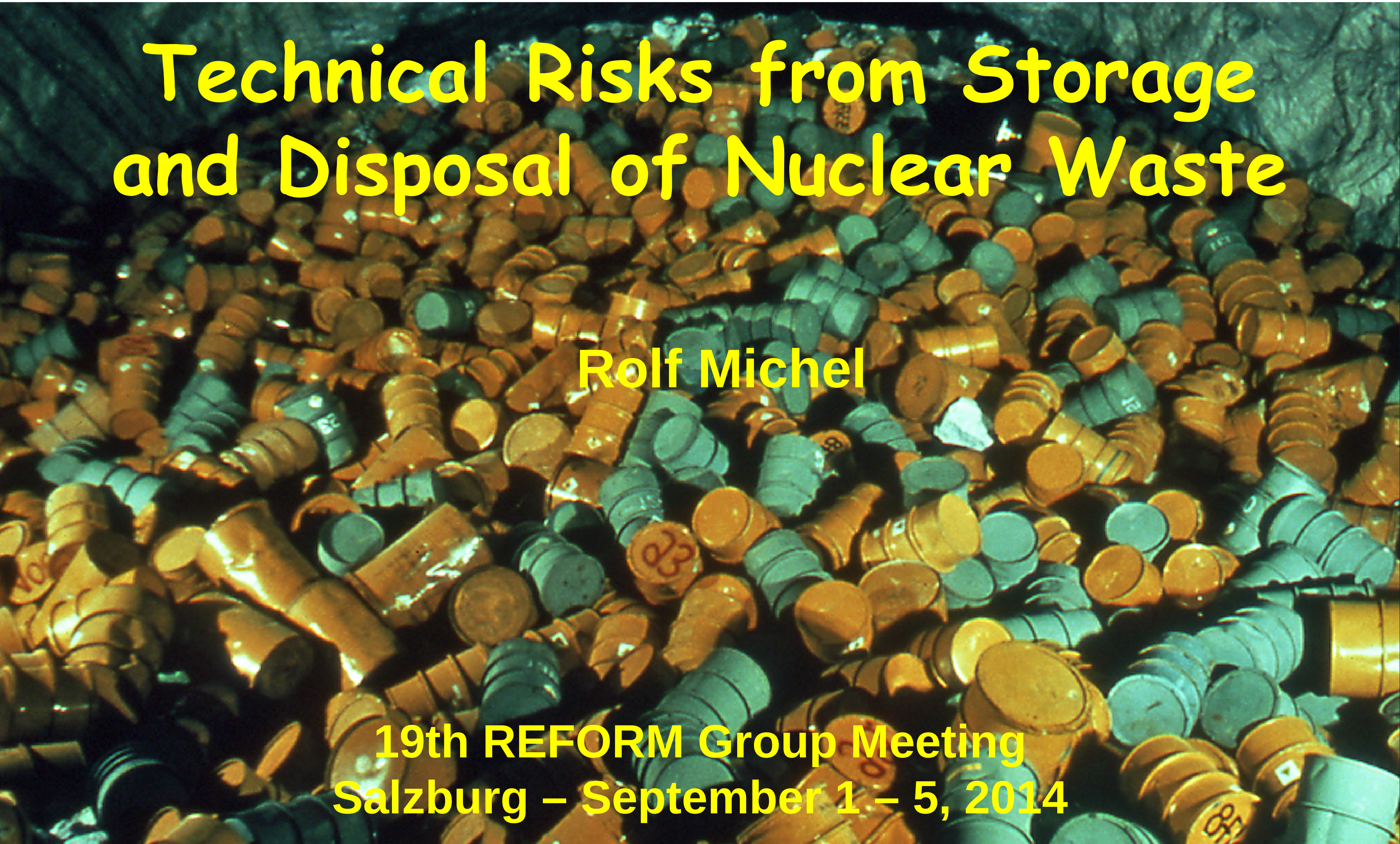
IRS

Institut für Radioökologie und Strahlenschutz
Leibniz Universität Hannover



Technical Risks from Storage and Disposal of Nuclear Waste

Rolf Michel

19th REFORM Group Meeting
Salzburg – September 1 – 5, 2014

Content

- What is risk?
- Radiological and technical risk
- Risk potential of radioactive waste
- Interim storage and final disposal
- Predictions of the future
  - Interim storage and retrievable disposal
  - Disposal in deep geological formations
- Conclusions and complications

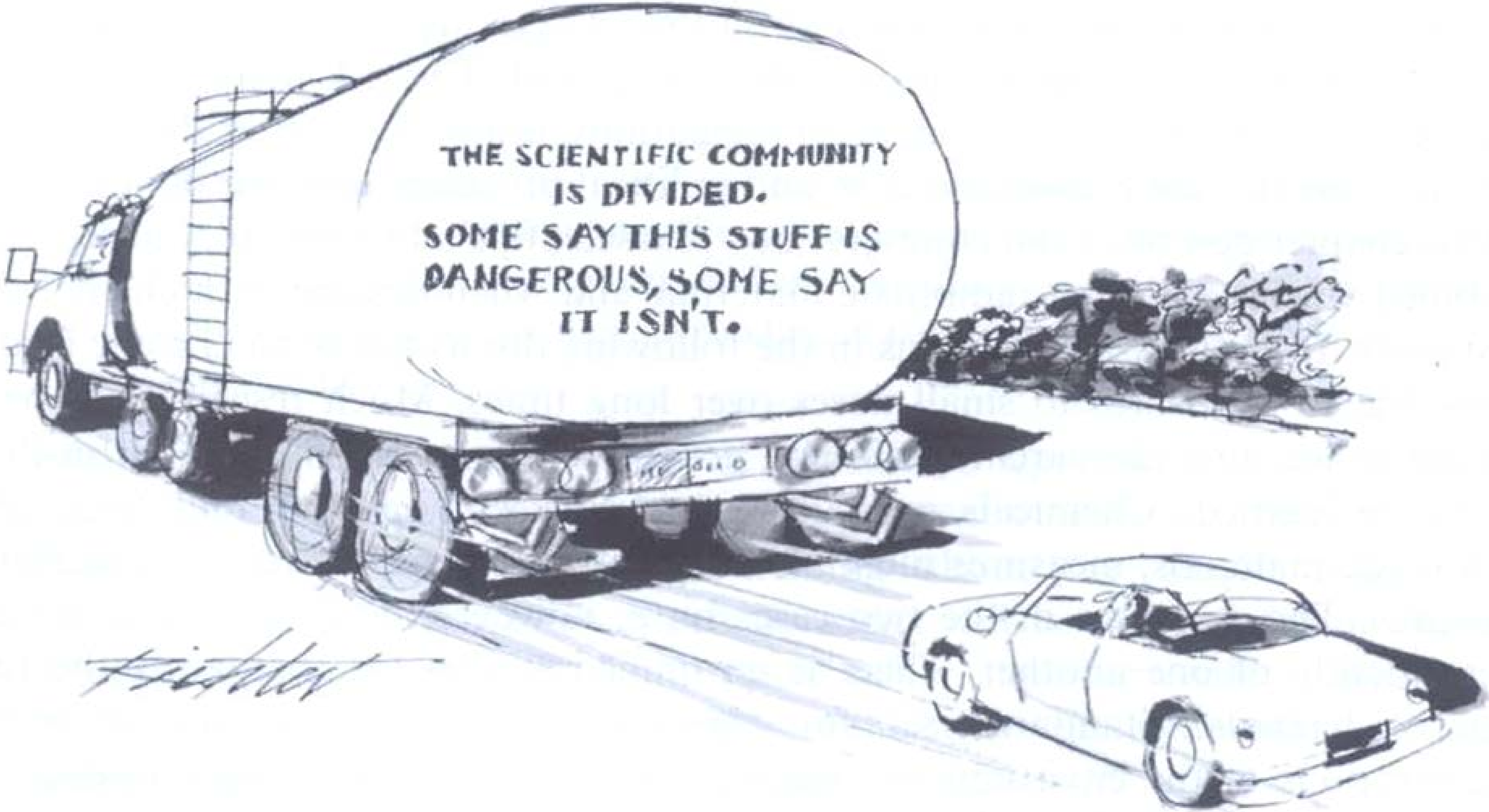
Our life is full of risks!

- health risks
- financial risks
- technological risks
- political risks
- environmental risks
- natural risks
- military risks
- terroristic risks
- chemical risks
- genetic risks
- …

… and there are nuclear risks:

- risks of reactor accidents
- risks of radiation accidents
- risks of malicious acts
- risks of radioactive contamination
- risks of nuclear energy
- risks of storage of radioactive waste
- risks of final disposal of radioactive waste

Now: what is risk?



It is all about the future!

So we could ask Cassandra.

But she is busy drawing lottery tickets and predicting the fall of Troy.

Fresco from Pompeii, Archeological National Museum Naples


It may be written in the stars …
… or we can try a scientific approach.
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UNAM / INAH

Risk: a definition

- **Risk: "a threat of loss, real or perceived, to that which we value." Vincent T. Covello (2013)**

- **Risk: uncertainty about an undesired outcome (endpoint).**

- **Uncertainty is quantified by probability of a quantity value (outcome, endpoint).**

Risk = probability × outcome (endpoint)

Chance

Chance = probability of a desired outcome

Radiological Risk

Risk =
Probability (P) × Detriment

Radiological Risk =
Exposure × P(stochastic disease given the exposure)

Risk of HLW storage or disposal

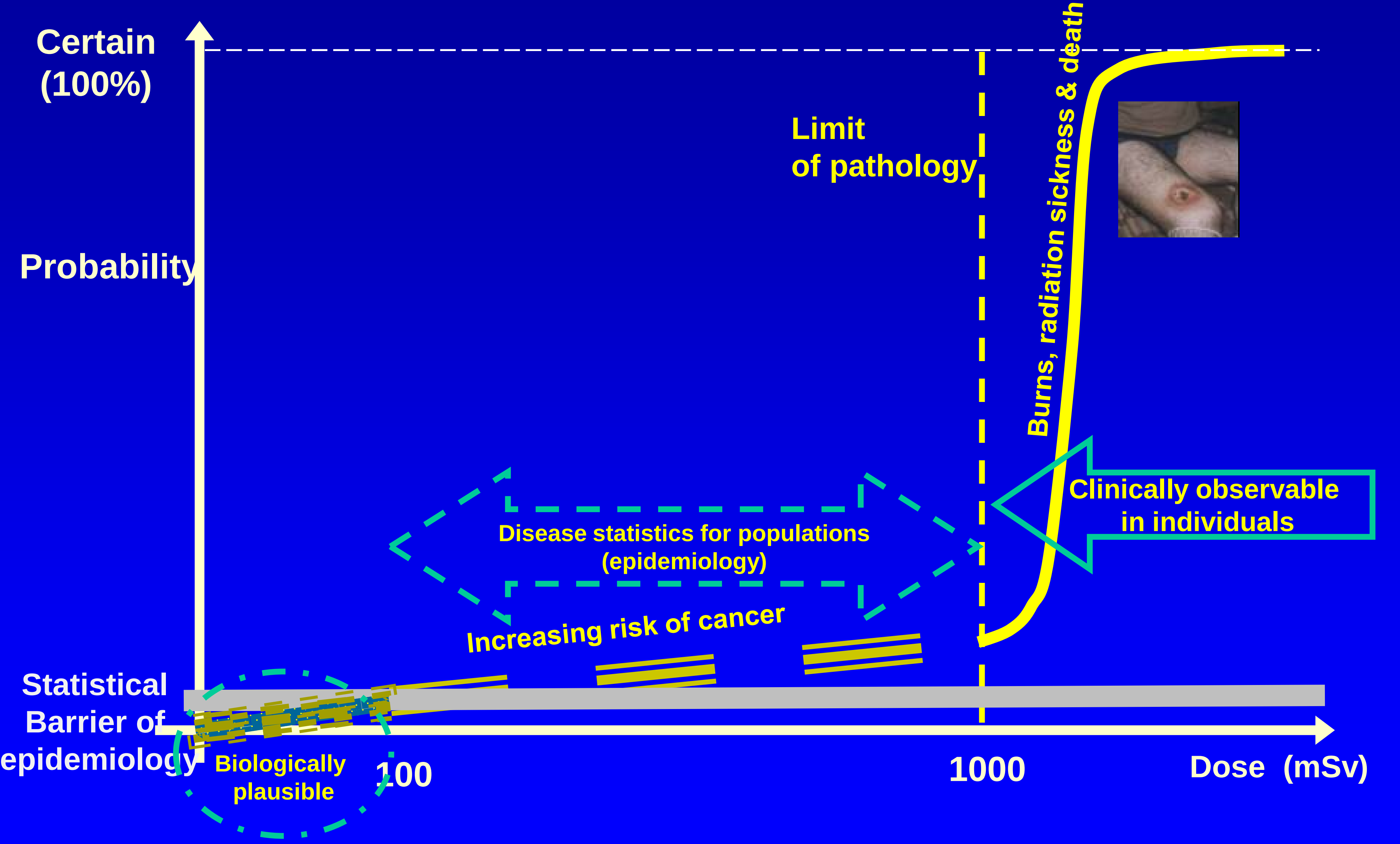
Radiological risk of HLW storage or disposal =

P(stochastic disease given the exposure) ×

P(exposure given a development of the facility) ×

P(development of the facility)

