Radio ecological background for the isolation approach for the safety assessment of repositories

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Abstract:
A repository for radioactive waste should only be licensed if it poses no hazard to man and the environment. State of the art is the calculation of the potential radiation exposure of individuals in the surrounding area. A new concept has now been developed to assess the safe closure of radioactive waste in the isolating rock zone. Six criteria allow the quantification of the impact of the repository on the natural environmental conditions starting from the isolating rock zone over pore water and accessible water to the concentration in flora and fauna and to radiation exposure of humans placing the hitherto only criterion into a wider context.

1 REGULATING LONG-TERM SAFETY

It is general consensus that radioactive waste must be isolated to prevent harm for future generations [1, 2, 3,]. These have the same right of physical health as people living today; their radiation exposure must not be higher than would be allowed today. There is no time limit of this protection goal. In the same way, protection of the environment has to be ensured for an unlimited period. The environment comprises not only the animated nature – explicitly flora and fauna [4] - but also unanimated nature, e.g. the groundwater [5].

Even below specified dose limits, the radiation exposure of man and the contamination of the environment have to be kept as low as possible – taking into account the state of the art in science and technology and the circumstances of each individual case [6].

2 DEMONSTRATION METHODS

2.1 Method applied so far

The state-of-the-art procedure is to show that the radiation exposure of humans is below certain specified dose limits. To do so, the migration of the radioactivity from the waste packages into the isolating rock zone and further on into the overburden with its aquifers is pursued. The geosphere-biosphere interface lies in wetlands or in waters abstracted from a well. With some assumptions on ecology, the radionuclide concentrations in the environmental media – water, soil, vegetable and animal foodstuffs and the potential radiation dose - sometimes also the risk – to humans are calculated. No other endpoint is taken into consideration.

The main source of uncertainty is the long time of follow-up in which the environment will change a lot. Today's conditions will therefore not always apply – but unknown is when and in which direction change will occur. Fig. 1 [7] gives an impression of the predictability.

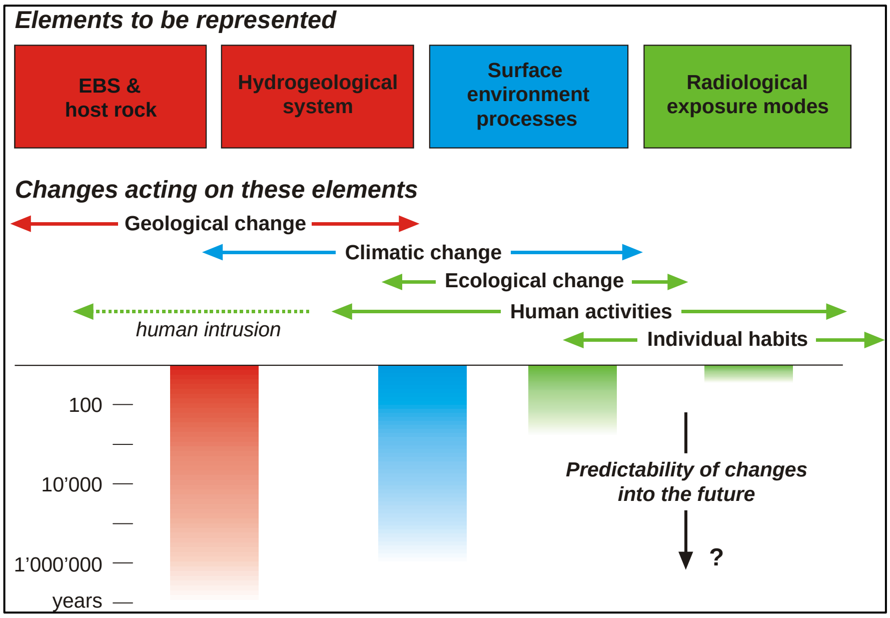

Fig. 1: Predictability of future developments [7]

While a prediction over a full million years is possible for the isolating rock zone and the host rock – otherwise the site would be unsuitable – the near surface hydro geological system will change unpredictably due to climatic changes. In the past million years, ice ages and periods of moderate or warm climate have alternated; Homo sapiens – modern man – appeared late in this period and evolved from the paleolithic level of civilization to the modern Industrial Age. No statement can be made on the next million years. Therefore, a reference biosphere has to be devised in which radiation exposure will not be underestimated at any time, neither by early arriving radionuclides nor by and later arriving ones. Unfortunately, the behavior in the environment of many important radionuclides is not sufficiently known. Consequently the probable future radiation exposure will be overestimated by several orders of magnitude.

