BIOSPHERE ASSESSMENT FOR SAFETY CASE OF FINAL DISPOSAL OF SPENT NUCLEAR FUEL

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Posiva has done safety assessment for final disposal of spent nuclear fuel to a deep crystalline bedrock repository. The purpose of the safety assessment is to obtain construction license for encapsulation plant and underground repository for spent nuclear fuel. The repository site has been selected and it locates in Olkiluoto, Eurajoki, Finland which lies in the Coast of Bothnian Sea. The ONKALO research tunnel has been constructed for the final repository to depth -450m. The future development of the terrain of Olkiluoto is governed by postglacial crustal uplift. Posiva is now preparing to update the assessment to meet the criteria of the operation license of the repository. In the biosphere assessment 2012 (BSA-2012) which is part of the safety assessment, Posiva shows that possible doses, coming from the repository, stay below the regulatory limit (0.1 mSv/a) for the whole biosphere assessment time frame of 10 000 years.

I. INTRODUCTION

Posiva's concept of final disposal of spent nuclear fuel (Fig. 1.) is based on the isolation of the radioactive material. The concept is based on several nested release barriers, including corrosion resistant copper canister, bentonite buffer, backfill and host rock. Used fuel rods are placed in the copper canister, within a cast iron inner part which gives mechanical strength for the canister. The copper canisters are placed over 400 meter depth of stabile crystalline bedrock. The filling of the disposal hole and the disposal tunnels will prevent the groundwater flow at the canister surface slowing down the corrosion and preventing the transport of the radionuclides from the canisters.[1] Also canister locations are chosen carefully to avoid any major fracture zones where movement of the bedrock might occur.

Posiva has done the safety assessment for the disposal concept, called TURVA-2012 and comprising reports describing e.g. design basis, performance assessment and features, events and processes relevant for disposal. Also formulation of radionuclide release scenarios is presented and radionuclide transport modelling starting from canister and ending up to surface environment. The part of safety assessment, which concerns surface environment and future development, is the Biosphere Assessment.[2] It is an entire portfolio of reports, including input data, modelling and assessment results.

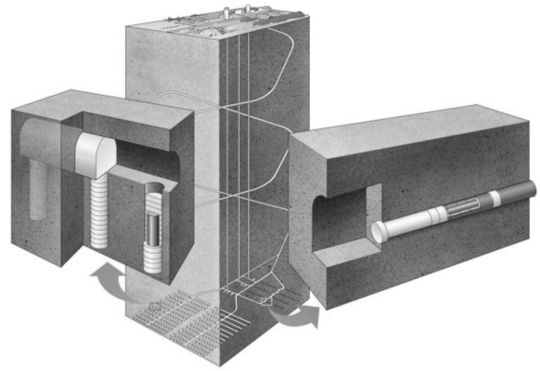

Figure 1. Two possible concepts of final disposal of spent nuclear fuel. Courtesy of SKB, Illustrator: Jan Rojmar

II. BIOSPHERE ASSESSMENT

The Biosphere Assessment portfolio describes the process and results of how the magnitude of hypothetical doses is assessed for the people living in the vicinity of the facility and who might be exposed to radiation by possibly released radionuclides from the repository.

Biosphere Assessment portfolio includes three main reports: 1) Safety case for the spent nuclear fuel disposal at Olkiluoto - Biosphere Assessment BSA-2012 (BSA-2012), 2) Safety case for the spent nuclear fuel disposal at Olkiluoto - Olkiluoto Biosphere Description 2012, and 3) Safety case for the disposal of spent nuclear fuel at Olkiluoto - Data Basis for the Biosphere Assessment 2012. There are also four biosphere assessment modelling reports: Terrain and Ecosystems Development Modelling in the Biosphere Assessment BSA-2012, Surface and Near-surface Hydrological Modelling in the Biosphere Assessment BSA-2012, Radionuclide Transport and Dose Assessment for Humans in the Biosphere Assessment BSA-2012, and Dose Assessment for Plants and Animals in the Biosphere Assessment BSA-2012.[2]

III. DOSE ASSESSMENT

The regulatory limit for the most exposed persons is 0.1 mSv/a and for other individuals significantly lower. [3] The dose assessment time frame shall be, by regulatory requirements, as long as the exposure can be estimated with sufficient reliability but for several millennia, which Posiva has considered to be 10 000 years.[4]

To be able to assess the dose from possibly released nuclides, Posiva has considered that such possible source could be originated from an undetected penetrating defect in the welding of the copper canister. This kind of defect is very unlikely but still most likely of the possible scenarios that might lead to a leakage of radioactive material and as such it is useful as a base scenario in the dose assessment.[4]

The dose assessment is a demanding modelling task which is separated into two larger modelling entities preceding actual dose calculations. At the end of modelling chain, the dose calculations are performed. The two main model entities, Terrain and ecosystem model and Radionuclide transport model are described in the following.

