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Institut für angewandte Ökologie
Institute for Applied Ecology

Repository project in Denmark – Some critical aspects and recommendations

Based on the current planning status

Conference „*The Management of Radioactive Wastes in Denmark*", Copenhagen/Christiansborg, March 24, 2015

by:
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Darmstadt/Germany, March 25, 2015

Final disposal of nuclear waste in general

1. Nuclear wastes require thorough disposal in safe disposal sites.
2. Any other „solutions“ are unreliable and not sustainable as they are associated with undue burdens and risks for future generations.
3. Safe disposal sites are those that enclose the waste reliably as long as the waste still is a hazard for people.
4. To search for and to identify such sites and to evaluate their suitability for that purpose it is necessary to predefine and establish safety criteria for enclosure performance.
5. Site selection processes without those predefined suitability criteria are pure random, their aims are use- and meaningless and their results are inacceptable.
6. In democratic countries it is a base requirement to seek for public consent on a) the concept, b) the applied safety criteria, and c) on the site selection procedure.

Some aspects in the Danish discussion*

1. **As the radioactive content of the Danish wastes is smaller than elsewhere, we can afford much weaker disposal standards.**
2. **The repository will comply with the radiation protection standards.**
3. **We do not need a deep geologic repository because our waste inventory is so small.**
4. **A deep geologic repository is much more expensive than a shallower one.**
5. **If we only can get rid of the small amount of spent research fuel we can reduce the required standards and save money.**
6. **For the spent research fuel we just need to drill a deep hole and dispose it there.**
7. **If we would just store the wastes for additional 100 years** possibly a solution would be easier to find.**
8. **Probably a phantastic method to destroy the wastes would be found in a few years so we would have to dig off the wastes.**

* by different stakeholders; ** The waste has already been under storage for some decades.

A few words on clearance levels ...

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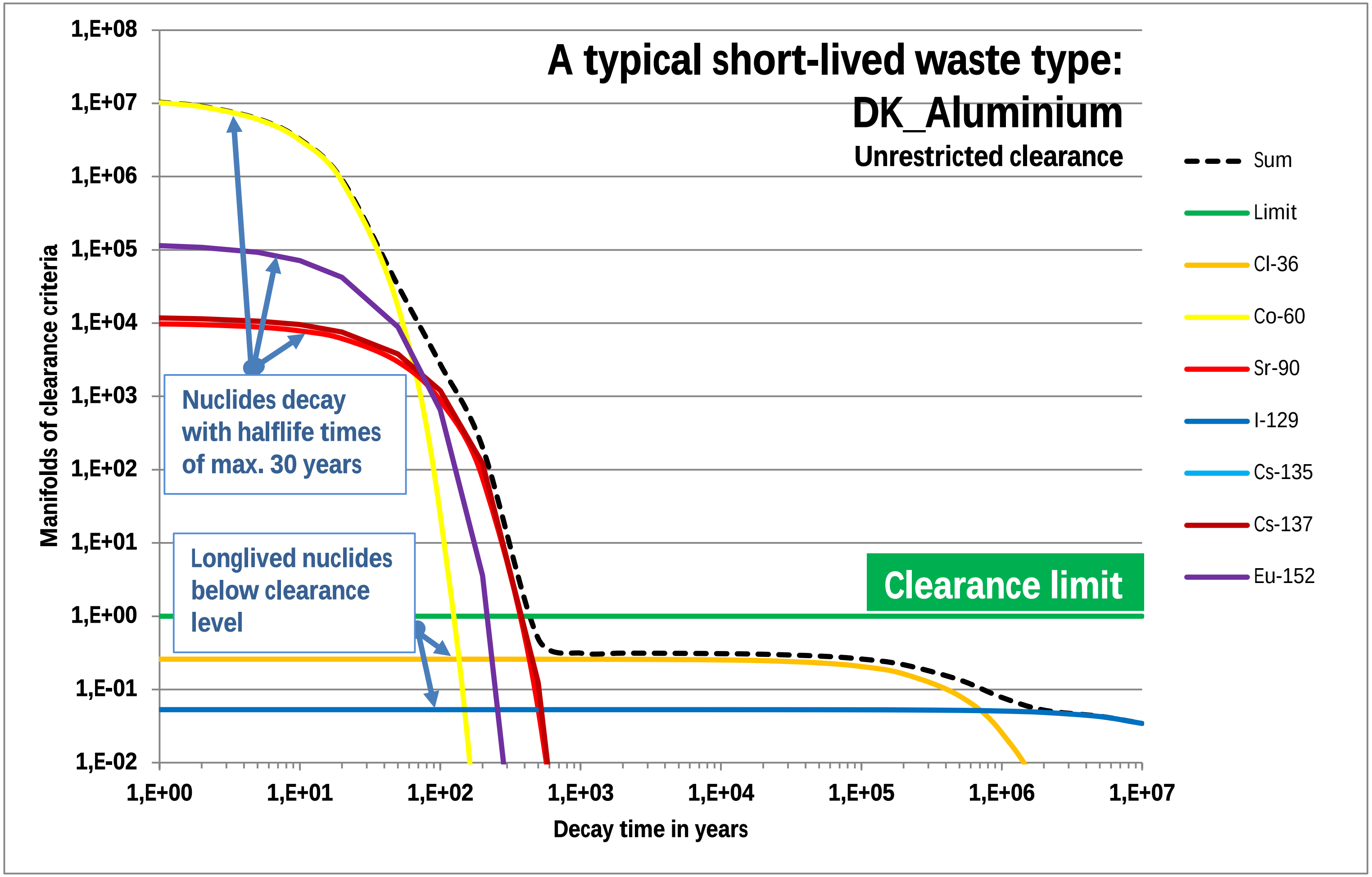
- It seems that our **application of clearance levels** to derive safety requirements for a repository from those levels was clearly misunderstood, so we again make it more clear **here** what clearance means, what it is used for here and what it was **not** meant for.