2.2 New approach: a set of six indicators

The new approach is the proof that the isolating rock zone is capable to seal the radionuclides so effectively that dose constraints will be maintained. A set of six criteria – instead of only one – shows step by step that natural radionuclide flux, radionuclide concentration and radiation dose will increase only slightly. The indicators are the following [8]:

1. Fraction of the amount of substance released into the boundary of the isolating rock zone (cumulated over the assessment time of 1 million years) less than 0,01 %
2. Additional concentration of U and Th (all isotopes) in the pore water at the boundary area of the isolating rock zone less than 1 µg /l U and 0.1 µg/l Th
3. Contribution to power density in the pore water at the boundary area of the isolating rock zone less than 1 MeV/l
4. Contribution to radio toxicity in deep groundwater at the boundary of the isolating rock zone less than 0.1 mSv/a
5. Additional concentration of natural radionuclides insignificant compared to pre-existing concentrations
6. Effective dose to humans less than 0.1 mSv/a

2.2.1 Fraction of amount of substance released

This indicator shows whether the repository is hermetically sealed. The isolation capacity of the isolating rock zone is predictable over one million years, if not, the repository is unsuitable. Criteria for isolation is that less than 0.01 % of the radionuclides emplaced penetrate into the boundary of the isolated rock zone within a period of a million years which is assumed to be insignificant.

2.2.2 Additional concentration of uranium and thorium released in the pore water at the boundary of the isolating rock zone.

The distribution of the isotopes between pore water and solid matter is a function of the chemical conditions and is therefore site-dependent. Fig. 2 (according to [9], converted) shows the concentration of natural uranium in ground water in Germany (1994) that are pumped up to be used as drinking water. This is not pore water, as pore water is inaccessible. The values are distributed lognormal across three orders of magnitude, and it appears that a concentration increase by 1 µg/l of natural uranium does not change the water quality much. For a better judgment, the slightly lower concentrations in drinking water are also given.

The concentration of thorium in water is usually less than that of uranium. The suggestion is therefore to limit the maximum additional concentration in pore water to a lower value, too.

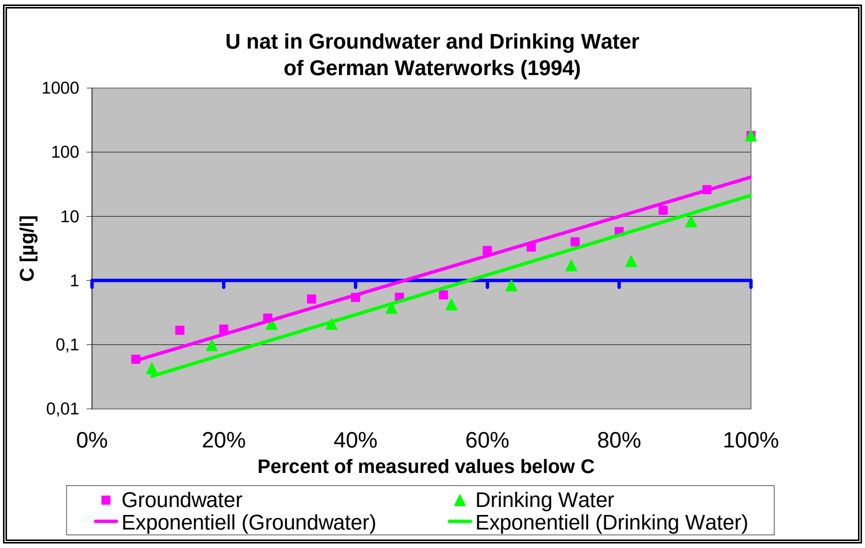

Fig. 2: Concentration of U_{nat} in waters from German waterworks (from [9], converted)

Contribution to power density in the pore water at the boundary area of the isolating rock zone less than 1 MeV/l

As many of the radionuclides emplaced do not occur naturally, it is not possible to specify any boundary concentration orientated on a natural concentration. The artificial radionuclides in pore water in the boundary area of the isolating rock zone can, however, be made comparable due to their radiation.

Power density is referred to as the energy that is released during the complete decay of a radionuclide in 1 l of water. An increase of power density by 1 MeV/l would mean that natural values are doubled. Some simplifications are applied:

- All radionuclides of a chain occur at the same concentration in the water. The influence of different chemical properties is not considered.
- The weighing factor W_R of alpha radiation is set 1 instead of 20. This simplification is conservative when the first radionuclides appear in the pore water (I 129, Cl 36, Se 79, Cs 135), but optimistic when the alpha emitters reach the pore water.
- Only the radiation of the radionuclides dissolved in pore water is taken into account, not the gamma and beta contribution from radionuclides in the solid matter. This is conservative only at first, too.

The question now arises how the increase affects living organisms in pore water, maybe chemoautotrophic bacteria or archaeae.

