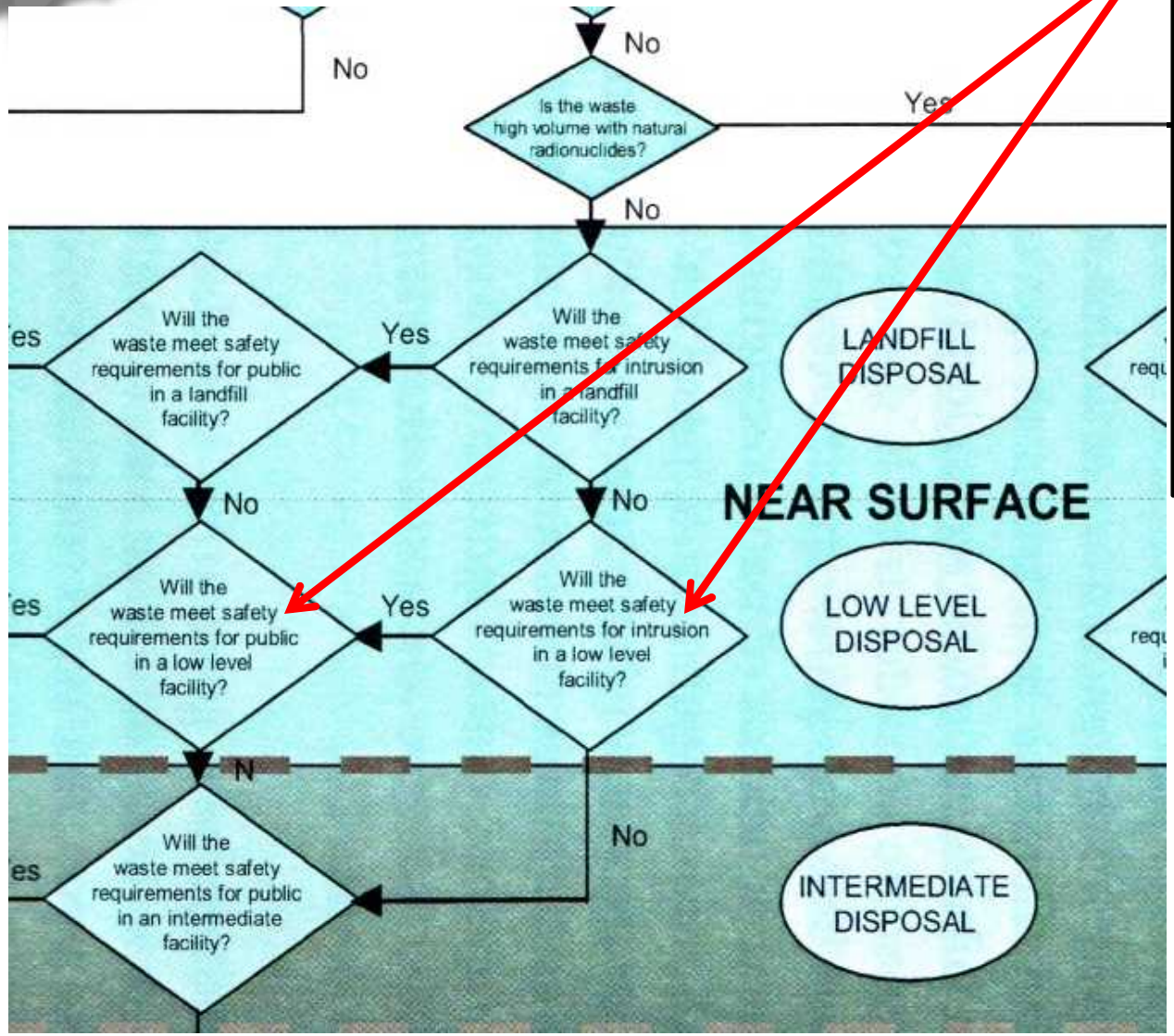
- Why we classify radioactive waste
- IAEA Waste Classification System
- U.S. Waste Classification System
- U.S. System for Classifying LLW

Focus on U.S. Nuclear Regulatory Commission Regulation of LLW

- *Licensing Requirements for Land Disposal of Radioactive Waste* (10 Code of Federal Regulations Part 61)
- Governs LLW from commercial activities (nuclear power plants, hospitals …)
- Effective since 1982

Goals of 10 CFR 61 Licensing Regulation

1. Protection of the general population from releases of radioactivity
2. Protection of individuals from inadvertent intrusion
3. Protection of individuals during operations
4. Stability of the disposal site after closure