Aspect #1: Small inventory = weaker standards

- The enclosure of radioactive material requires that the barriers remain intact for as long as the wastes remain hazardeous.
- Wastes that decay within a few days (some medical wastes resulting from diagnostics) can be cleared after a year.
- Wastes that decay within a few 100 years can be disposed under administrational safety guarantees (that means: people continously monitor and care for the safety and repair or replace barriers if necessary).
- Wastes requiring decay times for much longer than 1,000 years cannot be disposed under administrative rules. The enclosure of these waste types can only be achieved by a) geologic isolation layers or b) by extremely long-lasting technical barriers (Sweden).
- In any case the waste has to be isolated reliably for extremely long times.

Aspect #1: Small inventory = weaker standards



- Typical short-lived wastes decay within 300 to 500 years (!) to below clearance levels. For those, above-ground disposal with administrative control (e.g. to prevent from uninteded intrusion) is sufficient.

Aspect #1: Small inventory = weaker standards

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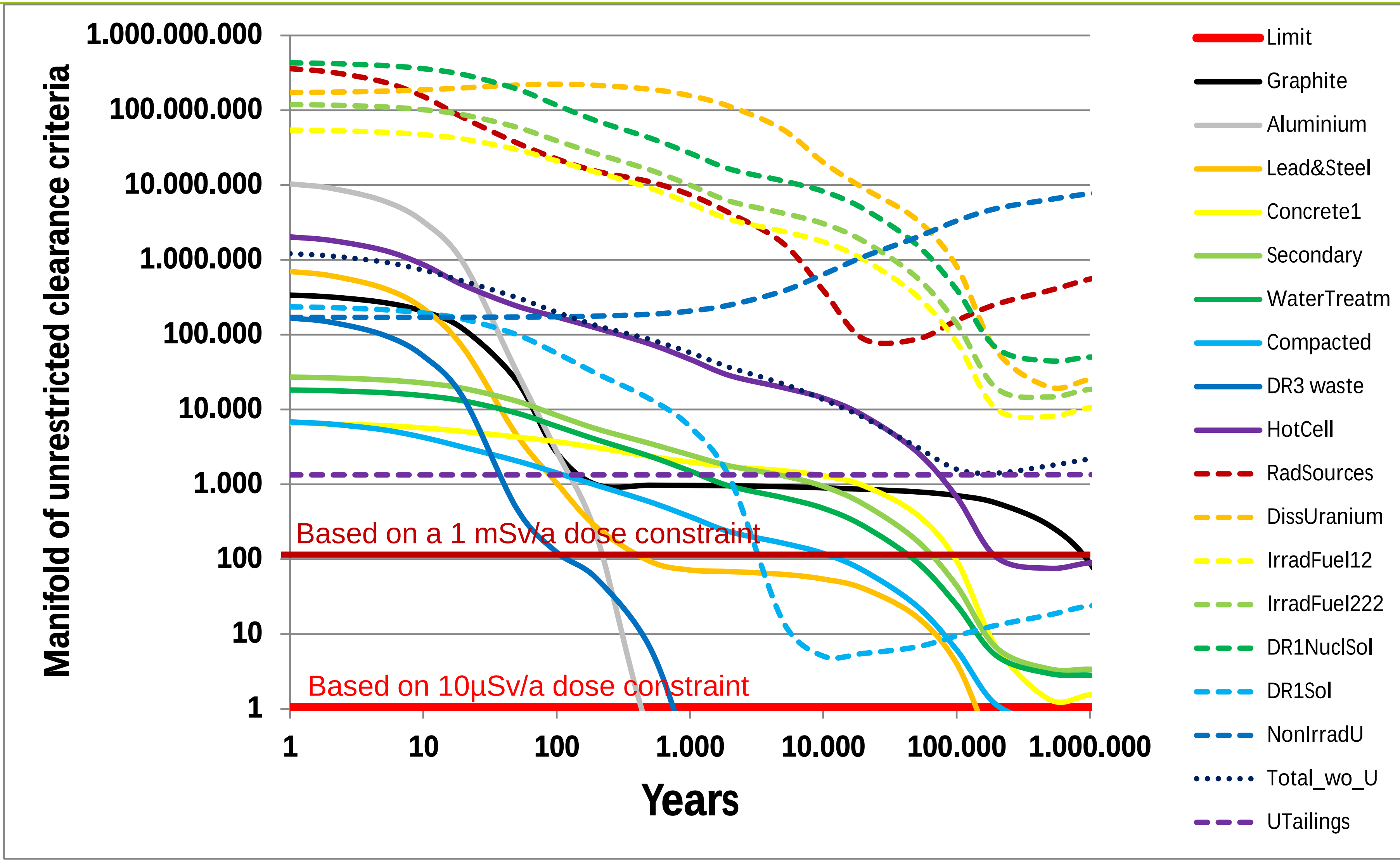
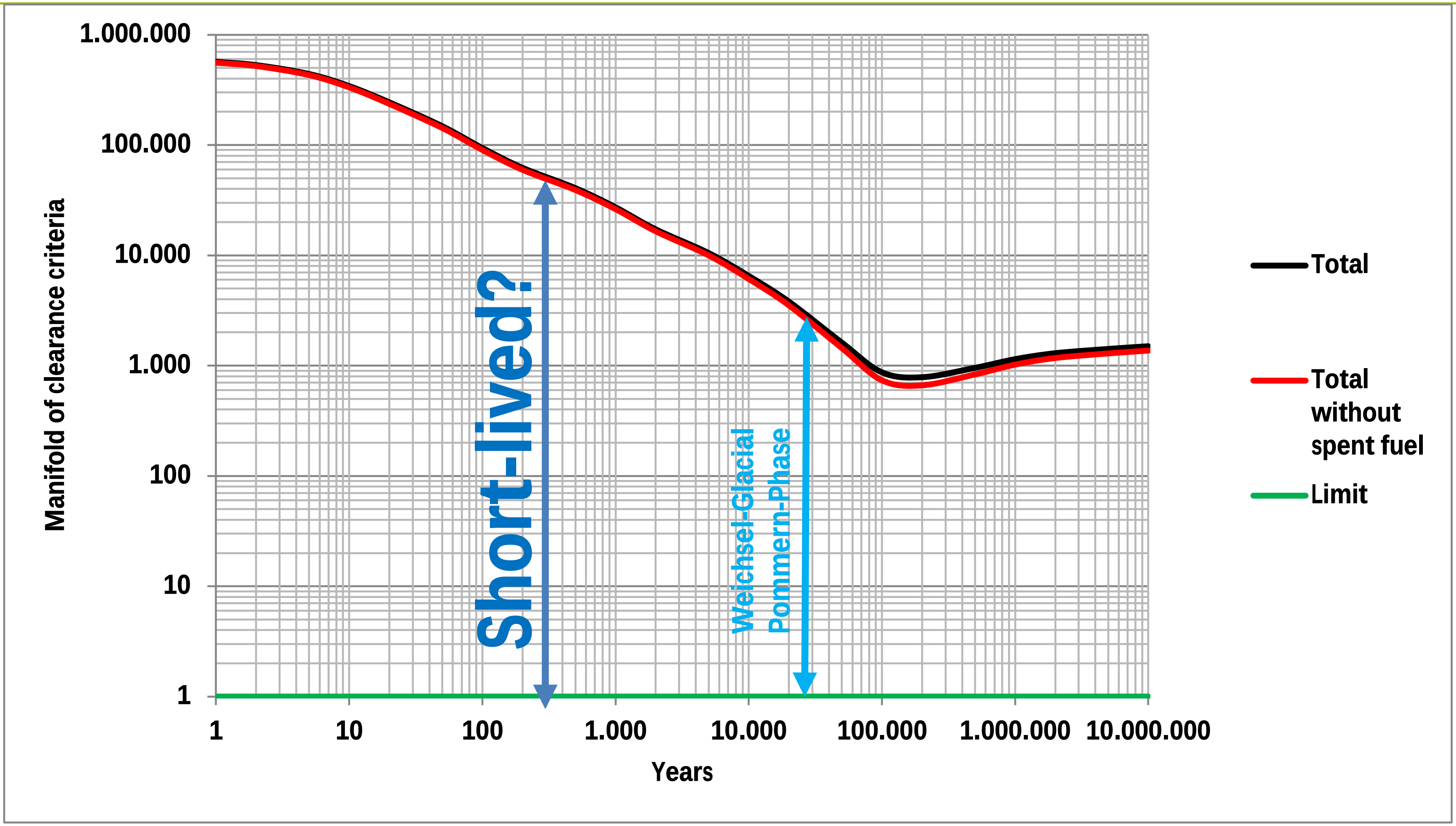