The living organisms would be irradiated both internally and externally.

- Regarding external irradiation, power density is a good measure. Considering the usual large bandwidth of the natural radionuclide concentration (see Fig. 2), receiving twice the amount of natural radiation (mean values) should do them no harm.
- As to internal irradiation the fast-migrating radionuclides have one thing in common: they are biologically essential, or they are similar to essential elements. The concentration of such elements in a living organism is nearly independent of the concentration in the surrounding medium. The higher the concentration of the stable element (or of potassium in the case of Cs 135), the lower is the accumulation factor. The concentration of potassium, chlorine and iodine in water near a salt dome is high by nature, and therefore, the accumulation factors are low. Information about Se 79 and the natural decay chains is still lacking.

2.2.3 Contribution to radio toxicity in deep groundwater at the boundary of the isolating rock zone less than 0.1 mSv/a

This indicator has the unit of a radiation dose, but it does not have any significance as a dose, rather is it a further indicator for the isolation capacity. It is calculated as follows:

The radionuclides leaving the isolating rock zone during the course of a year are theoretically dissolved in the amount of water which 30 humans would use within one year. The amount of water necessary is determined on the basis of assumptions regarding their nutritional habits and the production of their food, especially the amounts of irrigation. These two parameters – water consumption and amount and composition of food – are highly influencing the dose if the radionuclide source term is a concentration, but if the source term is an annual release, an (assumed) high level of consumption leads to (calculated) low concentrations, and the influence of the water consumption on the calculated dose becomes negligible. This parameter is thus suited as an indicator of the influence of the repository on the groundwater by all radionuclides, not only the natural ones.

2.2.4 Additional concentration of natural radionuclides small compared with pre-existing concentrations

This indicator only concerns natural radionuclides. It differs from indicator no. 2 by two features. Its local position is in accessible groundwater and it refers to each radionuclide in the natural chains, whereas indicator 2 is based on mass concentration of the elements uranium and thorium in inaccessible pore water. For indicator no. 5, the concentration of every radionuclide in the chains has to be calculated and compared with its natural distribution. The greater exactness in indicator no. 5 is justified because it is situated in the geosphere-biosphere interface.

According to the Framework Directive on Water Policy [5], any new discharge of contaminants into groundwater is forbidden. But an additional discharge into groundwater can hardly be regarded as “new discharge” if the contaminant concentration is only slightly higher than in the replaced water.

It has to be clarified what is "slightly higher". In decision statistics, a value differs significantly from a given whole if it evidently does not belong to it. It thus lies in the uppermost range of values or even above. This cannot be meant here. The demand is that the geometric mean may be increased by 10 %. Fig. 3 shows the statistical distribution of natural uranium in the groundwater extracted in Germany for use as drinking water from uncontaminated sites. An increase of 50 % is given instead of 10 % because of legibility. Standard deviations are calculated after taking the logarithms.

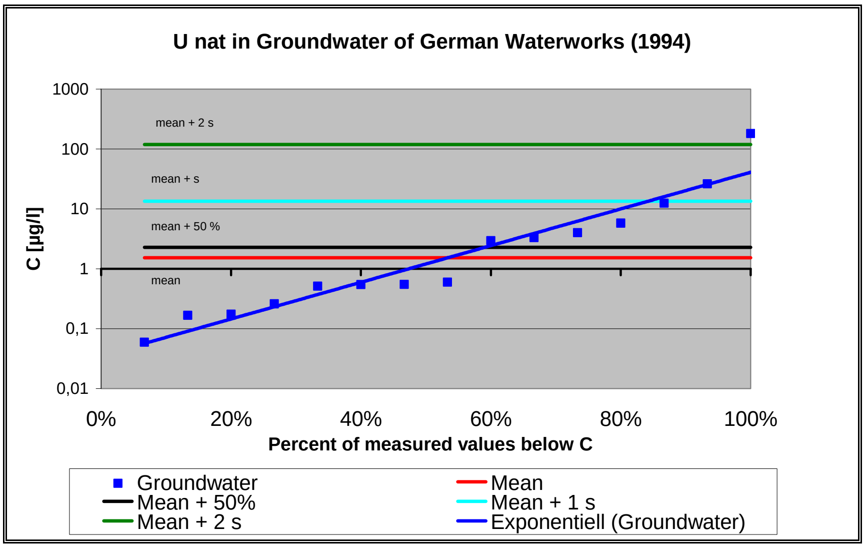

Fig. 3: Uranium in the groundwater of German waterworks (according to [9], converted)

The groundwater is the habitat of populations of living organisms, which must not be harmed. Dose limits have not yet been established [4], but the tendency seems to protect non-human species by reducing the frequency of early mortality and reduced reproductive success in individual animals and plants to a level where the impact on the conservation of species, maintenance of biodiversity, or the health and status of natural habitats or communities is negligible [11]. Together with the higher resistance against radiation of lower animals (animals except vertebrates), this would result in dose constraints several orders of magnitude above the limits applying to humans.