IAEA recommendations and NRC requirements are same: *protection of intruder* and *protection of member of public*

Goals of 10 CFR 61 Licensing Regulation

- **Protection of the general population from releases of radioactivity – Regulation requires site-specific, all pathways assessment of dose, for wastes *that migrate away from site (beyond 100 m boundary)***

Goals of 10 CFR 61 Licensing Regulation

- **Stability of the disposal site after closure** - **Regulation requires stable location and stable waste forms**

Goals of 10 CFR 61 Licensing Regulation

- Protection of the general population from releases of radioactivity
- Protection of individuals from inadvertent intrusion
- Protection of individuals during operations
- Stability of the disposal site after closure

Protection of Individuals from Inadvertent Intrusion

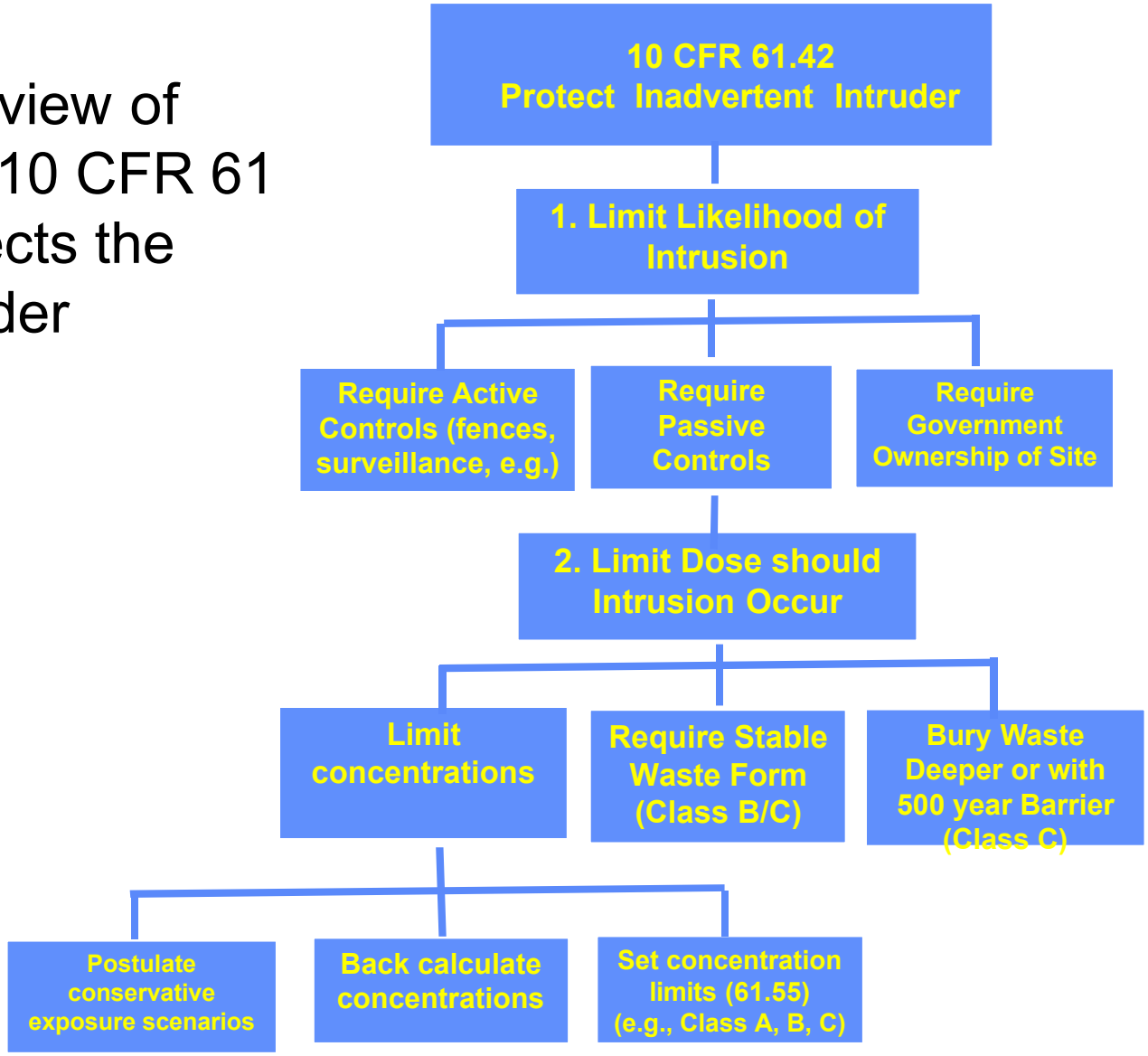
"Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time *after active institutional controls over the disposal site are removed*." § 61.42