- The Danish inventory is far from being short-lived.

Aspect #5: The spent research fuel is the problem



- The difference of the Danish inventory with or without the spent fuel is hardly to be seen in the diagram. Removal of the spent fuel and an extra-option for the spent fuel does not change the isolation requirements to a relevant extend.

Aspect #1: Small inventory = weaker standards

- **Four of the Danish waste types are by roughly million-fold above release criteria and remain tenthousand-fold above that criteria in a million years.**
- **None of the Danish waste types decays to below clearance levels before 300 years and only two in 1,000 years.**
- **None of those waste types can be termed „short-lived“ in the radiological sense.**
- **The total inventory („Total wo U“) remains 1000-fold above clearance levels.**

è **The Danish wastes require reliable and thorough isolation for very long times.**

è **Only geologic isolation systems provide the necessary long-term integrity to enclose the wastes reliably.**

è **The isolation requirements are not too different for nearly all the waste types, so building more than one repository type is inappropriate**.

Aspect #2 „The repository only has to comply with the emission standard“

IAEA Safety Standards say:

„The specific aims of disposal are:

(a) To contain the waste;

Containment is the prime target!

(b) To isolate the waste from the accessible biosphere and to reduce su stantially the likelihood of, and all possible

Isolation is the second target!

rtent human intrusion into the waste;

(c) To 1 inhibit, 2 reduce and 3 delay the migration of radionuclides 4 at any time from the waste to the accessible biosphere;

(d) To ensure that the amounts of radionuclides reaching the accessible biosphere due to any migration from the disposal facility are such that possible radiological consequences are acceptably low at all times.”

(Source: Specific Safety Requirements: Disposal of Radioactive Waste, IAEA No. SSR-5, Vienna 2011)

2007 recommendations (1)*

1. The disposal should be situated in an area with **homogeneous geological conditions**. It should be demonstrated that these conditions will be found with a high degree of probability at the selected sites. The geology of Denmark is in **many areas relatively heterogeneous**. However, it is the **goal to find continuous and homogeneous sediments or rock layers**.

Compliant with IAEA Safety Standards a)

2007 recommendations taken from: Peter Gravesen, Bertel Nilsson, Stig A. Schack Pedersen, Merete Binderup & Troels Laier (GEUS, MINISTRY OF CLIMATE AND ENERGY): Low- and intermediate level radioactive waste from Risø, Denmark. Location studies for potential disposal areas. Report no. 2 - Characterization of low permeable and fractured sediments and rocks in Denmark. - GEUS Rapport 2010/123

2007 recommendations (2)

2. The **geological deposits shall contribute to isolation** of the radioactive waste. This is most effective if the disposal is underlain or surrounded by tight layers such as e.g. clays, silts, lime stone or basement rocks.

Compliant with IAEA Safety Standards b)

2007 recommendations (3)

3. To restrict the water flow from the disposal it will be appropriate if the **disposal is sited in low permeable deposits**.

Compliant with IAEA Safety Standards c)

2007 recommendations (4)

4. The disposal shall be placed at **longest possible distance from groundwater aquifers**. The streaming conditions of the surrounding deposits or rocks must be low.

Compliant with IAEA Safety Standards c)

2007 recommendations (8)

8. Geological processes on the earth surface may not be able to influence on the security of the disposal.

Compliant with IAEA Safety Standards d)

Aspect #2: Issues that act counter of those targets ...

- The decision to only look at a depth of max. 100 meter:
  - Down to 100 m Danish geology is strongly influenced by past glaciations, the probability to find inhomogenious, strongly fractured and disturbed layers, that are unsuitable for final disposal, is maximised.
  - Layers at a depth of less than 100 m, that are currently intact, are prone to be influenced by future ice-ages. If those have to be taken into consideration in longterm safety assessments,
    - unpredictable consequences will result (exposing wastes on the surface, high dose rates in contacts with the waste, high leaching rates, etc.),
    - the estimated doses will, with a high degree of certainty, exceed the dose limit.