Radiation health effects



Malcolm Crick, UNSCEAR, IRPA (2014) modified

R. Michel, IRS, Leibniz Universität Hannover

Lifetime risk estimates in 10^{-2} Sv^{-1}

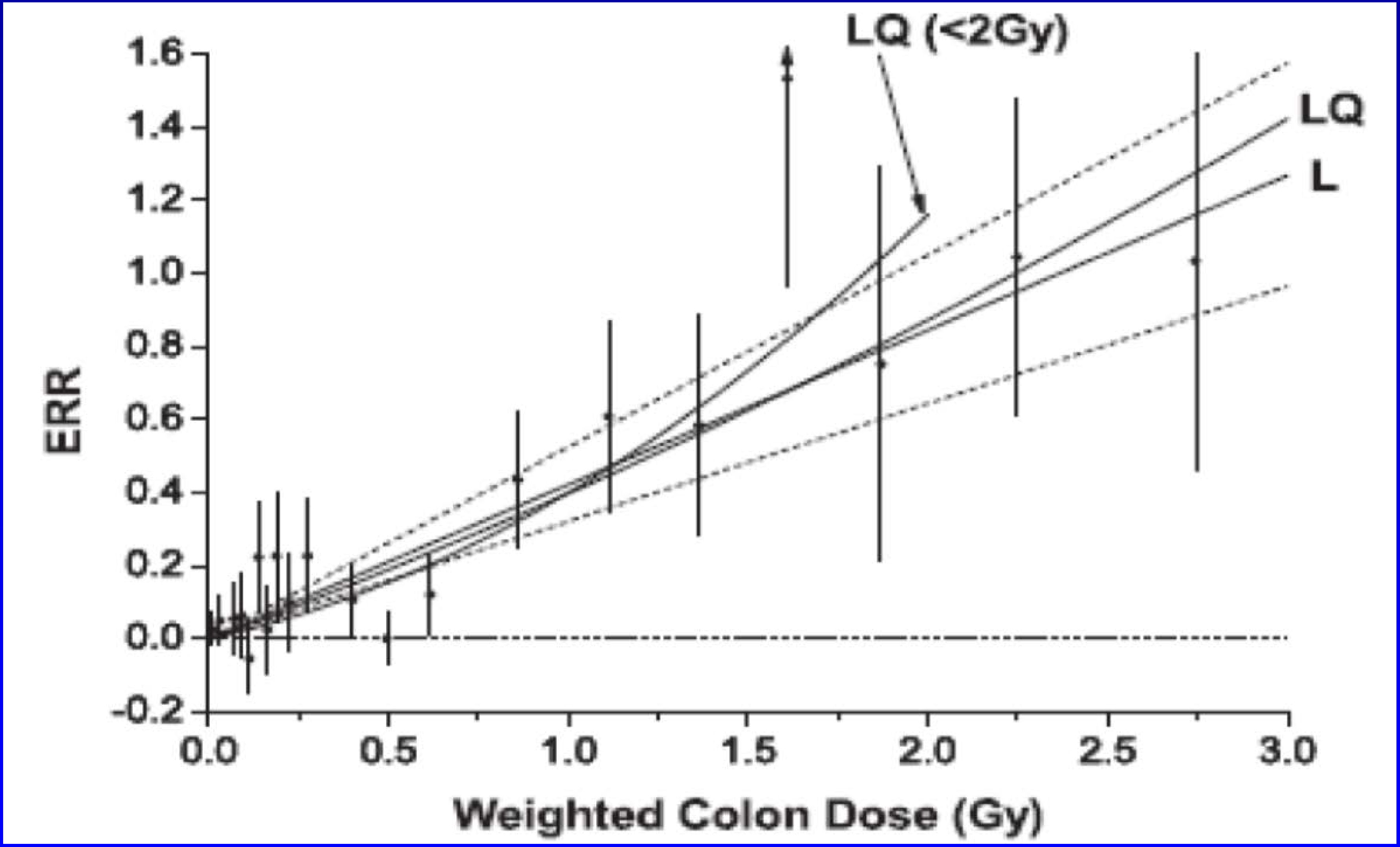
Averaging over five populations of all ages, both sexes

Risk of exposure-induced death	acute 0.1 Sv	acute 1 Sv
Solid cancer	3.6 – 7.7	4.3 – 7.2
Leukaemia	0.3 – 0.5	0.6 – 1.0

Uncertainties: factor of 2 - 3 higher at 100 mSv and include zero
Implicitly account for extrapolation to low doses (no need for DDREF)
Risks to children: need to be considered separately

UNSCEAR 2010 Report
Malcolm Crick, UNSCEAR, IRPA (2014) modified

Dose response for solid cancer



Ozasa et al. 2012

RSK/SSK (2002) Safety Principles

- The radiation exposure resulting from the depository shall be small compared to the natural radiation exposure of (1 – 10) mSv per year.
- Future consequences for humans and the environment shall not exceed that what we accept today.
- The consequences of the depository shall not exceed outside Germany those allowed in Germany.
- No active measures must be needed to attain long-term safety after closure of the depository.

RSK/SSK (2002): Protection Goals

Protection goal (indicative value) for likely scenarios after closure of the depository :

0,1 mSv/year

Protection goal (indicative value) for less likely scenarios after closure of the depository: (probability less than 10 % over the entire forecasting horizon of 1 Million years)

1 mSv/year.

For the time of the operation of a storage facility and for intermediate storage we have a dose limit of 1 mSv per year (as long as we have a radiation protection ordinance).

1 mSv per year is small compared to the variability of the natural radiation exposures of humans.

The potential stochastic consequences of an exposure of 1 mSv per year will not lead to any observable increase of diseases or fatalities.

Resulting long-term radiological risks

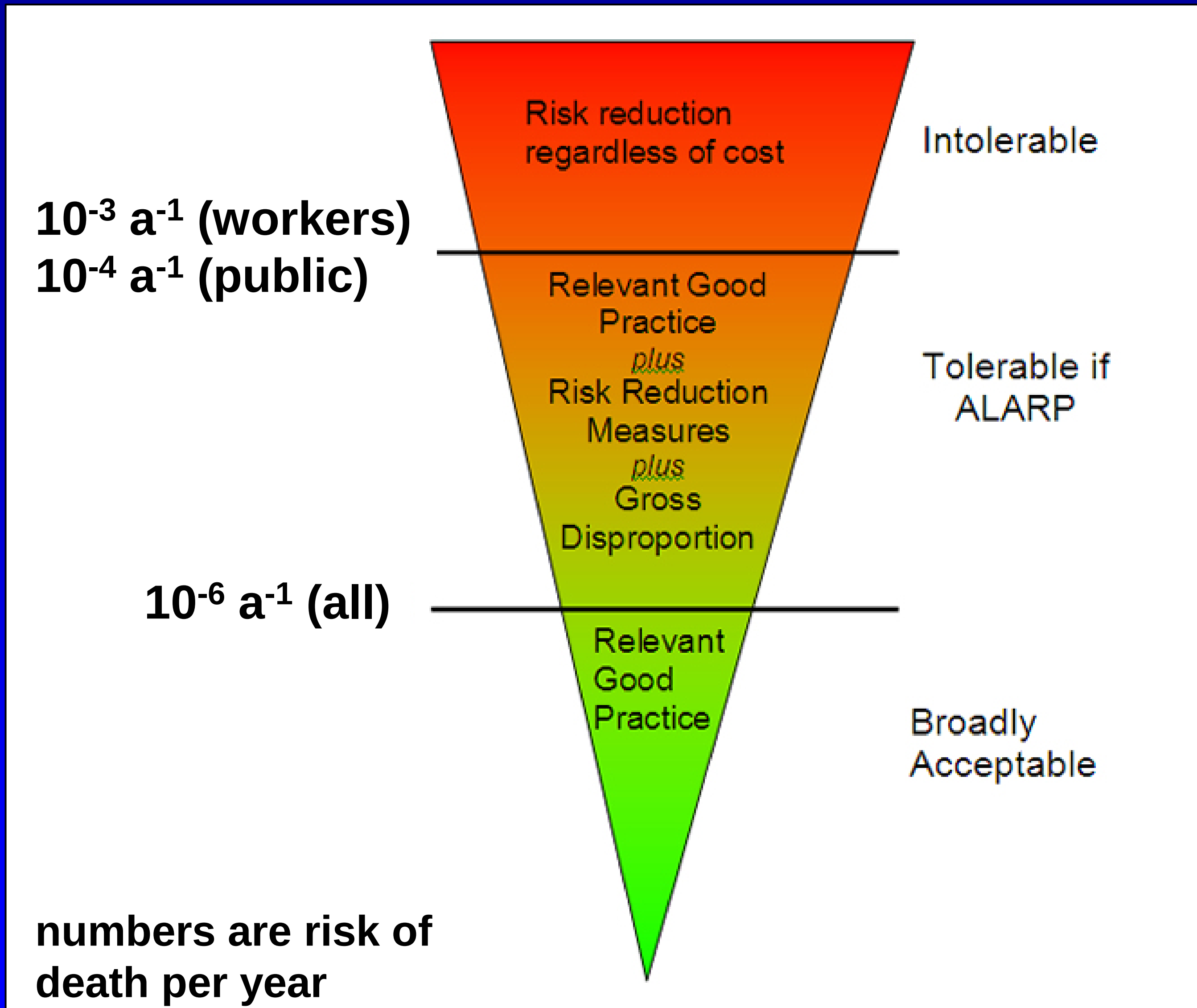
For likely scenarios of a depository:

$$0{,}1 \text{ mSv/year} \times 0{,}1 \text{ Sv}^{-1} = 10^{-5} \text{ per year}$$

For less likely scenarios
(P < 0,1 over 1 Million years):

$$1 \text{ mSv/year} \times 0{,}1 \text{ Sv}^{-1} \times 0{,}1 < 10^{-5} \text{ per year}$$

As Low As Reasonably Practicable (ALARP)



http://www.hse.gov.uk/foi/internalops/hid_circs/permissioning/spc_perm_37/

A concept of band widths

Chapman & McCombie (2004)

More details on radiological risks

- **Real risks**

  Risks which enhance the frequency in a recognizable way of a particular endpoint after an exposure.

- **Hypothetical risks**

  Risks after an exposure which can neither be observed by epidemiological means nor enhance the frequency of a certain endpoint , though there is a plausible hypothesis of a causal connection between exposure and endpoint and though the frequency of the endpoint can be calculated.

- **Potential risks**

  Risks which would be real or hypothetical if a potential exposure could occur.

Probability statements about the future: What is probability?

It is a Bayesian probability, a measure for the degree of trust an individual has into an uncertain statement.

It does not work with conventional or frequentist probability, i.e. probability being the stochastic limit of relative frequencies.

Risk matrix

Risk = Probability × Detriment

There is a complication: The same numerical risk can mean

- **a small probability and a large detriment or**
- **a large probability and a small detriment.**

Moreover, there are individual risks and collective risks.

A risk matrix allows to take these aspects into account.

Risk matrix for the description of equal risks as function of the probability of incidence and of the detriment

detriment							
catastrophic							
very large							
large							
medium							
small							
marginal							
	nearly impos-sible	improb-able	rare	occas-ional	often	frequent	probability of incidence

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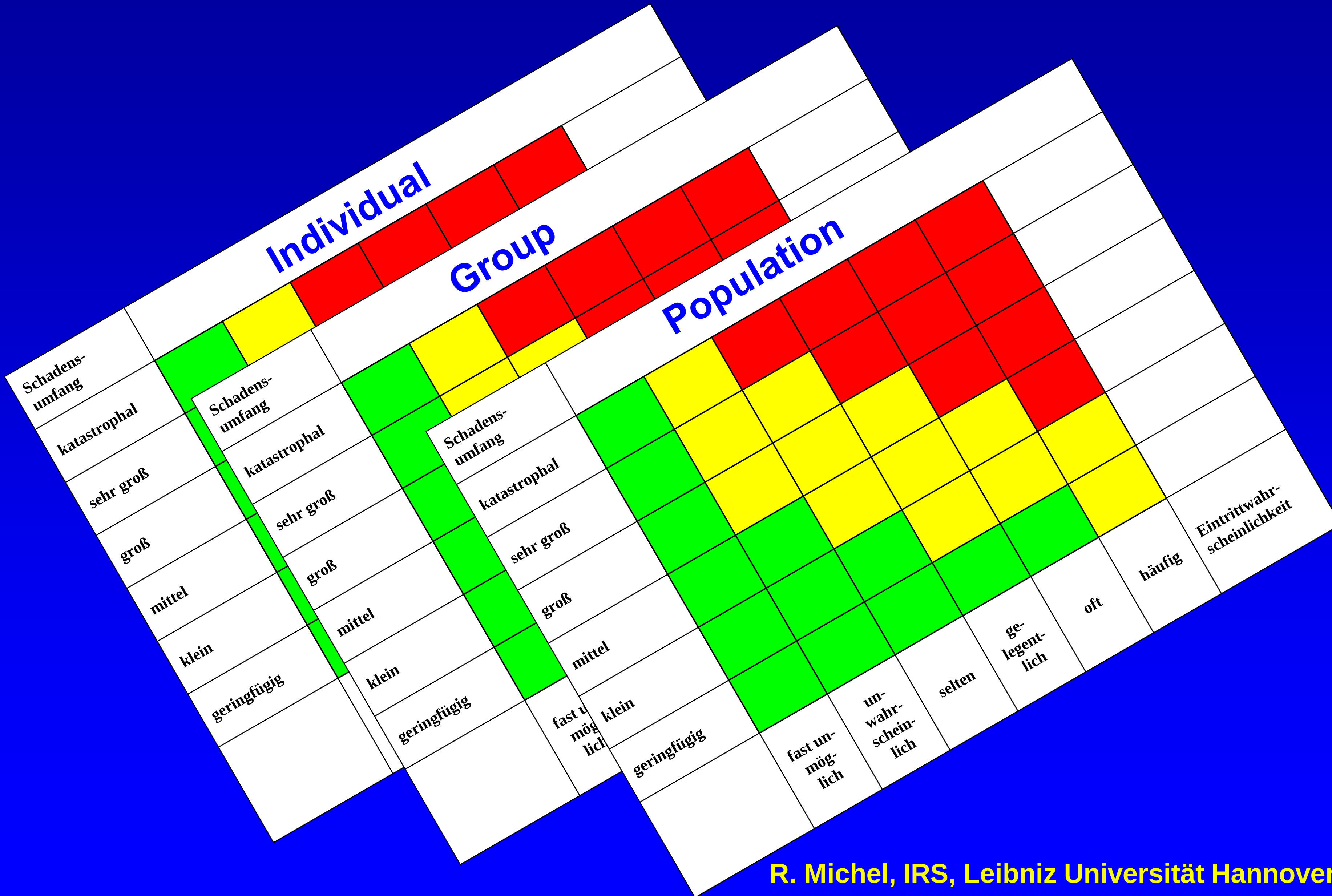
Risk matrices for the description of risks



The radiological and technical risks of storage and disposal of radioactive waste are not endangering entire populations.

detriment	for an individual or a small group						
catastrophic							
very large							
large							
medium							
small							
marginal							
	nearly impos-sible	improb-able	rare	occas-ional	often	frequent	probability of incidence