III.A. Olkiluoto biosphere description

The present state of Olkiluoto area is described in the *Olkiluoto biosphere description.* It contains all site specific information from land use, dietary habits and element pools and fluxes. Also history of Olkiluoto area is presented as it gives a good estimate about how terrain will evolve in the future.[5]

Biosphere description summaries all the data used in the modelling work, gathering of that data has included lots of data mining from literature, months of field work, and hundreds of analyzed samples.

Information to pools and fluxes of biomass and chemical elements has been collected from multiple intensive sampling campaigns from the reference area.

III.B. Terrain and ecosystem modelling

III.B.I Land uplift modelling

The first step to produce site specific dose assessment in a long time scale is to model the development of the terrain in the future. In Olkiluoto, one of the most determining features of terrain evolution is crustal uplift which originates from Late Weichselian glacial maximum when Fennoscandia was covered by 2.5-3 km thick ice sheet that depressed the earth's crust in the Baltic Sea region.[6]

Climate is other important feature that will affect the terrain development and land use, mainly due to the effects of sea level change. In the base scenario the climate is estimated to remain at the present state, but in variant scenarios also other possibilities including increasing carbon dioxide emissions have been taken into account.[7]

At present time, Olkiluoto is an island located at the coast of Baltic Sea, but after few millennia, because of land uplift, the shoreline has moved some kilometers and Olkiluoto is part of the inland with few lakes and rivers nearby. In Fig 2. the evolution of shoreline displacement is shown from present to assessment endpoint year 12 020. The Land uplift is based on Påsse's model which uses two arctangent functions for the isostatic rebound of the crust and the eustatic sea level adjustment. Model has been updated by Vuorela et. al. (ref. 6) with recent parameter data from Olkiluoto site.[7] In practice, terrain and ecosystem modelling is done in GIS-platform using specially developed toolbox called UNTAMO.

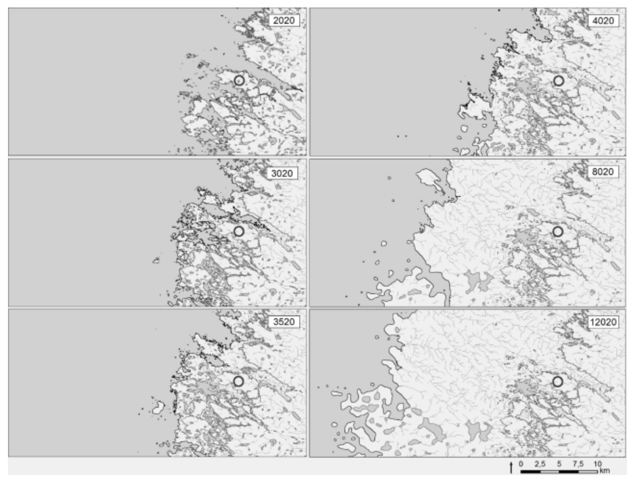

Figure 2. The whole modelling area from 2020 to year 12 020. The repository area is indicated with circle.

III.B.II Modelling of water bodies

Water bodies like lakes and rivers are modelled by conventional GIS analysis of flow accumulation. The discharge of rivers is modelled by data of site specific precipitation that ends up to the streams from the catchment area. River channel cross-section shape is dependent on the soil and sediment type.