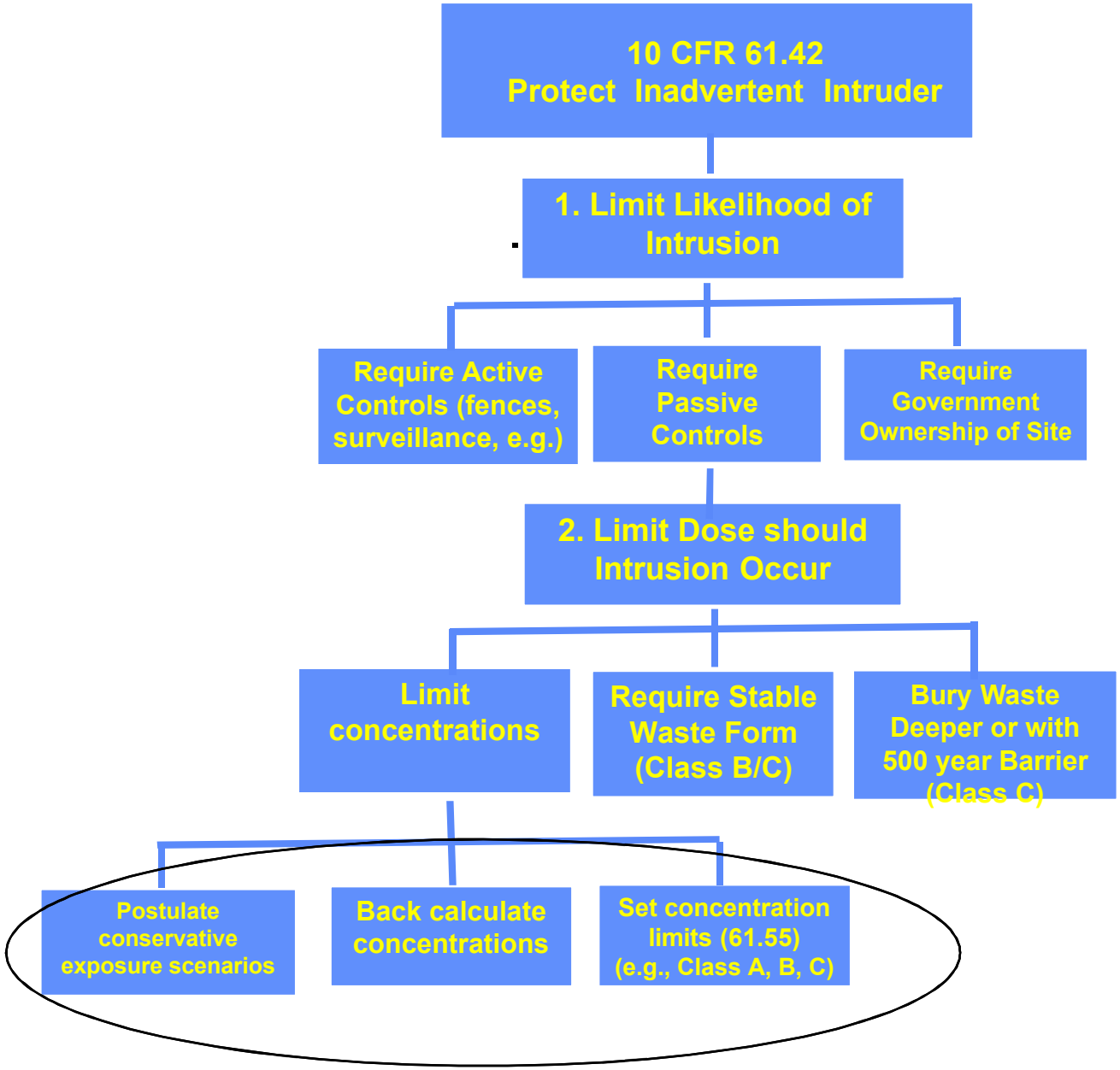
This is long-term safety, the safety after institutional controls cease

Protection of individuals from inadvertent intrusion

"Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed." § 61.42

Overview of how 10 CFR 61 protects the intruder




10 CFR 61.42
Protect Inadvertent Intruder
1. Limit Likelihood of Intrusion
Require Active Controls (fences, surveillance, e.g.)
Require Passive Controls
Require Government Ownership of Site
2. Limit Dose should Intrusion Occur
Limit concentrations
Require Stable Waste Form (Class B/C)
Bury Waste Deeper or with 500 year Barrier (Class C)
Postulate conservative exposure scenarios
Back calculate concentrations
Set concentration limits (61.55) (e.g., Class A, B, C)