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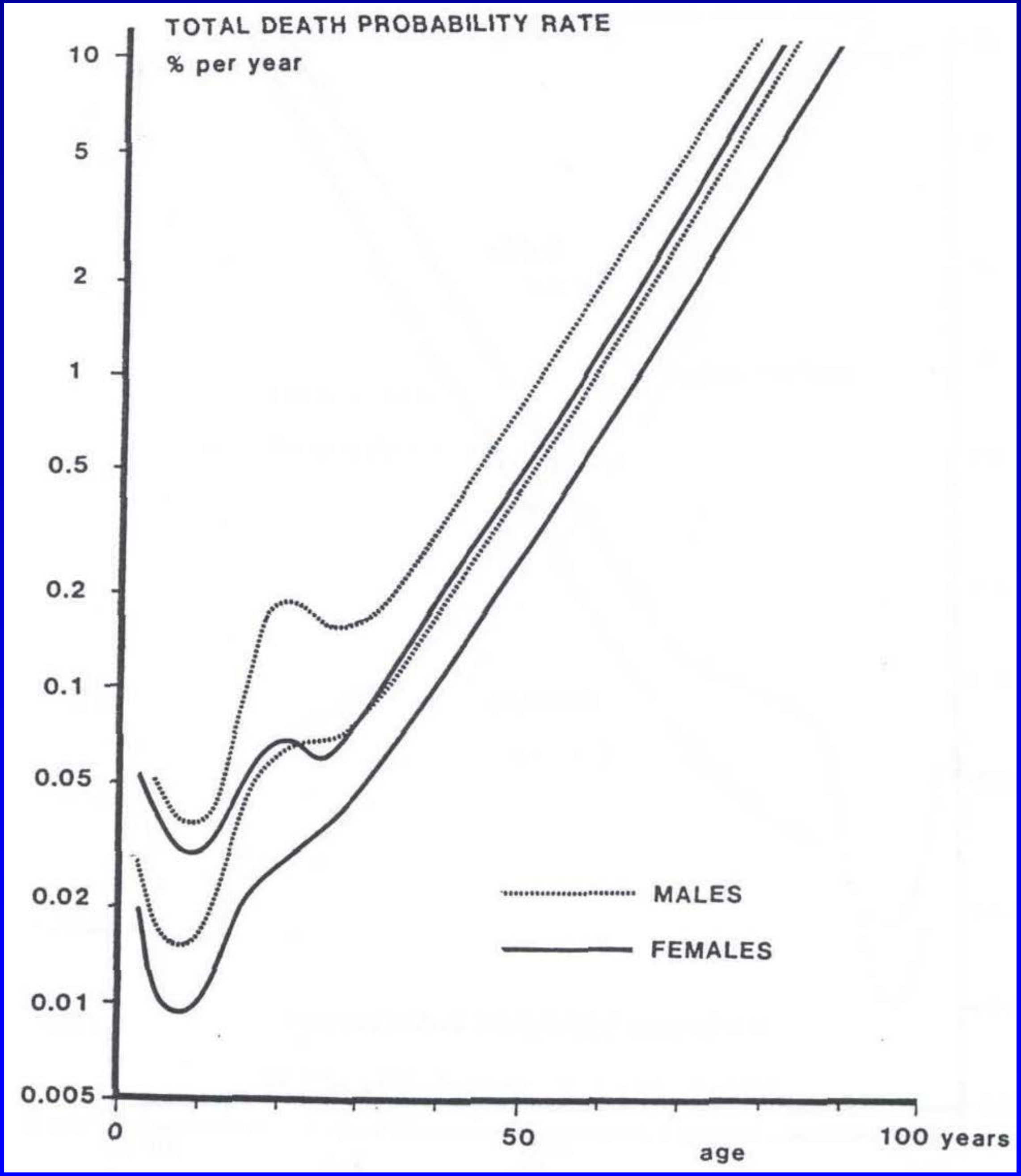
ARE YOU AT
RISK?



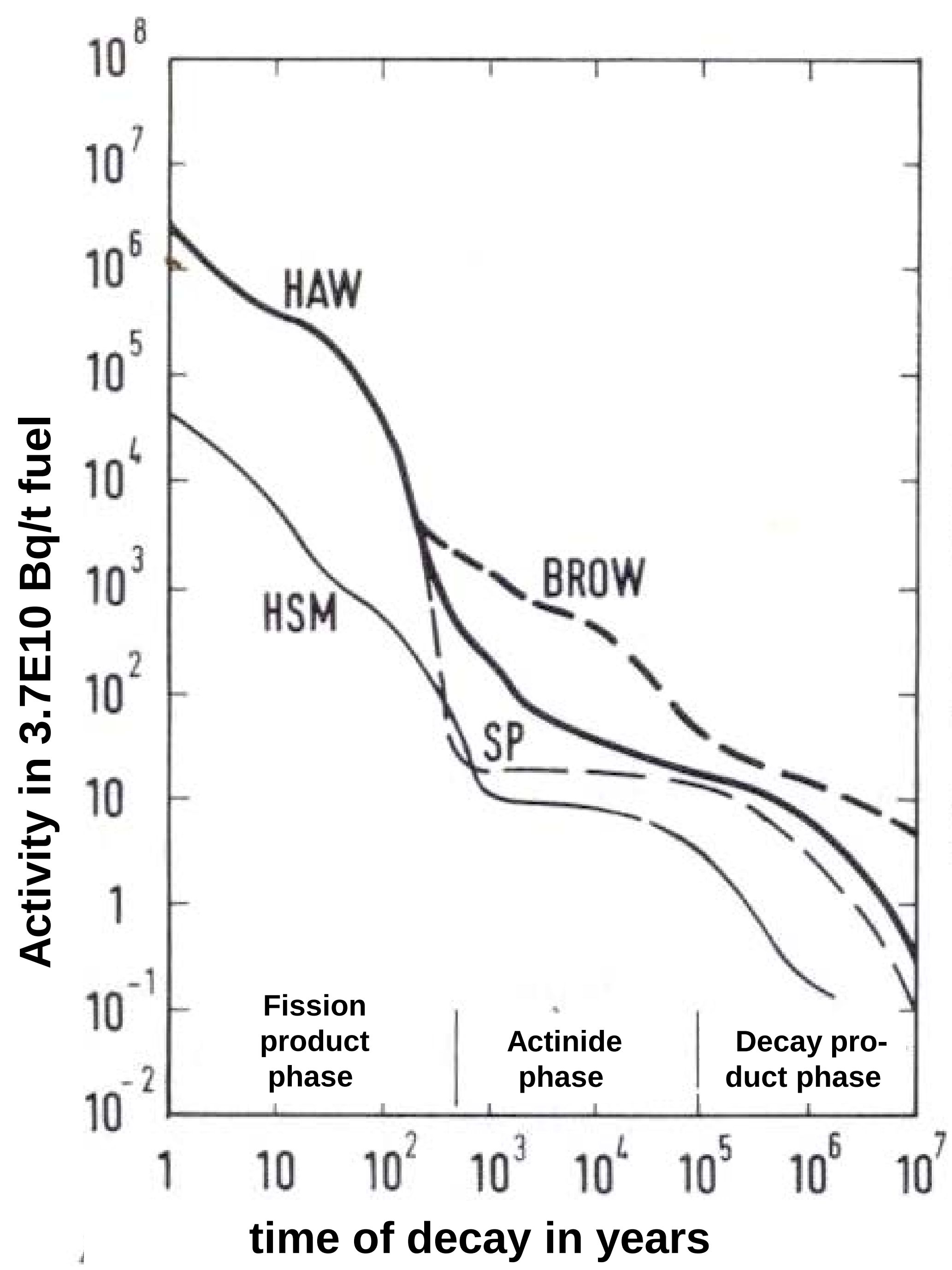
Yes, you are!

Annual probabilities of death (extreme values) for 18 countries considered „safe".

ICRP 60

Risk potential:

Radiotoxicity and the risk potential of a water pond



Activity of radioactive products

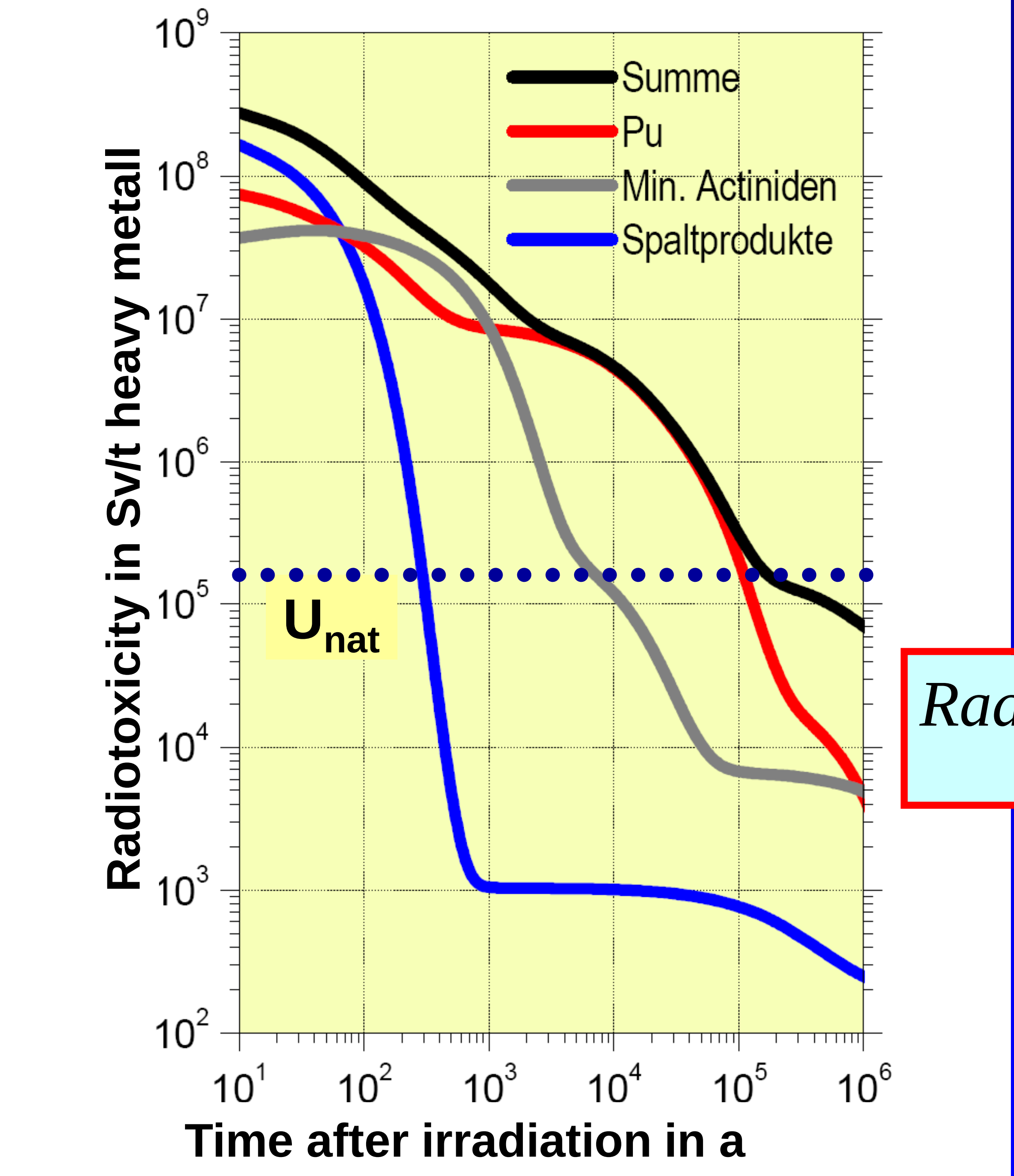
BROW = fuel elements without reprocessing

HAW = highly-active vitrified waste

SP = fission products

HSM = medium-active cladding and structural materials

Haug, 1982; Closs, 1980



Radioactive waste

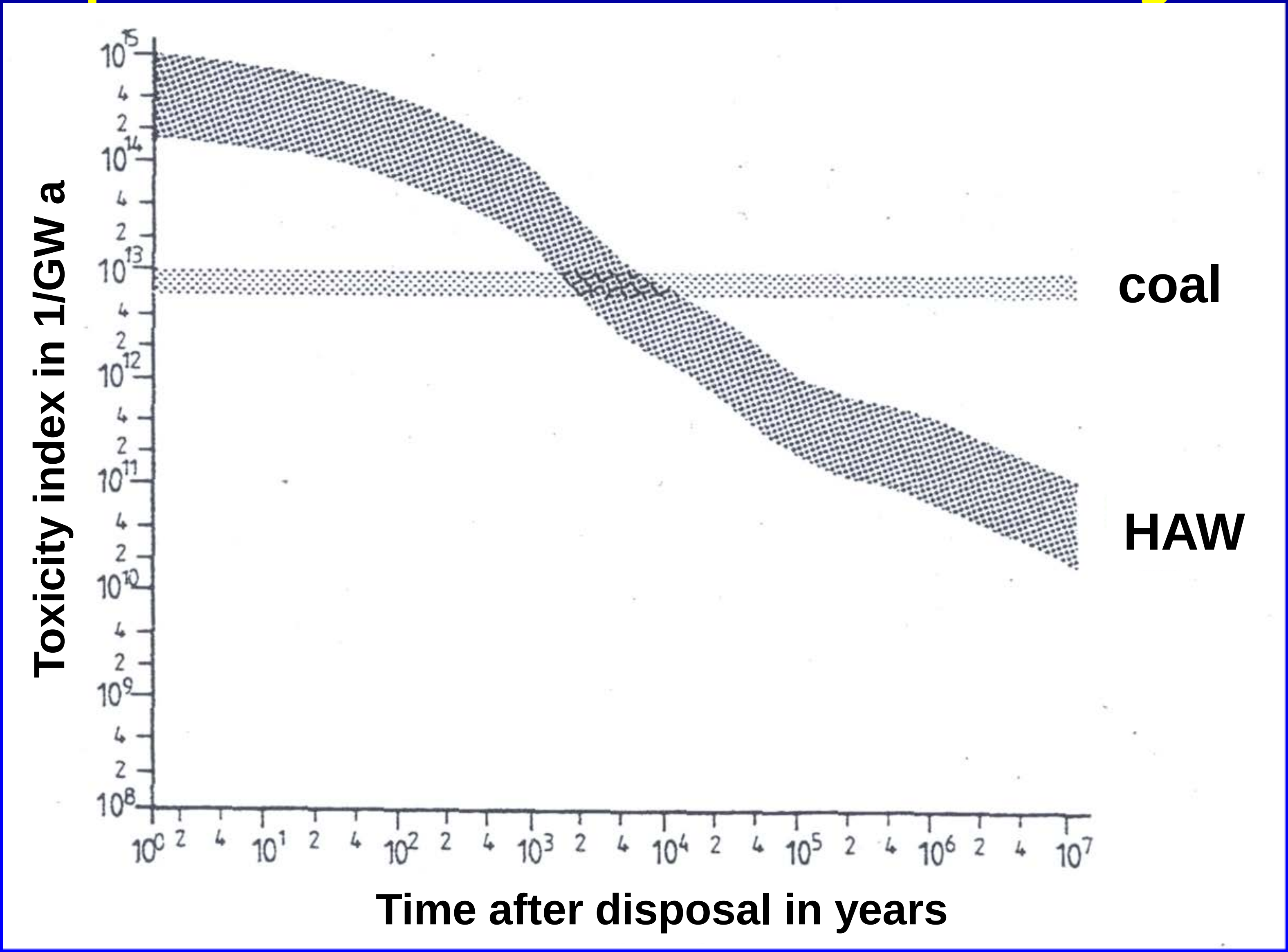
Radiotoxicity for direct disposal of the entire waste