In the model, lakes are formed when an area is deep enough that water can accumulate into it, but when the lake is shallow enough the area is identified as a peat bog. Also depending on fetch distance, water level height, flow rate and shelter from waves, growth of reed beds occur.[7]

III.B.III Modelling of peat bogs

Peat bog location is derived by the groundwater surface level and a threshold value of minimum groundwater level of 0.1m. The growth of the peat bogs is simulated by the model of Clymo et al. (ref 8) 1998 which is an old, tested model for Finnish mires. Also mires have a minimum size which is 0.5 ha and it can't grow on agricultural land.[9]

III.B.IV Modelling of erosion and sedimentation

Modelled erosion and sedimentation rates are constant which depend on land use type and surface soil type. To smoothen gyttja accumulation in reed bed boundaries, a Gaussian filter is used in reed bed accumulation.[7]

III.B.V Modelling of croplands

Location of croplands is defined by amount of solar radiation and soil type suitability. Also there are few other factors that affect the suitability of a land area to be a cropland, those are minimum area of a connected cropland, maximum groundwater table depth and minimum soil thickness.[7]

III.C. Radionuclide transport

Radionuclide transport starts from the assumed undetected defect in the canister, from where it is transported through the near field. Near field includes the canister itself, bentonite buffer, filling of the disposal tunnel and excavation-damage zone (EDZ) in the host rock. In the near field, nuclides are transported to the bedrock through the buffer by diffusion. In the bedrock, nuclides are transported in the water conductive fractures to the surface where they enter the biosphere.[10] These release locations are important input data for the dose assessment and have significant effect on the dilution of the discharge and on the doses. Few different surface locations are shown in Fig. 3; nuclides tend to surface in the shallow areas like, rivers, lakes or bay areas.[7] The release location that is selected as a reference case in biosphere modelling, is the one at the north of the current Olkiluoto island and noted as BS-RC.

III.C.I Screening of nuclides

Spent nuclear fuel contains broad range of different radionuclides, but due to functioning transport barriers of disposal system it is not necessary to include them all in the dose assessment. Solubility of the spent fuel is very low and the transport of released nuclides to the surface is significantly slowed by the different sorption and diffusion processes on the mineral fillings of the water conductive fractures. Also the water flow in the fractures is slow. These factors together cause that transport times to the biosphere for many of the nuclides are so long that by the time they have been transported to the surface, they have decayed to the level where they don't possess any threat.

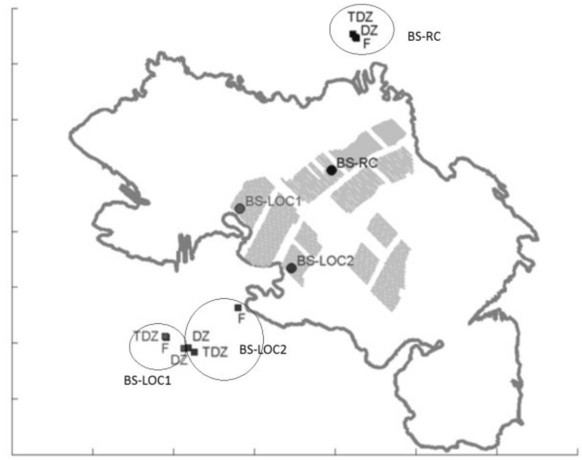

Figure 3. A dot indicates possible location of a defective canister and square discharge locations in the surface. BS-RC, BS-LOC1 and BS-LOC2 indicate different calculation cases and F-, DZ and TDZ different flow paths in the near field.

To identify possible nuclides that might still pose a threat in biosphere by radioactive decay, a two tiered screening model is used. Tier 1 is extremely conservative model where is assumed that a person is exposed for one year by inhalation, ingestion and external exposure to all activity which is released from the geosphere to biosphere in 15 millennia after the placement of the first canister. All those nuclides which induce dose less than 0.0001 mSv/year (that is a reference screening annual dose for humans) are screened out and the rest will continue to Tier 2.

In Tier 2 the nuclides screened in from Tier 1 are assumed to release from the geosphere to a lake and a well. From the lake, nuclides go to the three other modelled ecosystem types, to a forest, cropland and pasture. Also irrigation from the more exposed well or lake is used. Then the maximum dose from each exposure pathway (inhalation, external radiation, ingestion of food and water) is calculated and all those nuclides that still reach the 0.001 mSv/a screening dose limit are taken into account in the landscape modelling. These nuclides are C-14, Cl-36, I-129, Se-79, Mo-39, Nb-94 and Ag-108m.[11]

III.C.II Landscape modelling

To model transportation, accumulation and dilution of nuclides in the biosphere over long period of time, multiple complex processes are needed to consider. To control these processes in modelling, the area where nuclides might be transported is divided to biosphere objects (Fig. 4).