It is not likely that a “slight increase” of the concentration of natural radionuclides (criterion no. 5) would lead to any damage to biota. This has to be demonstrated on reference organisms. At the moment, ICRP is compiling a list of reference organisms [4], which however, does not include any higher animal living in the soil or groundwater [11]. Animals living in the groundwater itself, e.g. proasellus, are not a suitable reference organism as they cannot easily be caught; the mole which lives in soil could be more suitable.

It will probably be sufficient to calculate the radiation exposure of the reference organism(s) only once – then it will probably be known that no populations will be at risk as long as the dose constraint for humans is adhered to.

2.2.5 Effective dose to man less than 0.1 mSv/a

Proof of the compliance with this criterion has to be provided for all occurring radionuclides. The criterion has the same dimension as the fourth one, namely dose/year. Contrary to the latter, however, proper radio ecological calculation is essential. In this respect, this criterion corresponds to the only criterion presently used, but it differs because it is only one out of six.

The input parameter is the radionuclide concentration in the accessible groundwater, while indicator no. 4 refers to the influx of radio-toxicity into the pore water. In the calculation of indicator no. 6 the actual conditions of the near-surface hydrology are taken into account. Dilution with uncontaminated water plays an important role.

The radio ecology is to be embedded into today's biosphere. The biosphere according to Tab. 1 is assumed to remain constant over the entire period. There is a small group of 30 humans living in it, producing their own foodstuff. This does not correspond with the habits in Germany in the year 2007, but the assumption is necessary.

Climate	Today including variation in the last century
Geographical extent	Large enough for critical group of 30 people
Location, topography, orography	Today at the site
Biota	Today at the site
Hydrology, water bodies	Today at the site
Near-surface lithostratigraphy (soil, edaphon)	Today at the site
Human activity, farming technology, nutrition (quality and quantity)	Farming technology and food adapted to self-supporters, with consideration of today's living habits

Table 1: Boundary conditions for a reference biosphere

Radiation exposure of humans particularly depends on radionuclide uptake with food which is highly influenced by the amount of irrigation with contaminated water. This depends on the climate which also influences some other important parameters.

The radio ecology has to be modeled just as carefully as it has been so far. The uncertainty about the biosphere and the resulting necessary conservativeness is still as high as in the old approach.

Unfortunately, it is not possible to compare the calculated doses with naturally occurring doses. In radio ecological models, radionuclides enter the soil via irrigation, but in today’s reality, uranium has got there mainly from the underlying rock and from phosphate fertilizers. The important radionuclides Po 210 and Pb 210 [10] are deposited with precipitation because they are formed in the atmosphere as decay products from Rn 222.

Owing to these and other differences, any calculation on the basis of today's groundwater will lead to much higher radiation exposure levels than is actually observed, but this does not reduce the value of the calculation. It provides new possibilities of comparison.

In Germany, the actual natural radiation dose by ingestion is about 0.3 mSv/a, the external terrestrial radiation is 0.1 mSv/a [10]. The other pathways (inhalation, external radiation in buildings and cosmic radiation) are hardly influenced by a repository and therefore not taken into account here.

At present, a reference value of 0.1 mSv/a, is suggested as radio ecological safety indicator for the radiation exposure caused by a repository [3]. This corresponds to 5% of the total natural radiation exposure via all pathways or 25 % of the exposure via ingestion and external terrestrial radiation.

The uncertainty of radio ecological calculations could be leveled off if a limit was established as 25 % of the dose delivered when today's drinking water is used instead of contaminated groundwater for every pathway. With such a kind of limit it would be ensured that the additional radiation exposure of future generations would not be higher than the level that is permissible today.

3 ASSESSMENT AND CONCLUSION

The approach of six criteria shows whether a repository is safe. Only an insignificant part of the deposited radionuclides may leave the repository and penetrate into the border of the isolating rock zone. The additional five criteria show that the resulting increase in radioactivity, power density, contamination of the environment and dose to man are small compared to natural conditions.

Regarding the radiation exposure of future humans the new approach is a step forward. It would make sense to demand that the calculated additional radiation exposure via ingestion and external radiation in the remote future must not exceed 25 % of the current exposure level – calculated under the same boundary conditions with drinking water as the source concentration. This would correspond to today's relations between natural exposure and the limit for additional exposure. Doing this, the dilemma of the unpredictable radiation exposure in the far future could be resolved.

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