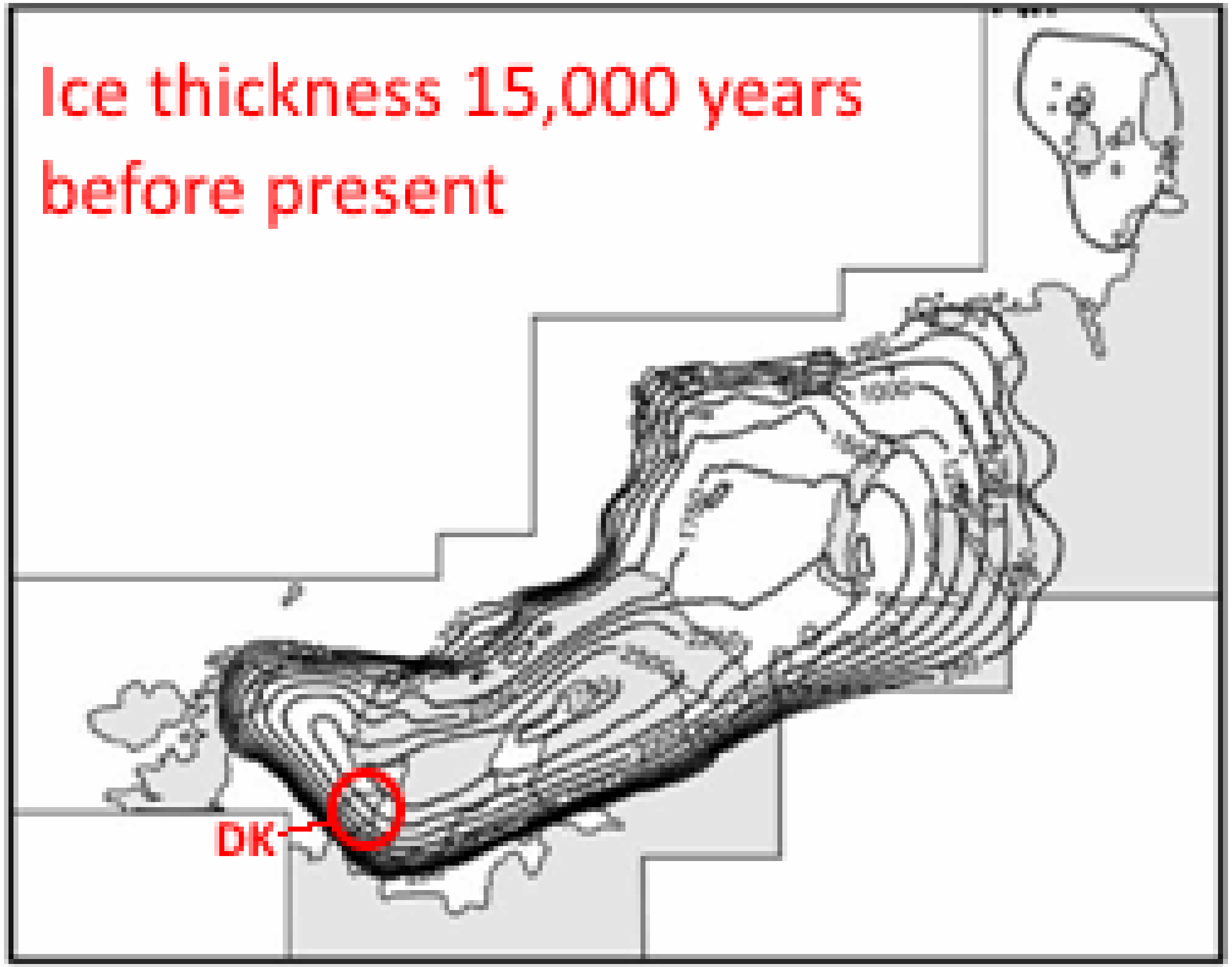
è Basic decisions in the site selection are counteracting against the formulated requirements.

Aspect #2: Compliance with standards

- That means:
  - A repository has predominantly to **enclose the wastes**.
  - Waste **enclosure is the primary quality standard** to comply with.
  - **Enclosure** is the central function to protect people and the environment!
  - The **enclosure** has to remain functional as long as the wastes are potentially dangerous, but at least as long as scientifically and technically possible.
  - Compliance with radiation protection standards is a sub-function of **enclosure quality**: if the waste is reliably enclosed, the protection standards are met anyway.
  - If the enclosure fails foreseeably (e.g. because of glaciation), compliance with whatever standard **can not be achieved** because men can come into direct contact with the waste.

Aspect #2: Compliance with standards

- An example: The carbon-14 in the **graphite waste** has a halflife time of **5,800 years**.
- Isolation time required for that waste is roughly **60,000 years**.
- So, one of the natural pheno-mena to be con-sidered are **ice ages**.