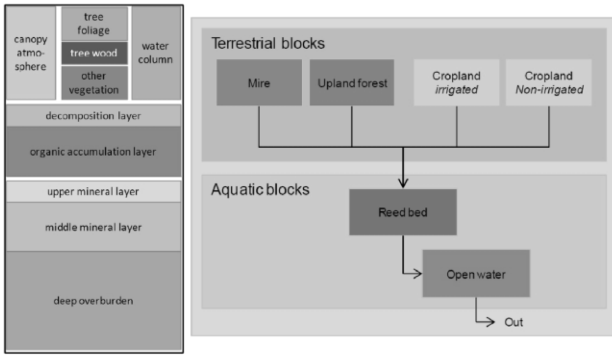

Figure 4. Biosphere object and its compartments.

Biosphere object contains all the information which is needed for the transport modelling of radionuclides. The input regarding which biotope a certain object at a certain time is, comes from the Terrain and ecosystem development model.

Considered different transport mechanisms inside an aquatic biotope object are:

- Uptake by plants from water
- Senescence of aquatic vegetation
- Advection in sediment and water
- Diffusion in sediment
- Sedimentation
- Resuspension
- Bioturbation

Considered different transport mechanisms inside a cropland and pasture biotope objects are:

- Uptake by plants from air
- Release of C-14 from soil
- Loss of C14 from air due to air exchange
- Advection in soil layers vertically and laterally
- Diffusion in soil layers
- Harvesting
- Root uptake
- Bioturbation
- Interception of radionuclides from irrigation
- Retention
- Translocation

Considered different transport mechanisms inside a forest and a wetland biotope object are:

- Gaseous uptake from air (C-14)
- Senescence
- Decomposition
- Advection
- Diffusion
- Decomposition
- Bioturbation
- Degassing (C-14)
- Root uptake
- Air exchange
- Groundwater recharge

III.C.III Object delineation

In BSA-2012 biosphere objects are chosen from the Terrain and ecosystem model results by hand considering all different possibilities of how nuclides can transport, so that only areas where nuclides can enter, are selected. Terrestrial objects can receive nuclides in three different ways:

- Irrigation
- Mass-inheritance (land uplift)
- Direct geosphere release

Any areas where nuclides might end up to are chosen, also those areas where the nuclides might end up to from those objects, via e.g. irrigation from the water source which has been contaminated from the runoff of previously contaminated irrigation. But this selection is only done once to prevent landscape model to expand too much. Also radioactivity contribution via those tertiary or further pathways would be insignificant. A single biosphere object describes a homogeneous area in certain time, e.g. lake segment which will later on fill up and end up to a cropland or a segment of a lake which will stay as a lake. Fig. 5 shows a part of resulting biosphere object delineation in the reference case (using release location BS-RC).[7]

Figure 5. Delineated biosphere objects in the reference case. Black circle indicates that biosphere object which is receiving the discharge of radionuclides.

III.D. Dose calculation

III.D.I Dose calculation for humans

Exposure pathways used in the dose calculation are food intake, water intake, inhalation of air and external radiation. Values for food energy intake and water intake are those of Reference Man from International Commission on Radiological Protection (ICRP 2002). Consumed food is produced locally as much as the area can produce and water is drunk from the local most likely sources as rivers, lakes and wells.[11]

The group of most exposed persons is considered to be 20 persons, based on ICRP recommendations for probabilistic analyses, modified for Posiva's deterministic calculations. The amount of total exposed persons is selected by current amount of people living in Eurajoki municipality, being 6000. This implies that the size of group of other exposed persons is 5980.

In Fig. 6 the annual doses to representative person from the most exposed group for reference case is shown. The doses peak in year 5020 and remain about at the same level to end of the assessment time window. Most of the dose originates from C-14 by ingestion of water at the peak year, but for most of the time, biggest contributor is food ingestion.[11]

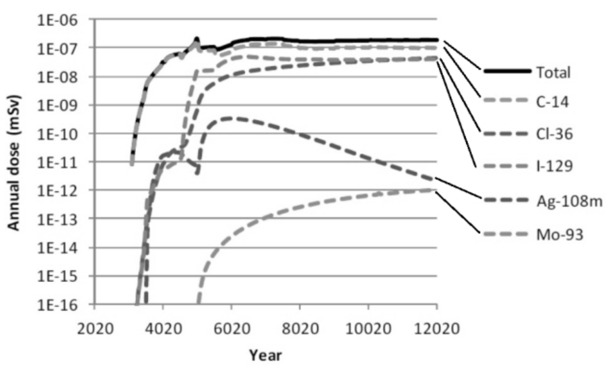

Figure 6. The annual exposure of the representative person from the most exposed group in the reference case.