$$Radiotoxicity = \sum_r A_{s,r} \cdot g_{i,r}$$

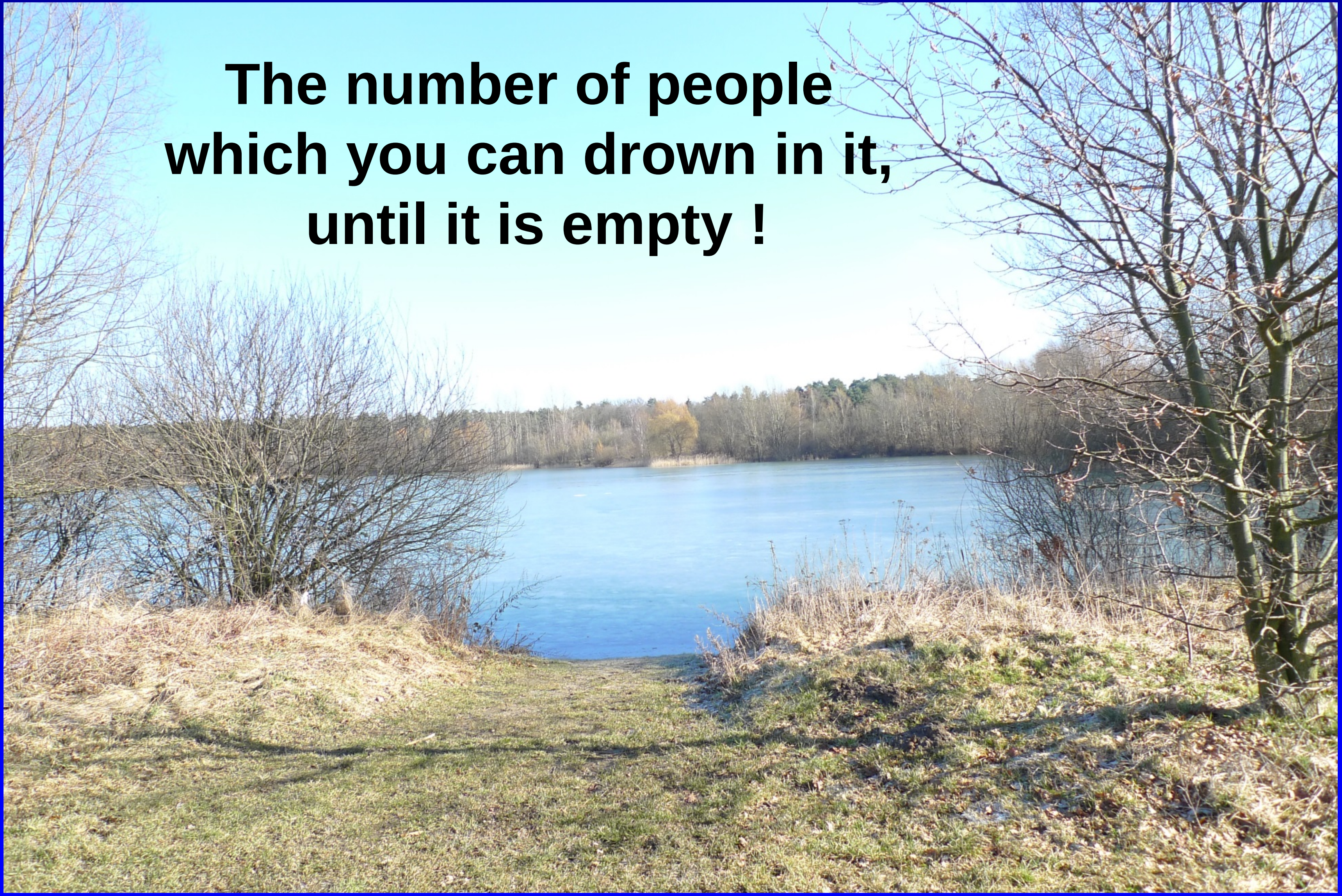
Radiotoxicity is the dose due to ingestion per mass of heavy metal.

Th. Fanghänel, 25 Years INE, 17.6.2005

Toxicity indices for direct disposal of HAW compared to that of ashes from burning coal



What is the lethal toxicity index of a water pond?



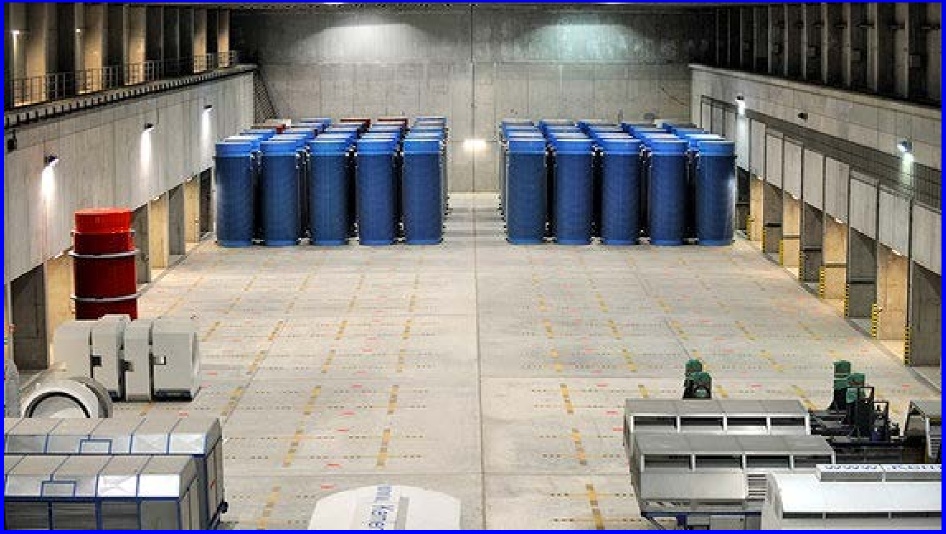
Conclusion:

You should not eat radioactive waste!

Toxicity indices do not tell you anything about the risk.

Intermediate above-surface storage

It means a lot of dose for the personnel.



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Above-surface storage and retrievable disposal need long-term stability of the human society.

History demonstrates that such a stability is highly improbable!

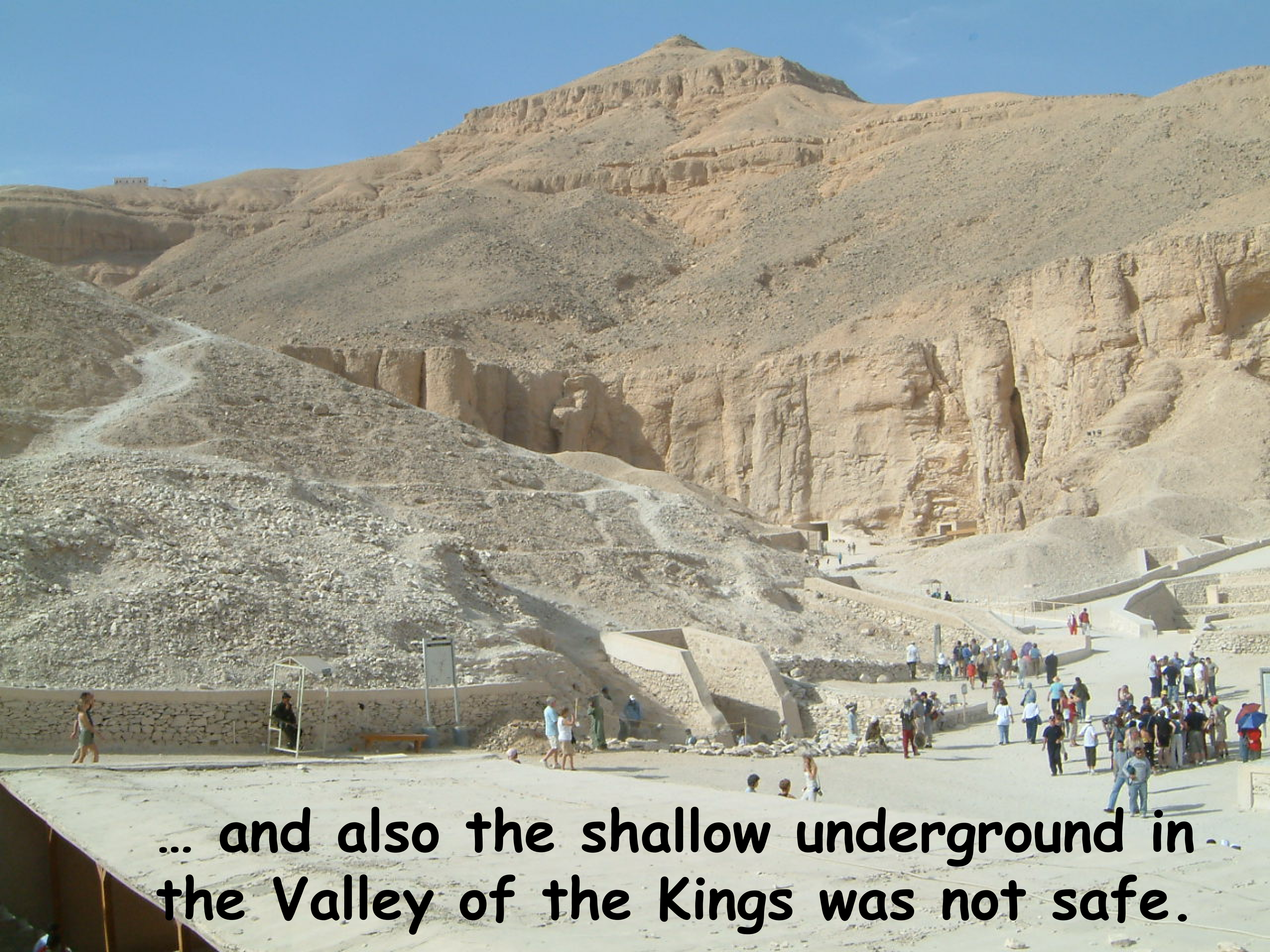
Michael Sailer: „ ***An welchem Standort auf der Welt hätte ein um das Jahr 1500 errichtetes Zwischenlager auch nur ein, zwei Jahrhunderte überlebt? Mit der glücklichen Erfahrung der nun gut 65 Jahre dauernden Friedens-periode und einer insgesamt stabilen, prosperierenden Ökonomie vergessen wir allzu leicht, dass dies in der bisherigen Geschichte Deutschlands (und anderer Regionen der Welt) keineswegs normal ist*****.“**

http://www.no-atom.de/index.php/nachrichten/atomm%C3%BCll/356-atommuell-kein-fass-ohne-boden

You can design a storage facility according to requirements of safety and security.

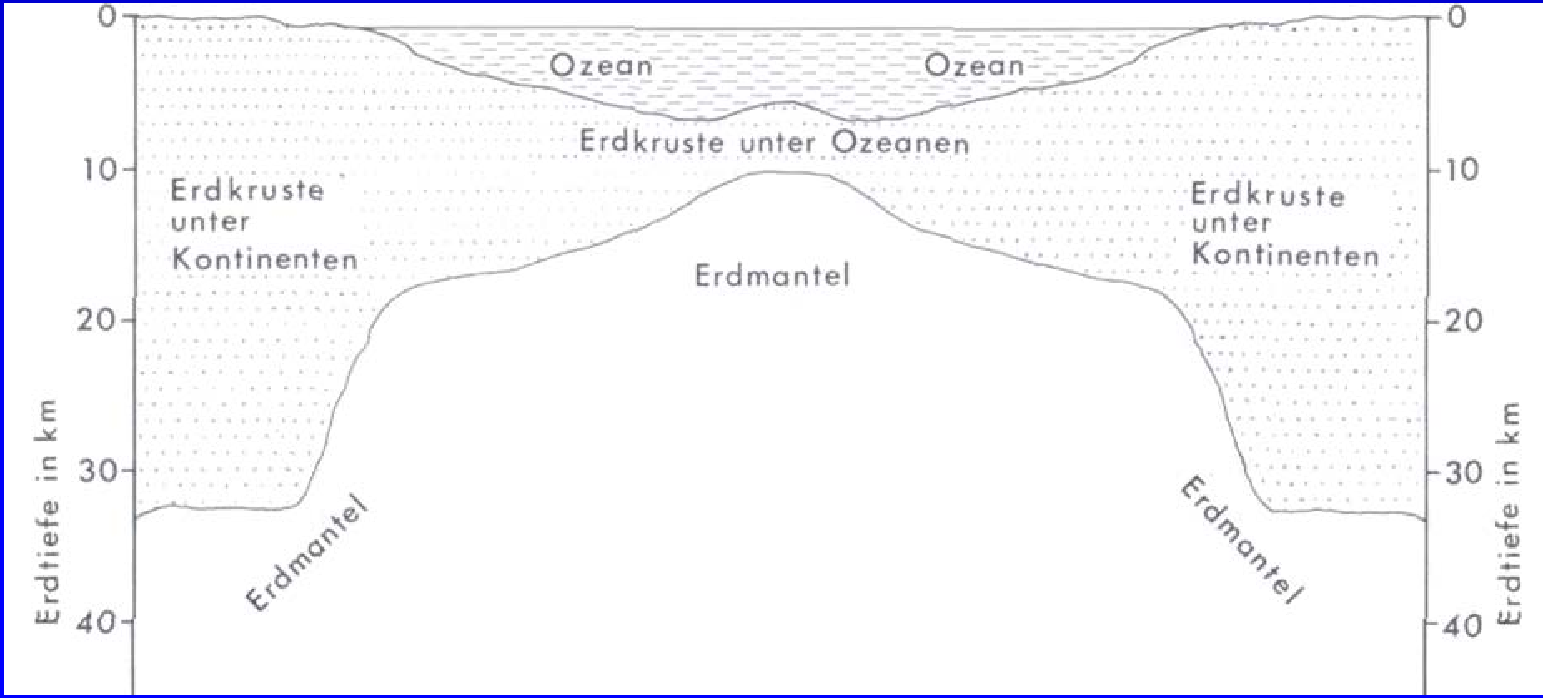
But, you cannot assign a probability to the development of human societies and consequently you cannot quantify the risk.