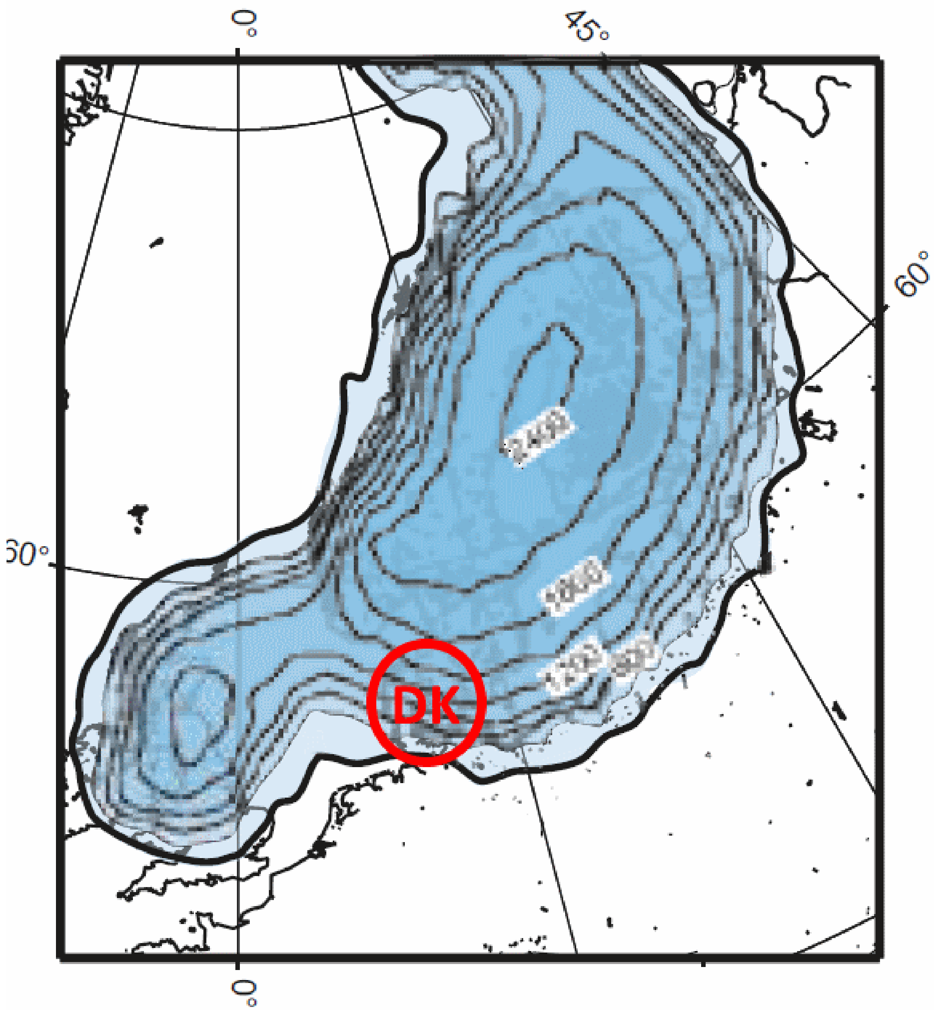


Source: Modified after Svendsen et al. 2004

Aspect #2: Compliance with standards

- The integrity of the disposal cell resp. repository has to be guaranteed over very long times.
- For surface-near locations, the integrity proof cannot be demonstrated.
- It is only possible to evaluate long-term safety and regulatory compliance in a reliably functioning isolation system.

vor 18.000 Jahren



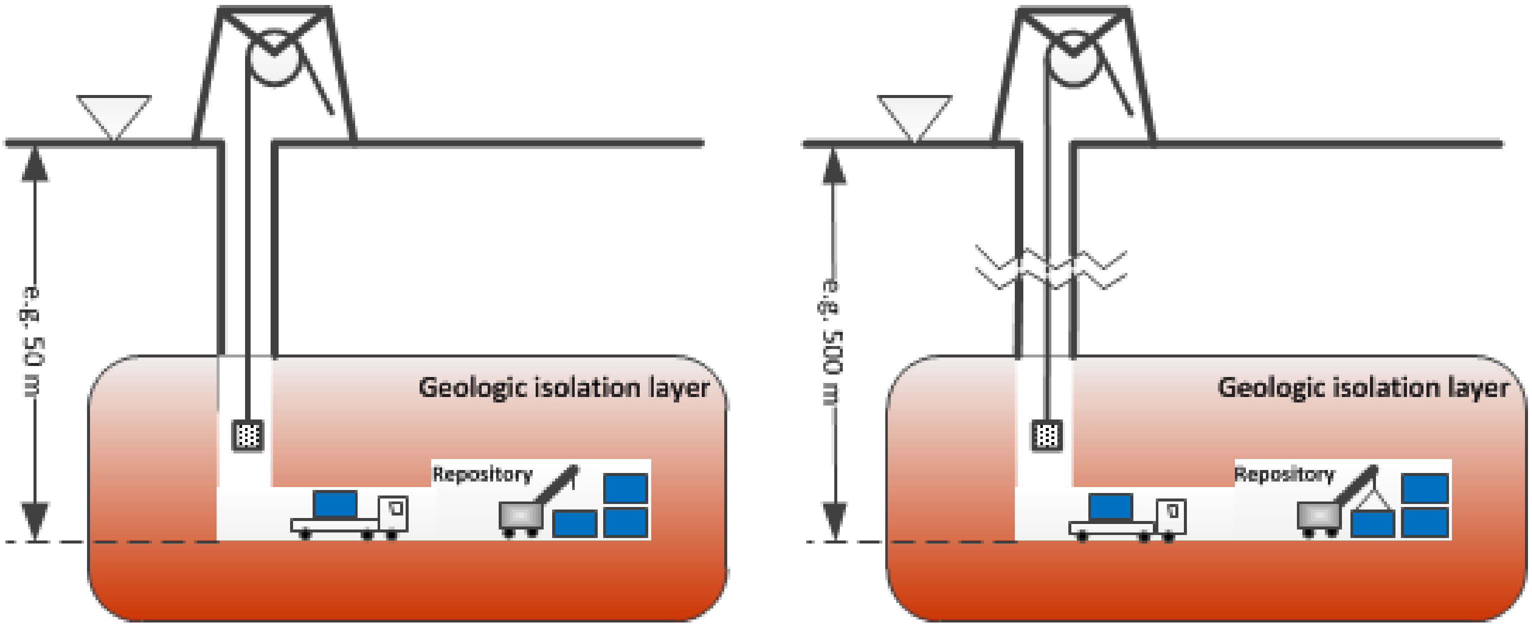
Source: modified after SKB: Long-term Safety Analysis Forsmark, 2011

Minimum requirements for final disposal sites

AkEnd requirement	Safety rationale behind the requirement	Applicability in the Danish case
Hydraulic conductivity of rock zone < 10^{-10} m/s	Transport reduction for mobile radionuclides	**Yes**
Thickness of rock zone > 100 m	Longterm stability of the enclosure zone	**Yes**
Depth of the top of rock zone > 300 m	Erosion protection + distance to surface activities + probability of unplanned intrusion + continental uplift buffer, + + +	**Yes**
Repository mine not deeper than 1,500 m	Heat protection of miners	**Yes**
Areal extension large enough (3 km² / 10km²)	Large enough space availability for German waste inventory	**No (much smaller)**
No rock burst vulnerability	Integrity of isolating rock zone	**Yes**
Geophysical stability over 1 Million years	Integrity of isolating rock zone	**Yes**

Aspect #3: Deep disposal is much more expensive

- In fact the economic difference between a shallow and a deep repository is in the worst case 450 m additional shaft drilling and 450 m of additional steel cable during shaft operation.