Doses in the reference case for the other exposed persons are significantly lower than in the most exposed group. As for the most exposed group also the other exposed group got their doses mostly from the C-14. Other most contributing nuclides are I-129, Cl-36, Ag-108m respectively.[11]

Along with the reference case there are multiple different calculation cases with different variables from dietary habits to different radionuclide release locations (Fig. 7.). For example in calculation case VS(A)-SOUTH2, where release location is south of Olkiluoto, doses are over two magnitudes higher than in the reference case. High doses are resulting from a small lake or a pond that people use as a drinking water supply and also most exposed group eat the fish from it.[11]

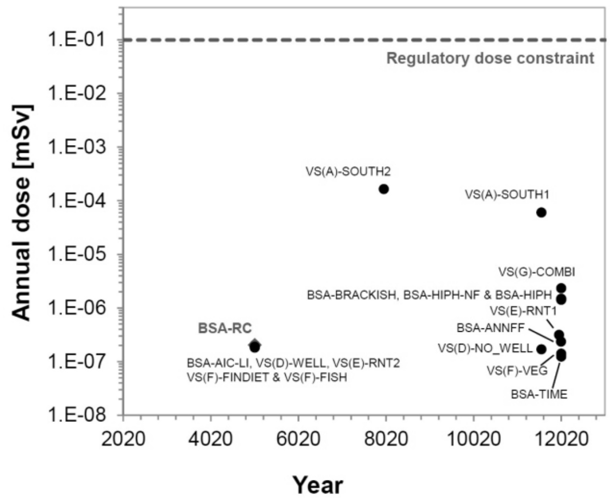

Figure 7. Maximum doses in different calculation cases for a representative person from the most exposed group.

It should be noted that transportation of C-14 in the biosphere was calculated by the specific activity model and it takes into count only released C-14 from the repository not naturally occurring C-14. [12]

III.D.II Dose for plants and animals

In YVL guides is stated that also radiation exposure to present kind of living terrestrial and aquatic populations shall be assessed. Also is stated that there should not be any decline in biodiversity or significant detriment to any living population.[13]

Dose assessment to plants and animals is based on landscape modelling and ERICA (Environmental Risks from Ionising Contaminants) tool. The tool includes Dose Conversion Coefficients (DCCs) for each reference organisms and radionuclides for external and internal exposure. With external DCCs dose absorbed from the environmental medium (soil, sediment or water) can be assessed and from the internal DCCs doses from the radionuclide concentrations within a reference organism.[13]

Representative species that were included in the assessment were chosen by following criteria[12]:

- Is it or might it populate the Olkiluoto area in the future.
- Does it have a greater exposure potential e.g. does it have soil-dwelling habits, is it occupying in groundwater discharge areas or it does not have a migratory behavior.
- Influence in the food webs.
- Is it a key stone species.
- Has it particular public interest.

- Availability of radionuclide transport data from the literature or from the site studies.

In the reference case the most exposed species is Pike which absorbed dose rate is 2.56 μGy/h and dominating radionuclide is C-14 in the organism itself. Biggest dose rates for plants and animals will occur in DS(D)-HABITAT (Fig. 8.), where plants and animals are thought to occupy the most contaminated area.[13]

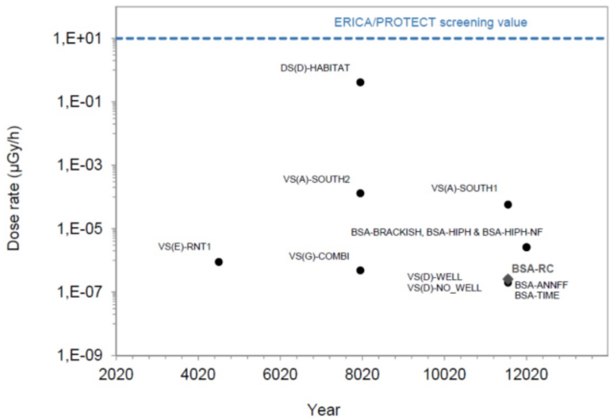

Figure 8. Absorbed dose rate maxima to the most exposed representative species in different calculation cases. For details, see (*Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto -Dose Assessment for Plants and Animals in BSA-2012)*

IV. CONCLUSIONS

Posiva has done a safety assessment for the repository for final disposal of spent nuclear fuel which includes a biosphere assessment. Possible doses arising from the hypothetical discharge of radioactive material from the repository are calculated.