Cheops' (~ 2620 – 2580 B.C.) pyramid was plundered …

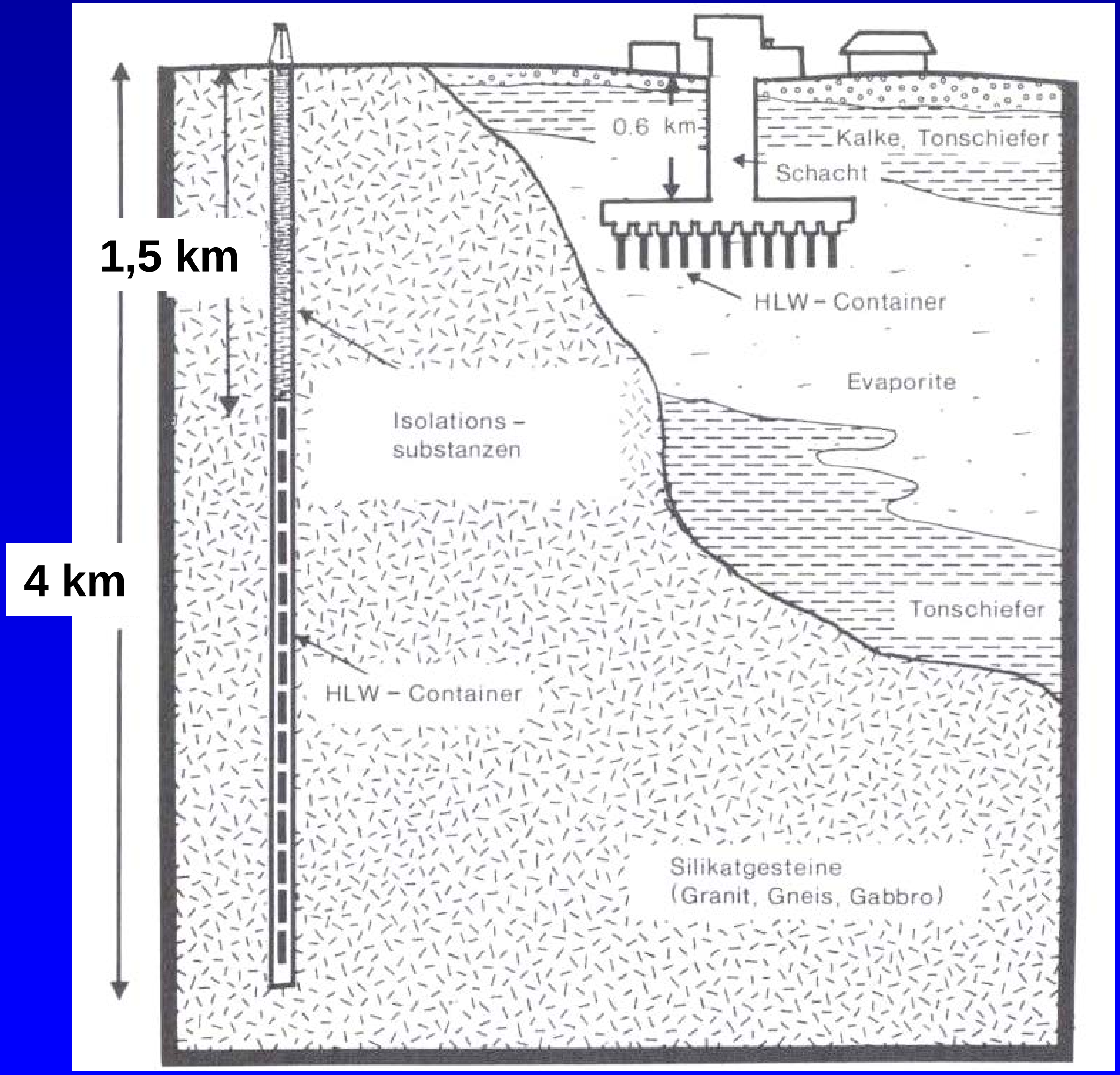

… and also the shallow underground in
the Valley of the Kings was not safe.

Therefore, other concepts for the final disposal of radioactive waste were considered.

- in space
- in the oceans and in sediments of the deep-sea bed
- in the Arctic ice
- on the continents in deep geological formations (crystalline formations, evaporates, clays, …)

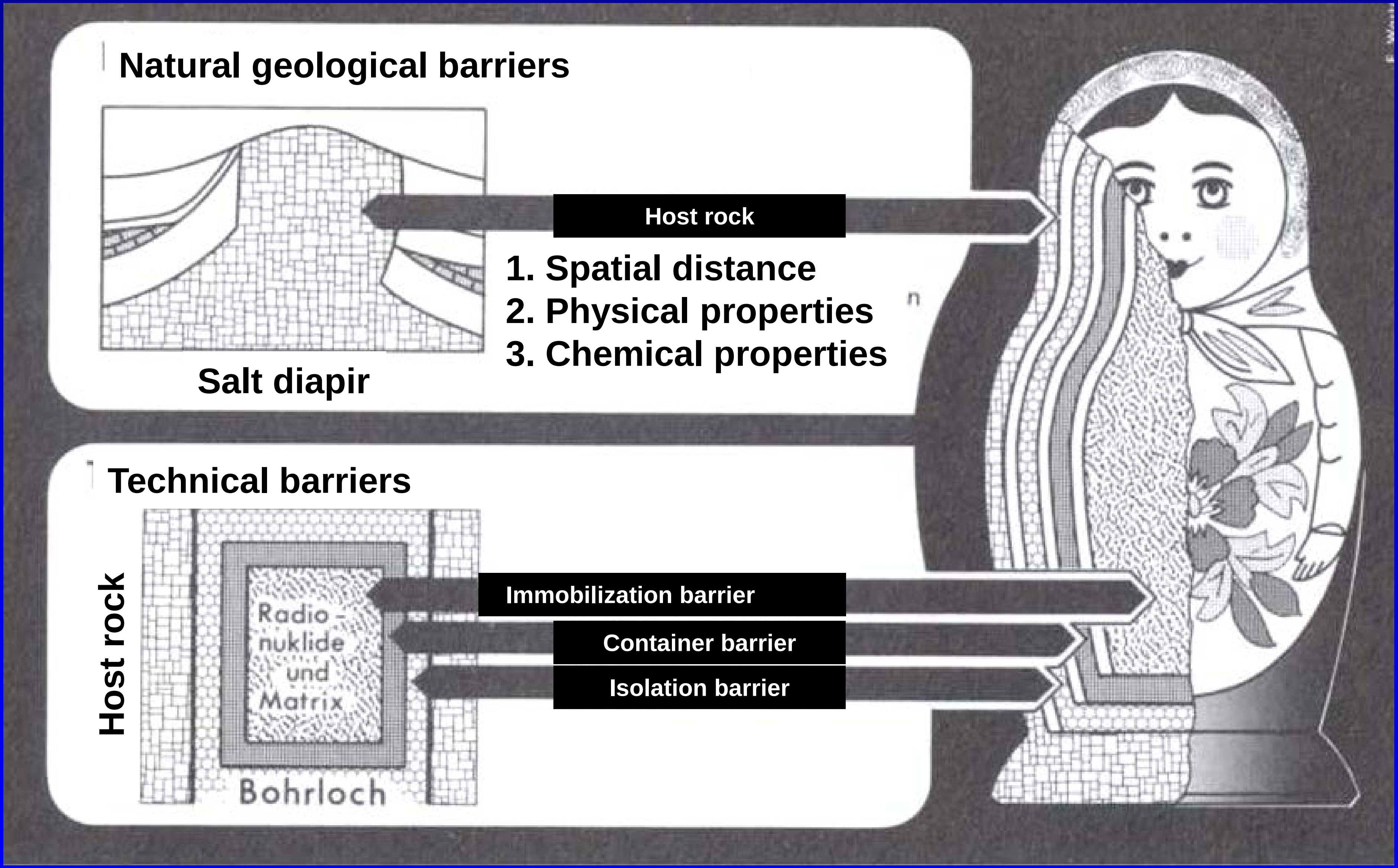


Geological formations can serve as natural barriers …



Ringwood, 1980

… and the multi-barrier concept was developed.

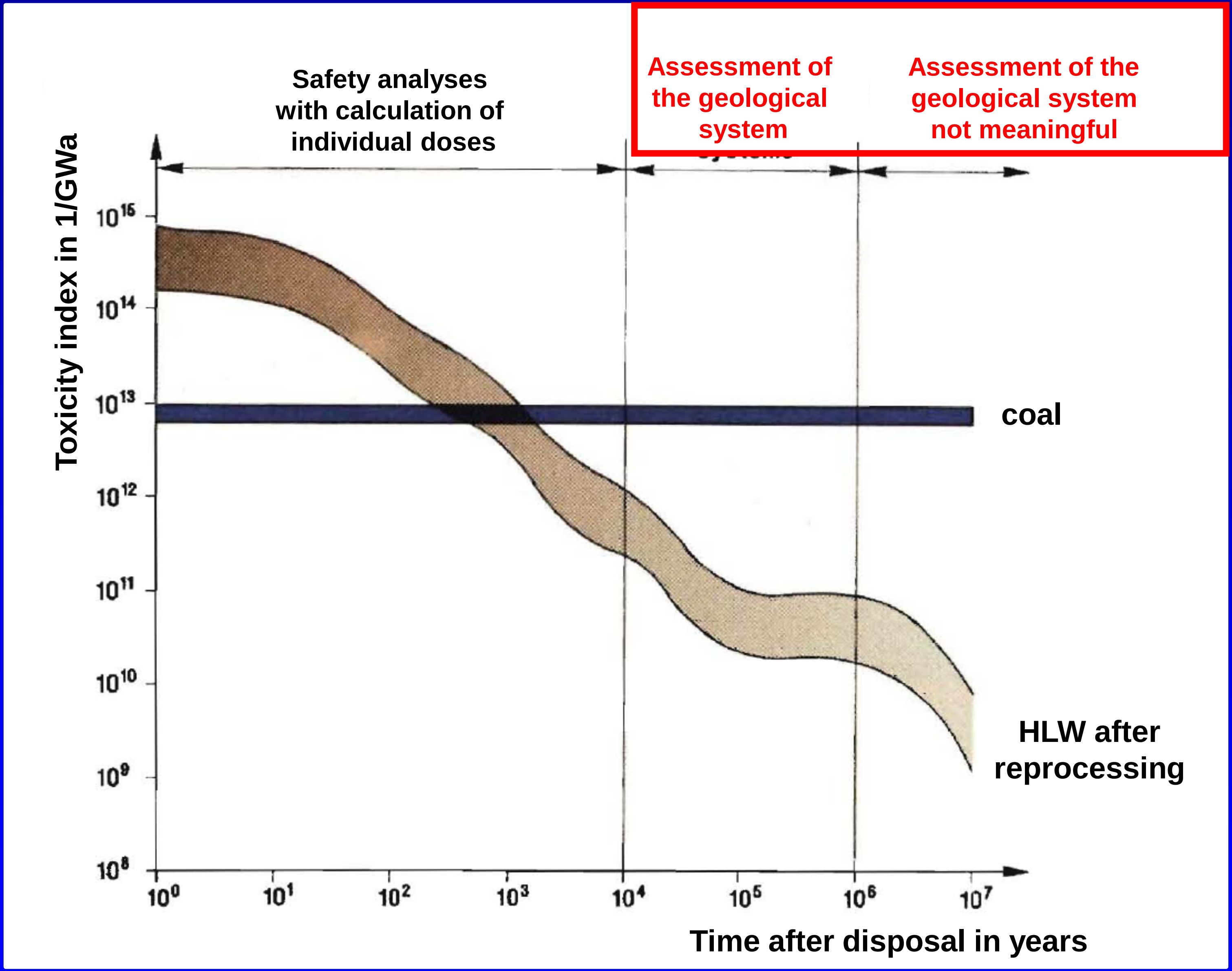


Geology in the Quartary

Formation	Abteilung		vor Millionen Jahren
Quartär	Holozän		
			0,01
	Pleistozän	Weichsel-Kaltzeit	
			0,07
		Eem-Warmzeit	
			0,12
		Warthe-Stadium Saale-Kaltzeit Drenthe-Stadium	
			0,29
		Holstein-Warmzeit	
			0,32
		Elster-Kaltzeit	
			0,4
		Cromer-Komplex (Warmzeit)	
		Menap-Komplex (Kaltzeit)	
			ca. 1,0
		Prä-Menap	
			ca. 2,0
Tertiär	Pliozän ff.		