- All other much more relevant cost factors remain merely the same.
- It could as well be that shallow disposal is more expensive because of the less compacted geologic formations, that are - at average - found in smaller depth (requiring extensive lining of mine openings).

Aspect #5: The spent research fuel is the problem

- As the analysis shows, three other waste types have similar radiological characteristics:
  - Radioactive sources,
  - Dissolved uranium,
  - DR1 Nuclear solution.
- If a different option is chosen for the spent fuel, different solutions have to be found for these other three waste types, too.
- The separation of these other waste types leads to an increasing number of projects/repositories, while the repository requirements remain mainly unchanged (that is: to reliably enclose the waste forever).
- The spent fuel is not a unique waste in the Danish inventory, the long-term isolation requirements are almost the same as for all other wastes.

Aspect #6: Spent research fuel down the borehole

- „Borehole disposal“ is not just blindly drilling holes in the ground, put the waste in and forget.
- Borehole disposal requires nearly the same like a geologic repository*:
  - Isolated geological layers with very low hydraulic conductivity and with a minimum thickness of ≈50 m are to be carefully selected to ensure sustainability and isolation over 1 Mio. years.
  - An extensive characterization program to make sure that the layer has those properties, is free of geological dislocations and is homogeneous enough (no sand layers, no fractures, etc.).
  - Plugging of investigation and emplacement boreholes is nearly as complicated as in a small repository.
- Borehole disposal is only simpler from the far distance and when disregarding all relevant safety issues.

* See: Specific Safety Requirements IAEA SSG-1 on Borehole Disposal (Safety Assessment, Characterisation)

Aspect #7: Wait and see ...

- The wait-and-see concept achieves nothing at all but risks.
- It does not reduce the risk (from ageing and leaking containers, of the loss of knowledge and experience, ...), but increases those constantly.
- People experienced in handling those wastes and with the required expert experience to control their hazards are already scarce in Denmark (and even in Germany). This will dramatically change in the future – further downwards.
- Any acceptable solution to control those risks requires a wide public consent. Doing nothing at all is a guarantee for the absence of societal controversies but achieves only the consent to continue doing nothing. It is the opposite of achieving a public consent on safety, safety standards and on acceptable/accepted risks.

Aspect #8: Methods to destroy long-lived nuclides

- This has been discussed since the end of the Fifties (for more than 50 years!). No solution has come up, all programs ended without new ideas on how to achieve that.
- No method has been found since then to agitate the long-lived nuclides (and only those!). Instead current research focusses solely on Plutonium and Americium, which are not the most serious nuclides in the Danish inventory and can be easily isolated in a geologic repository because they are immobile.
- The nuclear age is ending soon, and there will be no scientists left that care about these historic tasks any more. Technologies and knowledge, if not widely applied, are much faster ageing and get lost quicker and without any trace, other than stone-buildings.
- To wait for a genious solution in any future accepts never-ending risks for future generations to a much larger extend than those from even the worst repository concept.

Recommendations

1. There is no **safe** alternative to disposal in geologic isolation systems.
2. The Danish concept should foresee to dispose all of its wastes in **only one suitable location** that provides enough **isolation potential** to cover the whole spectrum of the wastes.
3. Denmark should seriously search for geologic layers* that guarantee for sufficient **long-term integrity** and **isolation** of the wastes**.
4. Any search should only be based on clear **safety-related criteria*****, that are state-of-the-art and that are carefully consented among and accepted by all relevant stakeholders****.
5. There is no need for quick action, but there is a need for **well-planned action** - without unreasonable short-cuts.

* Layers in 0..100 m depth are with a high chance unsuitable for the required long-term isolation.
** Those will automatically comply with radiation protection limits!
*** Site selection without clear criteria is at best useless.
**** Site selection without consent is a guarantee for a never-ending struggle.

Vielen Dank für Ihre Aufmerksamkeit!
Thank you for your attention!
Tak for din opmærksomhed !

Haben Sie noch Fragen?
Do you have any questions?
Har I nogen spørgsmål?

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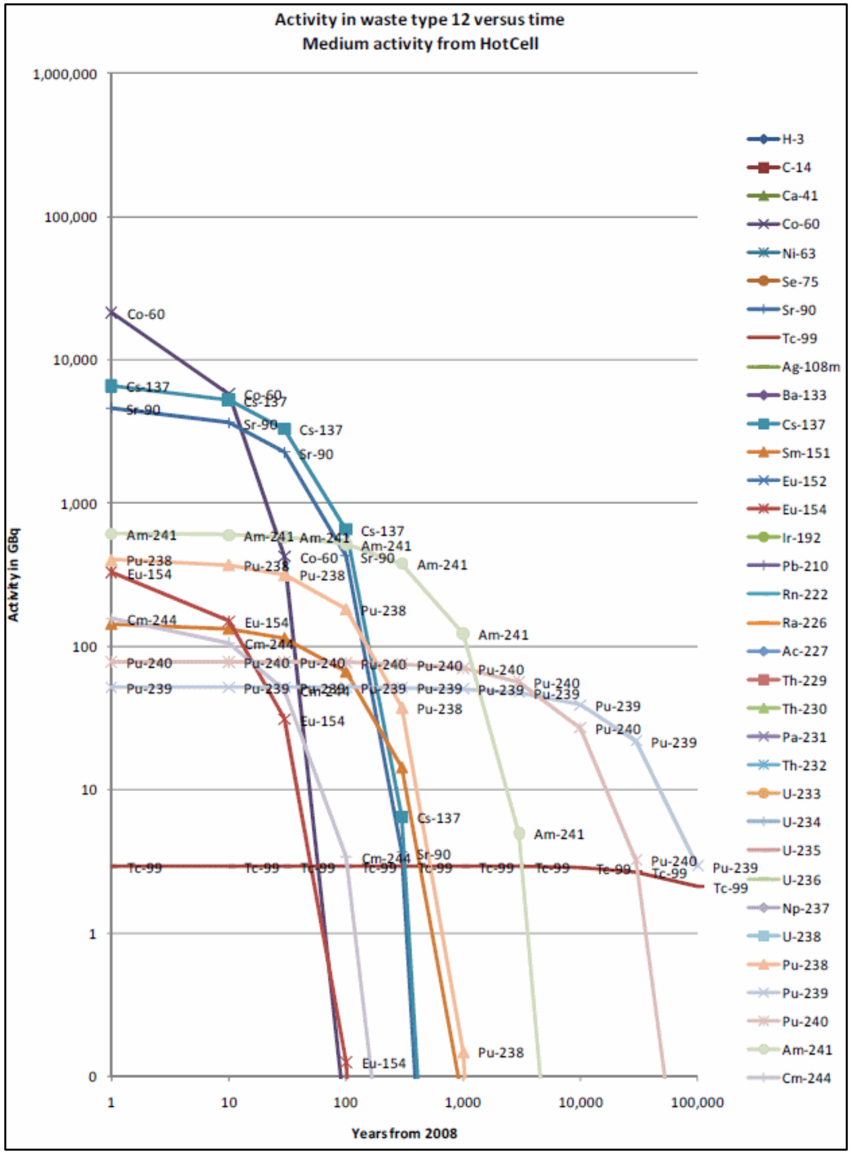
On the use of clearance criteria for calculating waste decay characteristica