Protection of Individuals from Inadvertent Intrusion

- 1982
- NRC developed two inadvertent human intruder exposure scenarios in a public participation process
- LLW is assumed to be soil-like and *radiologically homogenous,* with no durable hot spots
- Exposure scenarios then used to back-calculate limits to protect the intruder
- Based on the calculations, LLW is divided into four Classes - Class A, B, C and Greater than Class C, *based on concentration* (that is, based on curies per cubic meter)

Over Simplification of NRC Intruder Analysis

- In future, active control & passive controls & knowledge & surface recognition of LLRW disposal site are lost (temporary bureaucratic error, error involves small number people)
- Assumption based on global human experience

Controls, knowledge, recognition are lost

Inadvertent human intruder excavates basement in former LLW site

Two outcomes:

(1) intruder recognizes hazard or

(2) intruder does not recognize hazard

(1) Intruder recognizes hazard & there is acute “discovery” dose *or*

(2) Intruder does not recognize hazard & chronic dose based on:

(2a) construction scenario and

(2b) agriculture scenario

(2a) Intruder Construction Scenario – Intruder excavates basement, unrecognized *LLW uniformly mixed* with clean soil (8 parts soil to 1 part LLW) builds basement, some soil against basement, some in garden area, all pathways dose

(2b) Intruder Agriculture Scenario – Intruder lives in house and approximately subsistence farms from garden with homogenized LLW, all pathways dose assessment

Small Example of NRC models for Assessing Dose to Inadvertent Intruder

- **Expresses resistance of the waste to mobilization by intruder.**
- **Property of the waste stream at disposal and exposure pathway.**
- ***Airborne Pathways***

  $f_{w,air} = f_{w,acc} \times f_{w,disp}$, where

  $f_{w,acc}$ ≡ accessibility index, (-)

  - **= 1** for surface-contaminated waste and waste containing radionuclides in soluble form
  - **= 0.1** for waste with significant metallic content, with both activated and surface crud contamination
  - **= 0.01** for activated metals

  $f_{w,disp}$ ≡ dispersibility index, (-)

  - **= 1 for no waste form credit (i.e., soil)**
  - **= 0.1** for waste that crumbles or fractures extensively and decompose quickly
  - **= 0.01** for mix of above and below wastes
  - **= 0.001** for waste likely to resist biological and chemical attack with significant compressive strengths (e.g., good synthetic polymer)

Over Simplification Part 61 Intruder Assumptions

- NRC back-calculated concentrations of LLRW, so that intruder dose from (1) discovery, (2a) construction and (2b) agriculture scenarios < 500 mrem
- Class A, B & C limits from back-calculated values:
  - Class A from Construction or Agriculture @ 100 years
  - Class B from Discovery @ 300 years
  - Class C form Construction or Agriculture @ 500 years
- Resulting values published in Tables 1 & 2 in 61.55

10 CFR 61.55 – Concentration Limits to Protect the Intruder - Table 2

Radionuclide	Concentration, curies per cubic meter		
	Col. 1 [Class A]	Col. 2 [Class B]	Col. 3 [Class C]
Total of all nuclides with less than 5 year half-life	700	([1])	([1])
H-3	40	([1])	([1])
Co-60	700	([1])	([1])
Ni-63	3.5	70	700
Ni-63 in activated metal	35	700	7000
Sr-90	0.04	150	7000
Cs-137	1	44	4600

[1] There are no limits established for these radionuclides in Class B or C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling, and disposal will limit the concentrations for these wastes. These wastes shall be Class B unless the concentrations of other nuclides in Table 2 determine the waste to the Class C independent of these nuclides.

10 CFR 61.55 – Concentration Limits to Protect the Intruder - Table 1

Radionuclide	Concentration curies per cubic meter
C-14	8
C-14 in activated metal	80
Ni-59 in activated metal	220
Nb-94 in activated metal	0.2
Tc-99	3
I-129	0.08
Alpha emitting transuranic nuclides with half-life greater than 5 years	[1]100
Pu-241	[1]3,500
Cm-242	[1]20,000

[1]Units are nanocuries per gram.

10 CFR 61 Subdivides LLW

- Based on analysis of potential doses to an inadvertent human intruder, NRC divides LLW into 4 classes:
  - Class A
  - Class B
  - Class C
  - Greater-than-Class-C
- Hazard is then linked to a set of controls (Class A has least controls (100 years), GTCC (> 500 years) is not typically appropriate for near-surface disposal)

THANK YOU