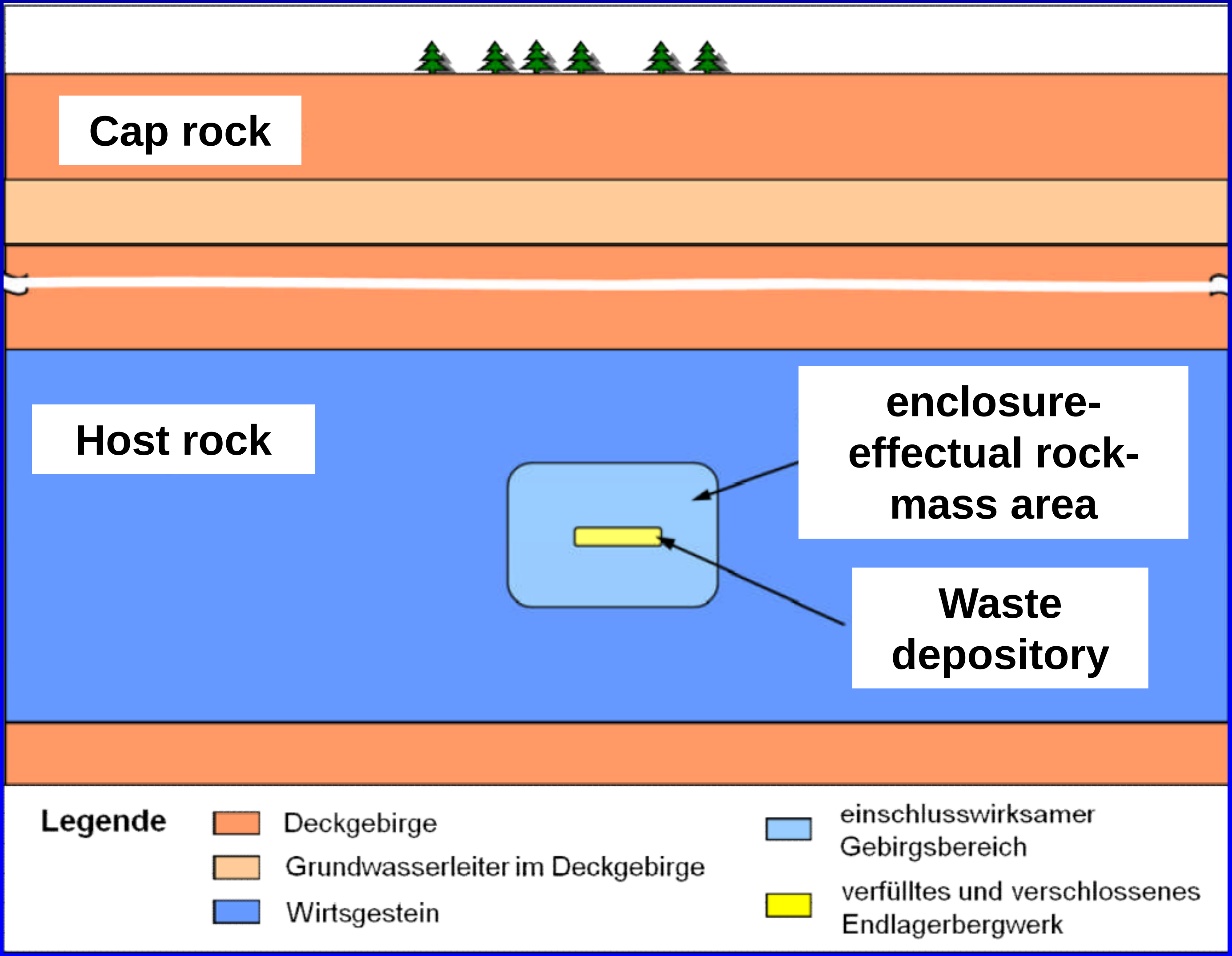
BfS, 1992

Development over time of the facilities in the context of toxicity indices



In Germany, the concept of an enclosure-effectual rock-mass area is discussed in order to facilitate the assessment of geological site over long time spans.

Scheme of a final depository with the enclosure-effectual rock-mass area as the safety-relevant area in the host rock



GRS-247 (2008)

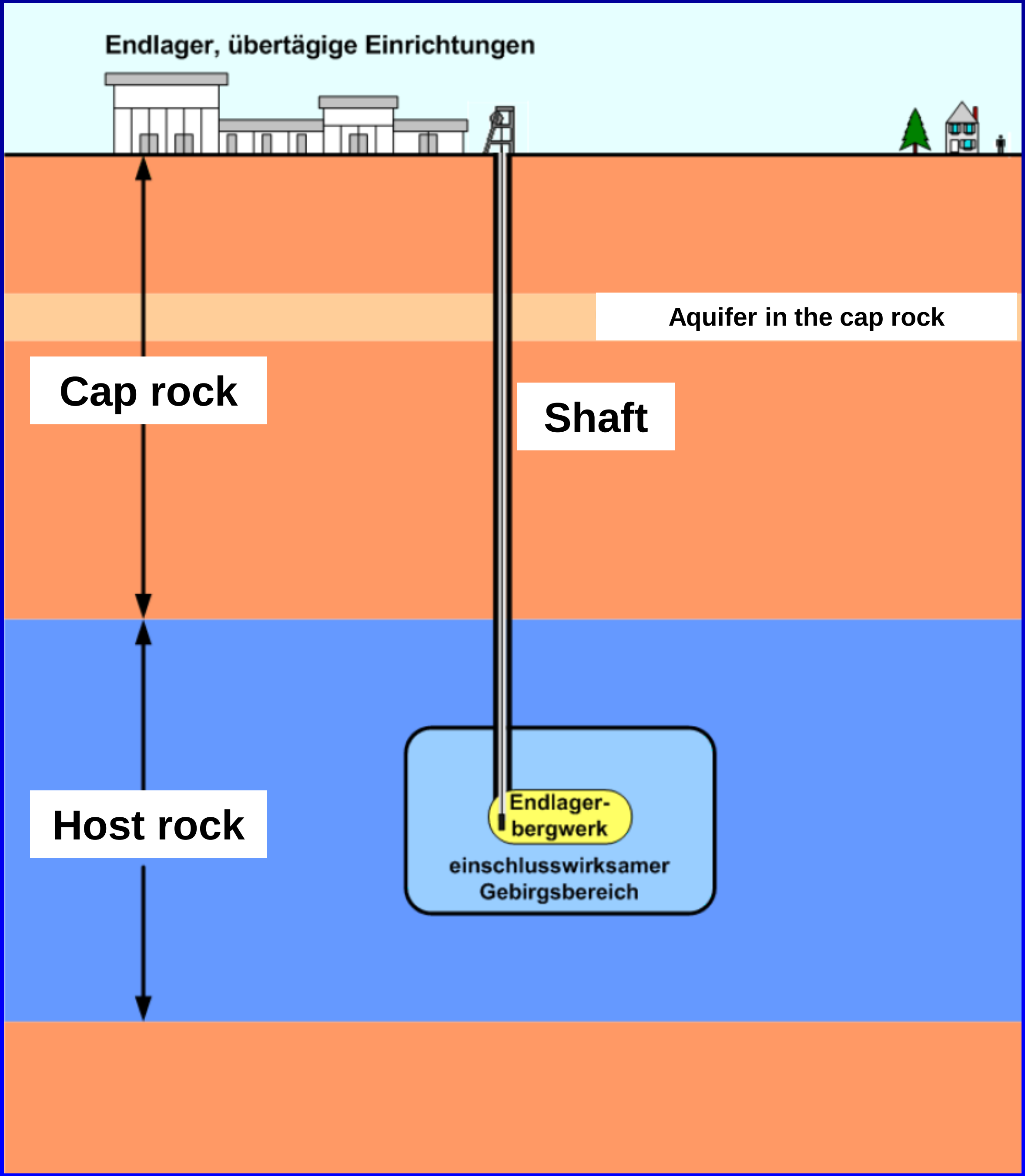
Einschluss-wirksamer Gebirgsbereich

=

enclosure-effectual rock-mass area

=

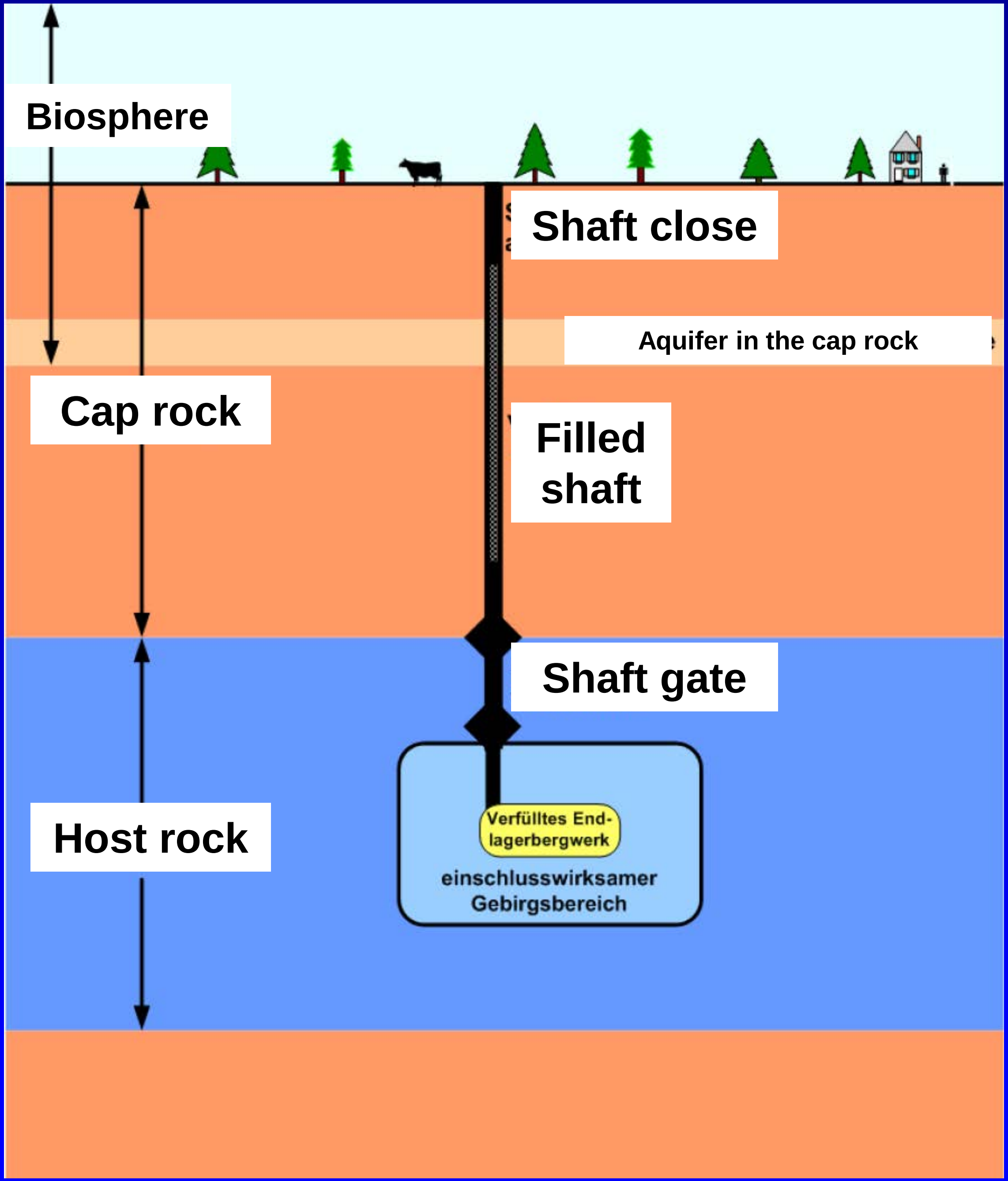
isolating rock zone



The concept of the enclosure-effectual rock-mass area

during operation of the depository

GRS-247 (2008)

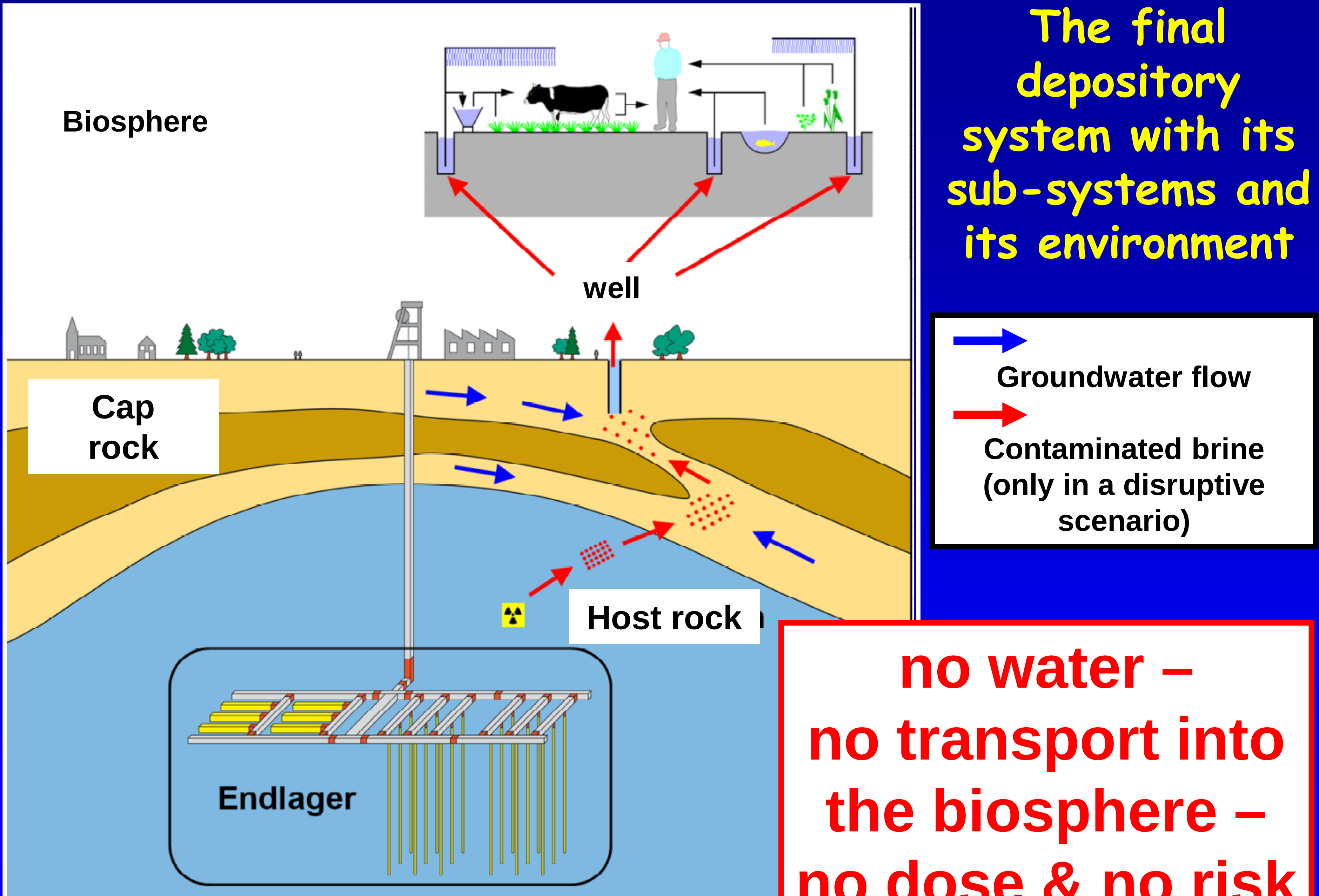


The concept of the enclosure-effectual rock-mass area

after closure of the depository

GRS-247 (2008)

The final depository system with its sub-systems and its environment



no water – no transport into the biosphere – no dose & no risk

GRS-247 (2008)