A side aspect of my presentation on the rationale behind the use of clearance criteria

Gerhard Schmidt

Method: Activity calculations



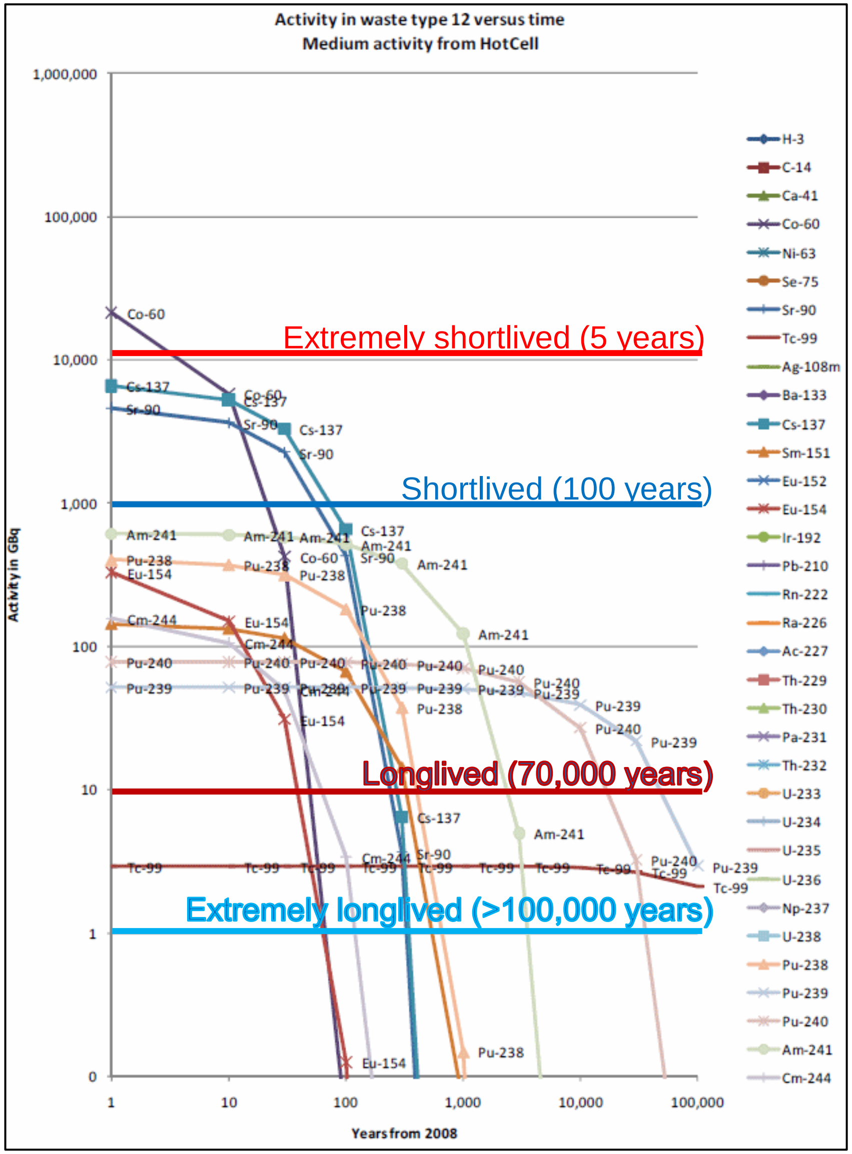
Usually activity calculations and criteria are applied. As an example the decay curve for Hot Cell Waste is displayed. Note that the waste consists at least of the 34 different nuclides listed here!

Those calculations, if applied to identify repository isolation times required, have the shortcoming that they provide no „safe level“.

Wherever you place your reference level the character of the waste changes completely.