According to the biosphere assessment, all regulatory requirements considering the situation after the closure of the repository are filled and no harm to the future generations will happen. Also radiation levels for plants and animals will stay at the level where any detrimental effect to the populations will not happen.

In biosphere assessment multiple different scenarios have been used to assess the long term safety of the repository. In all those cases doses are few or multiple orders of magnitude below the regulatory limit of 0.1 mSv/a which is only 4,2 % (ref. 14) of the average annual naturally induced dose worldwide.

At the moment Posiva is updating the safety assessments for operational license application. With that the biosphere assessment will be updated with new model parameters, new site oriented information, new calculation cases and an additional inventory of radionuclides from low and intermediate level repository.

ACKNOWLEDGMENTS

Work shortly summarized here was done as a part of Posiva's construction license application for construction of the repository of final disposal of spent nuclear fuel. All reports included in the safety assessment can be found from www.posiva.fi.

REFERENCES

1. Posiva Oy, *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto - Design Basis 2012*, p 54, Posiva Oy, Eurajoki, Finland (2012).

2 Posiva Oy, *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto - Biosphere Assessment 2012*, pp 21-22, Posiva Oy, Eurajoki, Finland (2013).

3. The Radiation and Nuclear Safety Authority (STUK), *Regulatory Guides on Nuclear Safety (YVL)*, YVL D.5 3.2, STUK, Helsinki, Finland (2013).

4. Posiva Oy, *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto - Synthesis 2012*, pp 7, 15; Posiva Oy, Eurajoki, Finland (2012).

5. Posiva Oy, *Olkiluoto Biopshere Description*, pp 233-234, Posiva Oy, Eurajoki, Finland (2013).

6. A. Vuorela, T. Penttinen, A.-M. Lahdenperä, *Review of Bothnian Sea Shore-Level Displacement Data and Use of a GIS Tool to Estimate Isostatic Uplift*, p 7, Working Report 2009-17, Posiva Oy, Eurajoki, Finland (2009).

7. Posiva Oy, *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto Terrain and Ecosystems Development Modelling in the Biosphere Assessment BSA-2012*, pp 65-69, 73-81, 94-95, 183-184; Posiva Oy, Eurajoki, Finland (2013)

8. R.S Clymo, J. Turunen, K. Tolonen, The limits to peat bog growth, *Philosophical Transactions of Royal Society*, 303B, 368-388 (1984)

9. Posiva Oy, *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto - Data Basis for the Biosphere Assessment BSA-2012*, pp 469-476 , Posiva Oy, Eurajoki, Finland (2014).

10. Posiva Oy, *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto -Assessment of Radionuclide Release Scenarios for the Repository System 2012*, pp 136-140, Posiva Oy, Eurajoki, Finland (2012).

11. Posiva Oy, *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto -Radionuclide Transport and Dose Assessment for Humans in the Biosphere Assessment BSA-2012*, pp 39-45, 50-51, 140, 157-163, 206; Posiva Oy, Eurajoki, Finland (2014)

12. R. Avila and G. Pröhl, *Models Used in the SFR1 SAR-08 and KBS-3H Safety Assessments for Calculation of C-14 Doses*, pp 7, Working Report 2007-107 Posiva Oy, Eurajoki, Finland (2008).

13. Posiva Oy, *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto -Dose Assessment for Plants and Animals in BSA-2012*, pp 29-31, 39, 62 91, 128; Posiva Oy, Eurajoki, Finland (2014)

14. United Nations Scientific Committee on The Effects of Atomic Radiation (UNSCEAR), *Sources and effects of Ionizing Radiation- Annex B:Exposures of the Public and Workers from Various Sources of Radiation,* p 322, United Nations, New York, USA (2010)