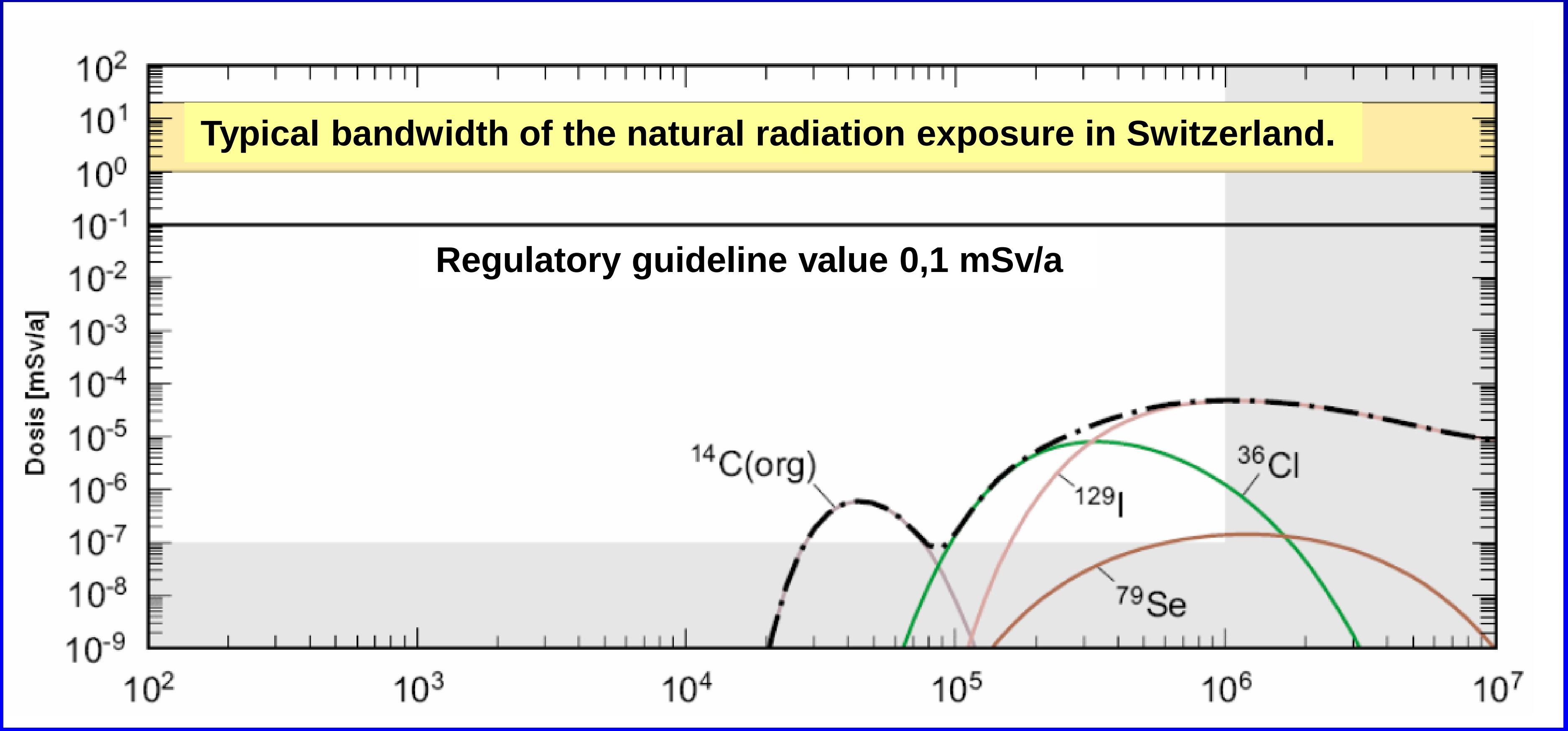
What happens in disruptive scenarios?

You need water

- **to destroy the technical barriers**
- **to corrode the container**
- **to dissolve the immobilization barrier**
- **to transport radionuclides in the near-field**
- **to transport them to the aquifer in the far-field**
- **to contaminate foodstuffs and drinking water**

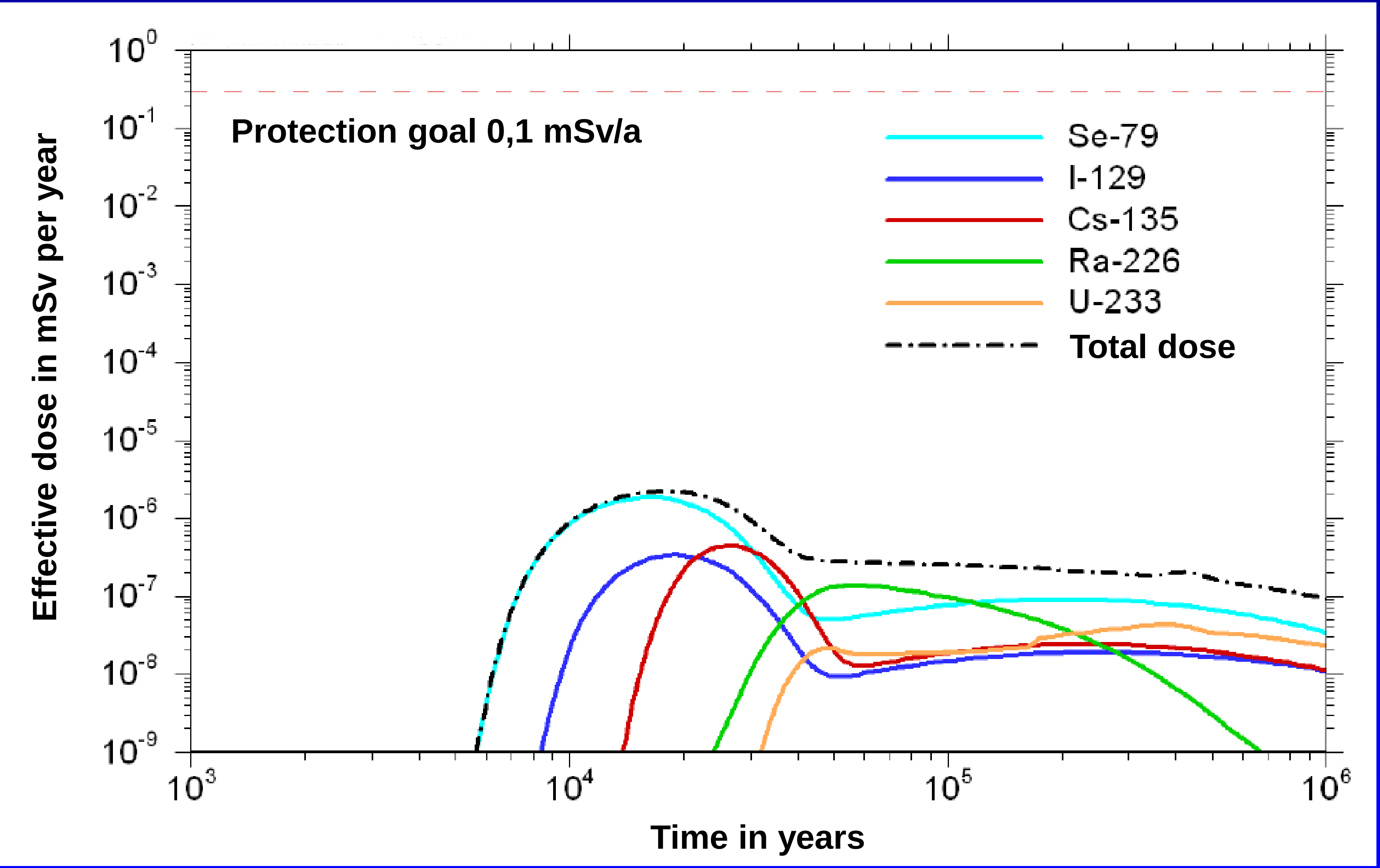
Then you get a dose as calculated
for the safety case!

Contributions of different radionuclides to the exposure in a long-term safety analysis for a final depository in mudstone, acc. to /NAG 02/.



GRS-247 (2008)

Calculated radiation exposures after closure (generic depository in a salt dome, Scenario: influx of 100 m³ brine each from two inclusions into a borehole with vitrified waste)



GRS-247 (2008)

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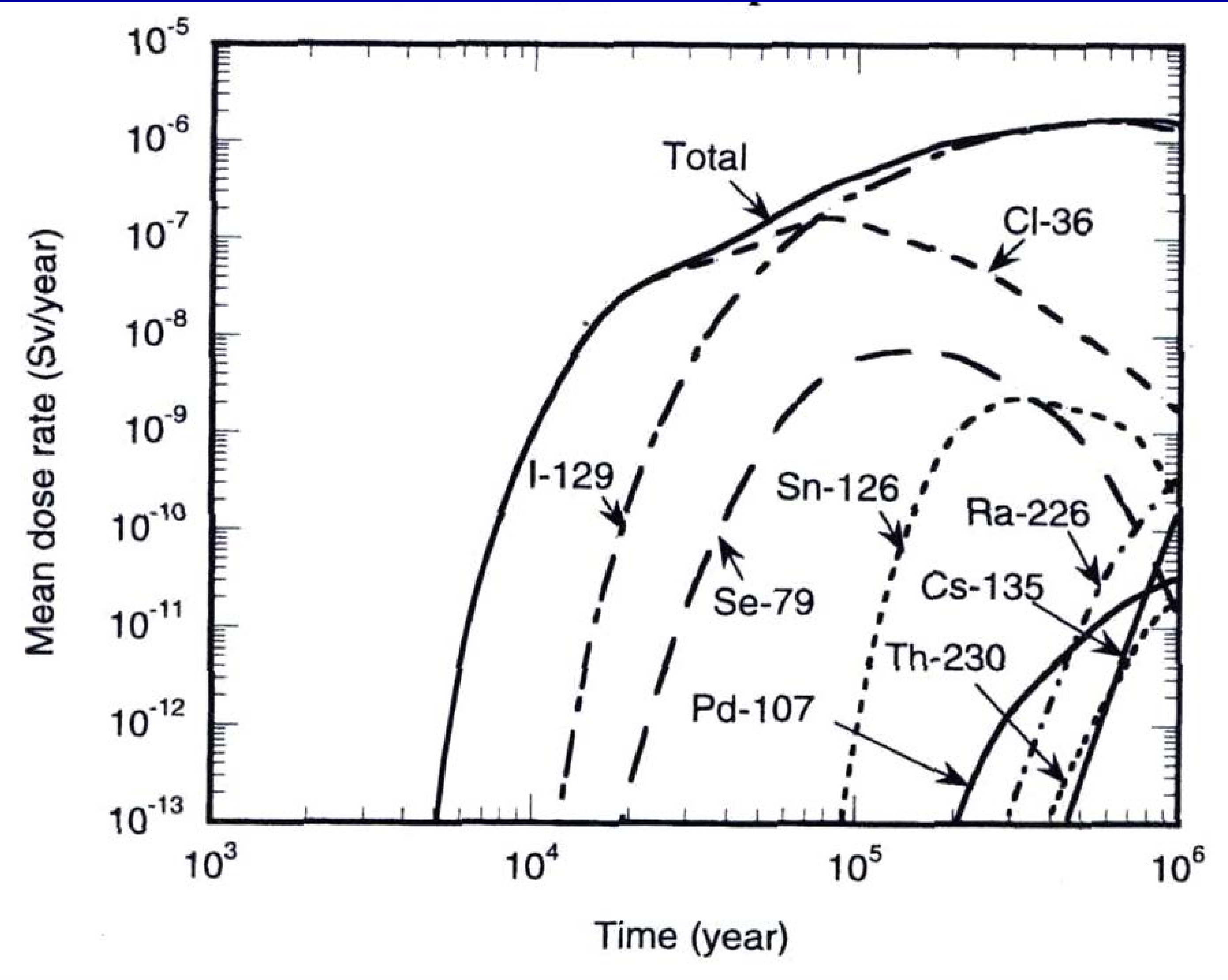
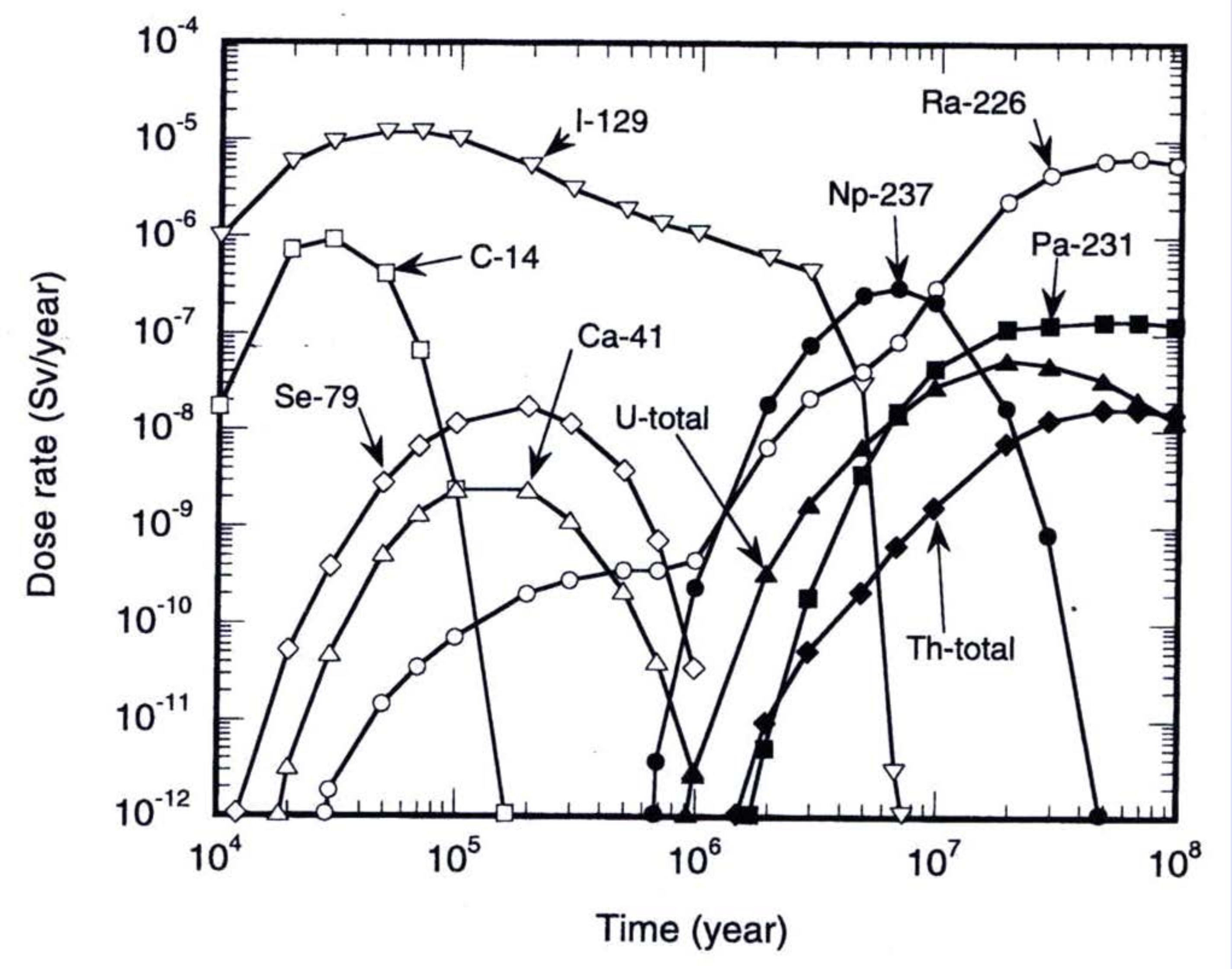
Evolution of the Individual Dose Rate in Spain
40 GWd/tHM UOX Spent Fuel