Picture taken from: DD/COWI: Prefeasibility study

Method: Activity calculations

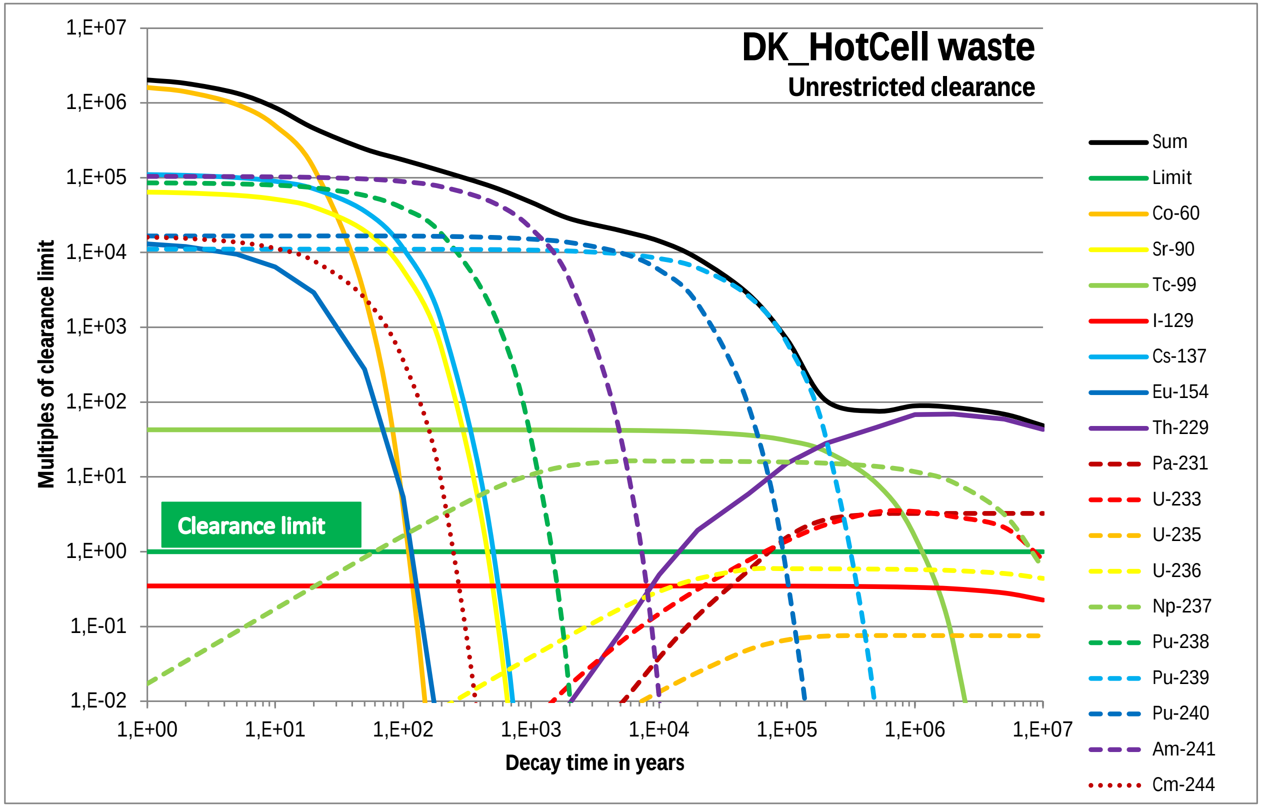


The picture demonstrates that it is impossible to derive the longevity of wastes from the activity decay curve, because the calculation lacks an **objective** risk basis to compare with. Wherever you place your compare value, the longevity can range from extremely short-lived to extremely long-lived, so you end up with pure random.

A basis would be that if the content of radionuclides in the waste is so small so that the waste can be cleared as „non-radioactive“ waste.

Picture taken from: DD/COWI: Prefeasibility study, modified

Alternative method: Clearance levels



Source: own calculation based on DD waste composition data

If decayed to below clearance levels the waste requires no control of whatever type any more.

The waste then can be used to construct a chair or house from it, it can be inhaled or eaten, and the doses posed are all below the 10 µSv/a limit, that poses a risk of less than 1-in-a-million for an individual health damage.

The waste then requires no disposal in a repository any more, because any person that comes in direct contact with it faces only a trivial health risk. Containment and isolation in a repository then are not necessary any more. The clearance levels for waste reflect exactly for which time these protective functions of a repository are required (in that case: longer than 10 million years).

Other effects of considering the clearance levels as an objective criterion

The clearance levels are derived from multiple scenarios and so cover most of the potential exposure pathways (such as direct radiation, ingestion in foods, dust inhalation, enrichment in fish and other pathes) for each specific radionuclide, so that clearance values cover numerous potential exposure types and pick the most relevant of these. They are conservative, so that future doses are not underestimated. But they are not too conservative to come to false conclusions.

Another positive effect of the clearance level is that the activity of a nuclide in Bq or its concentration in Bq/g does not reflect the specific dose conversion factors (for inhalation or ingestion, in Sv/Bq), but the clearance levels reflect that. Dose conversion factors vary over five orders of magnitude, so this error source is avoided by use of clearance levels.

Clearance levels also reflect in part the mobility and bioaccumulation properties of the nuclides, so are closer to the doses to be expected from a repository.

Clearance levels do not reflect the geochemical mobility of the radionuclides. That is the only relevant difference to a full-scale safety assessment.

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What clearance levels do not mean ...

- to leave the wastes standing around until they can finally be cleared

  (the necessary times are so extremely long that this is no responsible waste management option but increases risks in an unreasonable manner and places undue burdens on future generations)

- one can only apply clearance levels if those are nationally defined and fixed

  (the purpose for which clearance levels are used here have nothing to do with the formal clearance of wastes, they only provide an objective (!) level for the dangerousness of wastes)

- that Denmark has to define clearance levels

  (definition of clearance levels only makes sense if real wastes can and will be cleared)

- is exporting German clearance levels to other countries

  (whatever clearance levels are selected, either those from the Basic International Safety Standards BSS, from Euratom Safety Standards or the German clearance levels, the results are a little bit different for single radionuclides, but the main result for the longevity of wastes remains approximately all the same; the resulting differences are only of academic importance)

- is that the 10 µSv/yr criterion is in any case applicable

  (this is indeed a relevant point because only Denmark and Germany have a formal 10 µSv/yr dose criterion for final disposal, identical with clearance doses; other countries define much higher levels (e.g. USA or France); those are covered by shifting the „clearance limit“ one or two orders of magnitude higher (which in most cases has no effect on the final results))

Conclusions on clearance levels

We are **not** proposing to

- define clearance levels in Denmark (besides the ones already in place),
- follow the clearance concept and replace the repository with the clearance of wastes, or
- to define a period after which the repository is cleared (setting rules today for in 10 million years is a ridiculous undertaking).

We are **proposing** to

- use the clearance concept to **derive time requirements** for the **safe enclosure and isolation** of wastes in a repository,
- use the clearance concept to derive **minimum geologic layer properties** (such as layer integrity and thickness, layout against natural phenomena, etc.) for the repository.