NEA, Actinide and Fission Product Partitioning and Transmutation, NEA/OECD, 1999

Evolution of the Individual Dose Rate in Sweden
45 GWd/t HM MOX Spent Fuel



NEA, Actinide and Fission Product Partitioning and Transmutation, NEA/OECD, 1999

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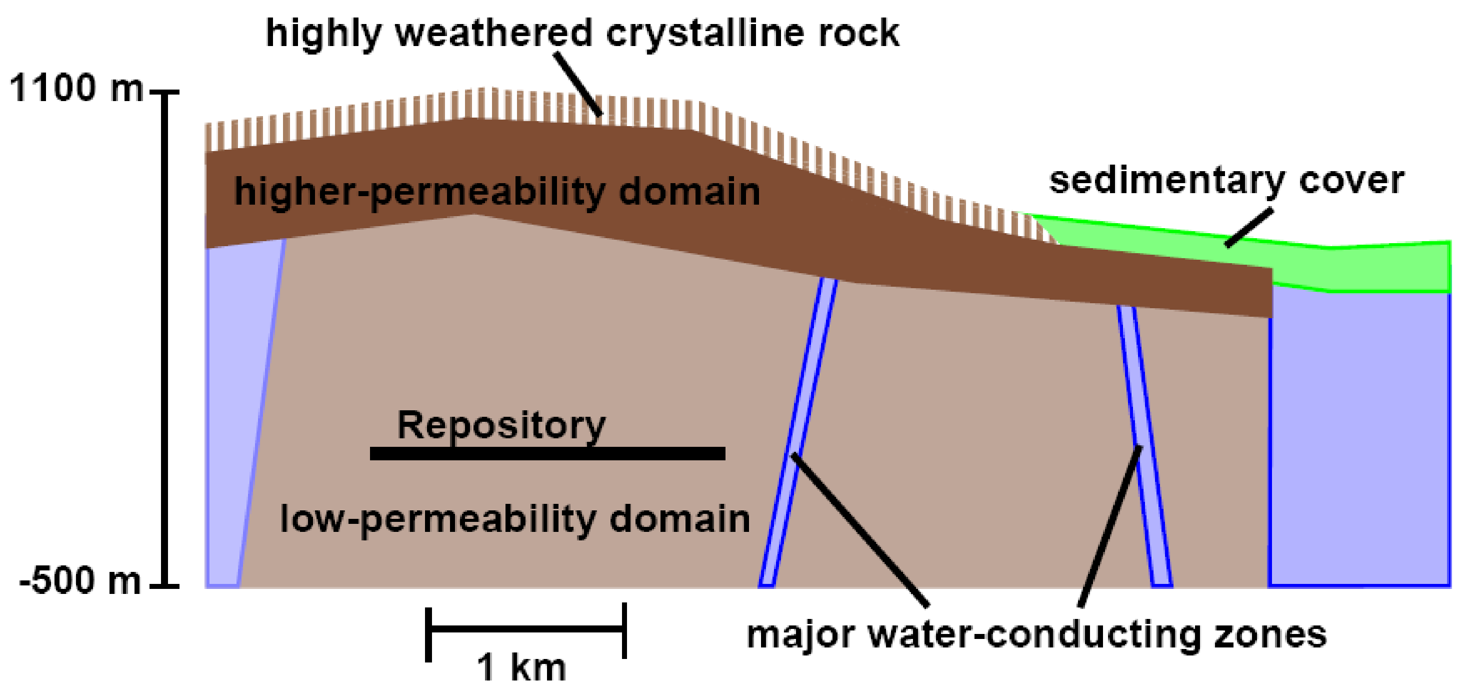
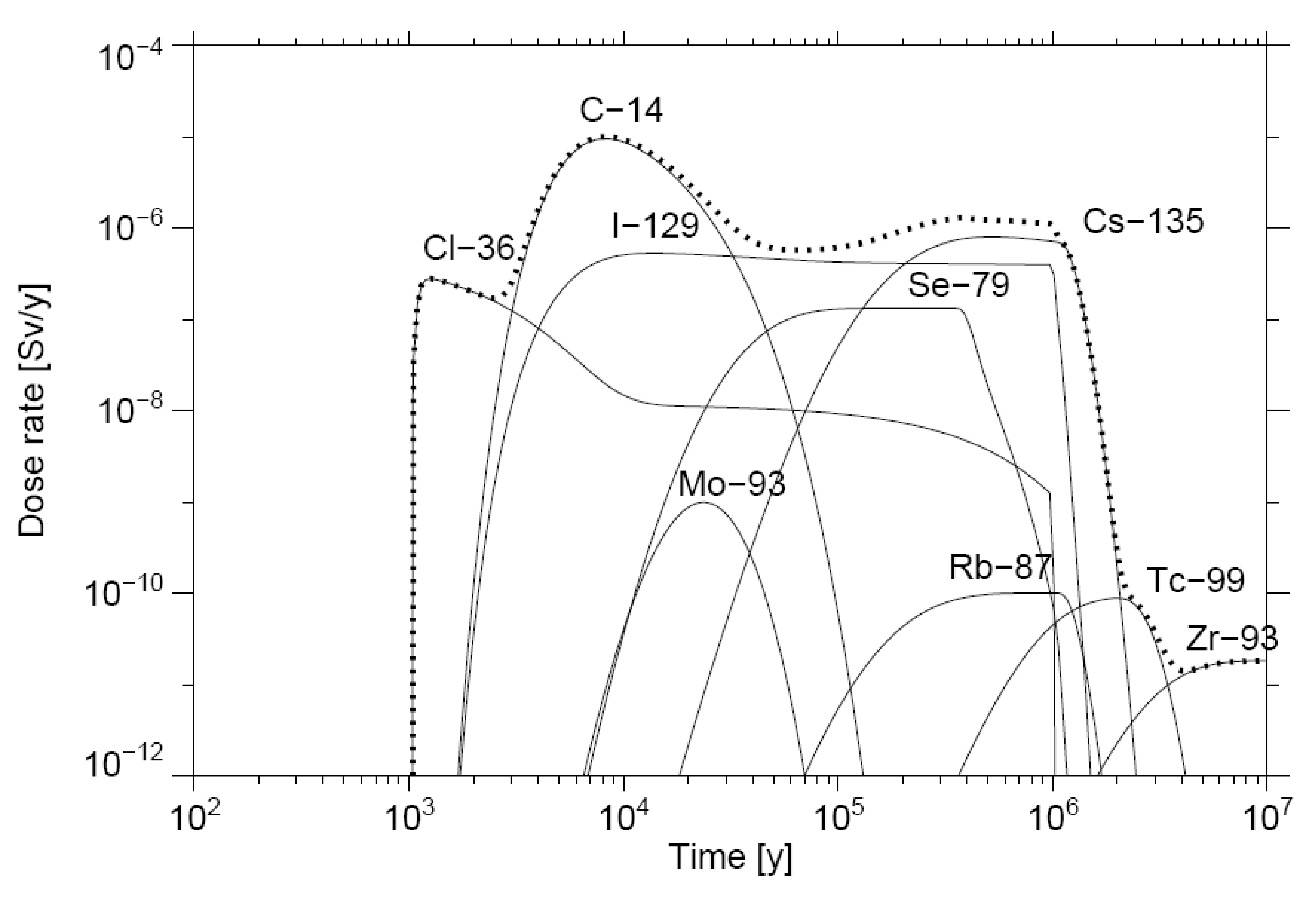
Schematic description of the generic crystalline German site with hydraulic conductivities assumed



- low-permeability domain of crystalline basement $K = 5.6 \cdot 10^{-11}$ [m/s]
- higher-permeability domain of crystalline basement $K = 2.8 \cdot 10^{-7}$ [m/s]
- highly weathered crystalline rock $K = 1.0 \cdot 10^{-5}$ [m/s]
- sedimentary cover $K = 1.0 \cdot 10^{-5}$ [m/s]
- major water-conducting zone $K = 3.2 \cdot 10^{-7}$ [m/s]

GRS-154 (2000)

Dose rates due to activation and fission products in the reference scenario in a generic crystalline formation.



GRS-154 (2000)

Some quick and dirty calculation

UNSCEAR: Life-long death risk = 0,1 Sv^{-1}

Life-time 100 a → mean death risk = 10^{-3} Sv^{-1} a^{-1}

= 10^{-9} μSv^{-1} a^{-1}

For a 10 µSv a^{-1} exposure the risk is 10^{-8} a^{-1}.

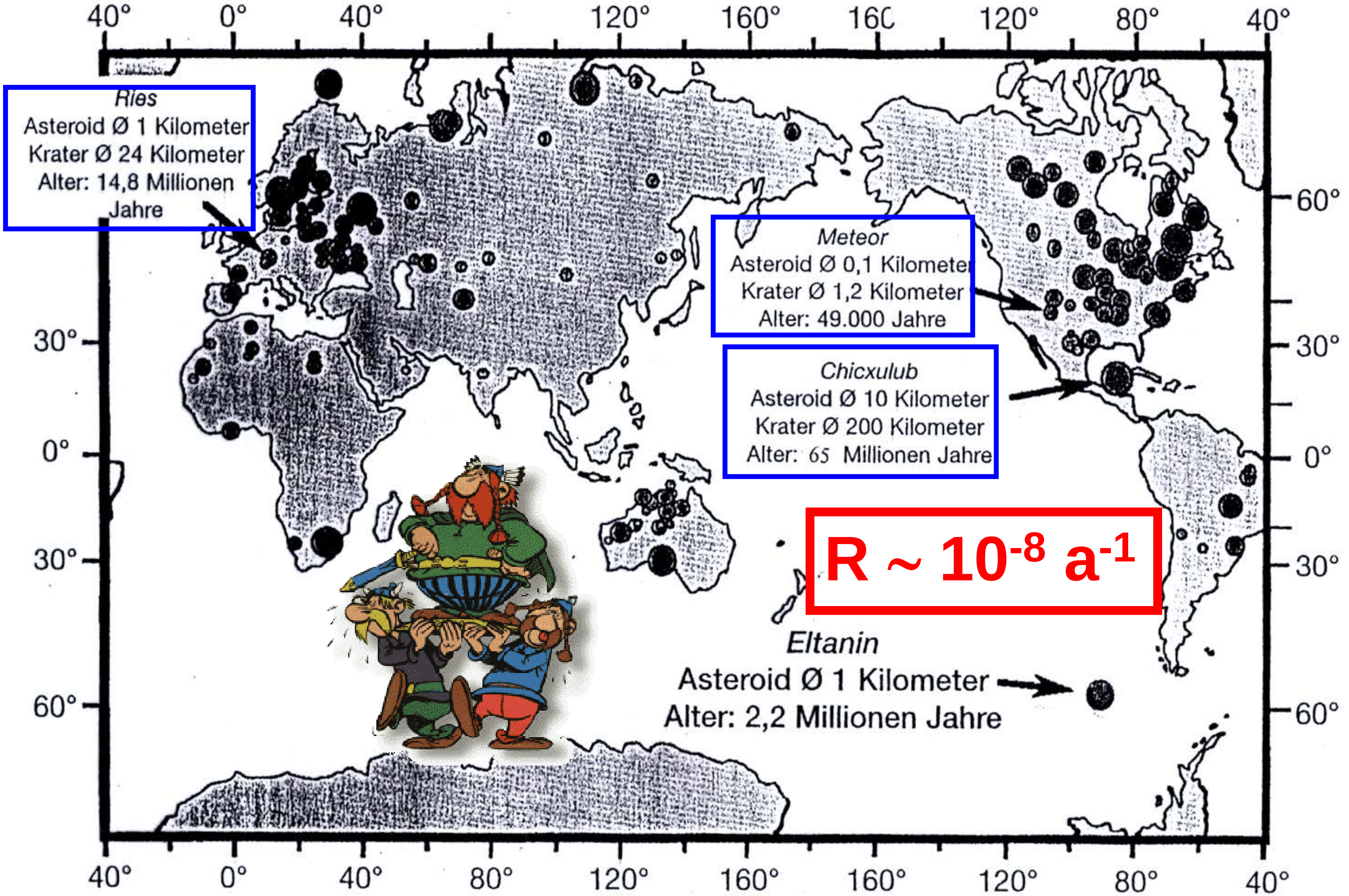
What is the meaning of a death risk of

$$10^{-8}\ a^{-1}$$

?

… for an individual, a group, or an entire population.


$R \sim 10^{-8}\ a^{-1}$



Verteilung der heute bekannten Einschlagkrater auf der Erde. Ausgewählte Beispiele mit Angabe des Asteroiden- und Kraterdurchmessers und des Einschlagalters

Gersonde et al. (1997)

Geo, 1.11.1991

In 1954, Hewlett Hodges from Alabama was hit by a meteorite.

Geo, 1.11.1991

In Wethersfield, Connecticut, a meteorite hit the same house in the years 1971 and 1982

Conclusions

- You cannot quantify the risk for the intermediate storage of nuclear waste since you cannot assign a probability to the development of human societies.
- The final disposal of HLW in deep geological formations is technically feasible with tolerable risks.
- Only disruptive scenarios lead to potential radiological consequences in the biosphere in the very far future via the water pathway.
- Even if water is available, the exposures resulting potentially from a well-chosen and –constructed final depository can be regarded as negligible.
- However, there are some complications.

1. The question in the public is:

Is it safe?

The scientific answer is:

There always remains some risk!

2. The reality of the perception of radiological risk

…

Japan News | nuclear fear is growing 12.4.2011

http://japannews.best100japan.com/eathquake-in-japan-news-and-comments/japan-may-raise-degree-of-nuclear-risk.html/attachment/japan-news-nuclear-fear-is-growing

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The End

www.irs.uni-hannover.de/3.html