Technical Report

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Final disposal of fuel – electron radiation outside copper canister

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Summary

Gamma radiation intensity outside a copper canister in the final repository was earlier calculated. The gamma radiation fields were calculated with straight-forward point-kernel technique, and the corresponding dose rates were estimated by use of standard conversion factors gamma flux to dose rate. It has, however, been discussed how accurate the previous calculation model determines the dose rate in the water in the bentonite layer close to the copper surface. The actual local dose rate is determined by the flux of secondary electrons at the copper surface. This flux also constitute a current through the surface, which perhaps affects the corrosion of the copper material. The material combination at the surface, copper followed by bentonite and water, may locally affect the flux of secondary electrons.

New calculations, using coppled photon and electron transport theory, have been performed in order to estimate the flux of electrons at the surface. These calculations are presented in this report.

The following main conclusions are drawn:

- Calculated gamma radiation dose rate outside the copper canister is compared to the calculated dose rate from secondary electrons. The two determinations result in rather similar dose rate levels. The results show, that the influence of the local conditions at the surface is rather small, and that the radiation dose to water outside the copper surface is reasonably well determined by the gamma dose rate.
- The secondary electrons means a net current leaving the copper canister. The current density is, however, very small compared to naturally occurring currents due to corrosion processes.

Contents

1 Introduction

Gamma radiation intensity outside a copper canister in the final repository was earlier calculated /1/. The gamma radiation fields were calculated with straight-forward point-kernel technique, and the corresponding dose rates were estimated by use of standard conversion factors gamma flux to dose rate.

It has been discussed how accurate the previous calculation model determines the dose rate in the water in the bentonite layer close to the copper surface. The actual local dose rate is determined by the flux of secondary electrons at the copper surface. This flux also constitute a current through the surface, which perhaps affects the corrosion of the copper material. The material combination at the surface, copper followed by bentonite and water, may locally affect the flux of secondary electrons.

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2 Calculation model

The Monte Carlo code MCNP4C /2/ has been used for the calculations. The geometrical model is based on the earlier calculations /1/, and comprises 12 BWR fuel bundles. The model is shown in Figure 2-1, and is further commented below.

The MCNP model includes the following cell areas:

1. 12 BWR fuel assemblies. Each assembly is homogenised and is assumed to fill the holes in the cast-iron structure (BxB = 15.6x15.6 cm^2). Materials data for the assembly is taken from /1/.
2. The fuel assemblies are encompassed in a cast-iron cylinder, with density 7100 kg/m^3 and other diameter 95 cm.
3. The cast-iron is surrounded by a 50 mm thick copper canister, density 8930 kg/m^3.
4. The copper cansister is surrounded by bentonite (57%) plus water (43%), with average density 2000 kg/m^3.

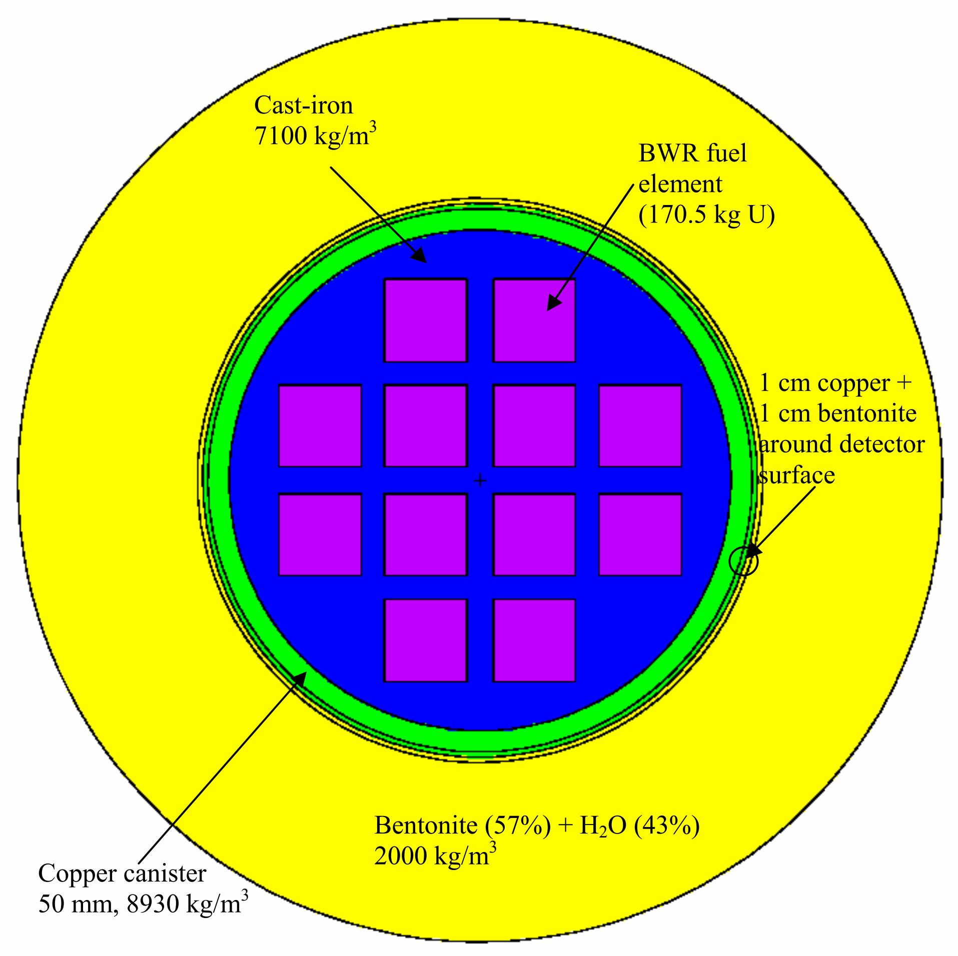

***Figure 2-1**. MCNP model for copper canister containing 12 BWR fuel elements.*

Note that 1 cm layers of copper and bentonite plus water are separately treated at the boundary between the materials. The reason for these extra regions is that the calculation of secondary electrons are restricted to that area. A total active length of 3.68 m is assumed, and all photons and electrons outside that length is killed in the calculation.

The same gamma source term as the reference case in /1/ is used, which represents BWR fuel with burnup 38 MWd/kgU and a decay period of 30 years. The used source term and energy group structure is presented in Table 2-1. A flat source term distribution in the axial direction is assumed.

The following detector representations are included in the calculation:

1. Average photon flux recalculated to gamma dose rate at the copper/bentonite boundary.

2. Total current of electrons through the copper/bentonite boundary.

3. Average electron flux at the copper/bentonite boundary.

Totally 5 million source photons were started in the calculation. Significant multiplication of photons reaching the detector areas was used in order to reduce the variance. A statistical accuracy of typically ±5% for the total detector response was obtained, which was judged adequate.

Table 2-1. Gamma source term in spent BWR fuel (38 MWd/kgU, decay 30 y /1/).

E_min [MeV]	E_max [MeV]	Photons/ kgU/s
0.075	0.15	1.25E+11
0.15	0.2	1.02E+11
0.2	0.51	1.07E+11
0.51	0.8	2.25E+12
0.8	1.5	3.62E+10
1.5	1.66	1.81E+09
1.66	2	4.16E+07
2	2.5	5.77E+04
2.5	3	6.92E+05
3	3.5	1.20E+04
3.5	4	6.97E+03
4	4.5	4.04E+03
4.5	5	2.35E+03
5	6	2.12E+03

3 Calculation results

3.1 Gamma

The resulting average gamma dose rate at the copper/bentonite boundary is presented in Table 3-1. The calculated photon flux is recalculated to gamma dose rate by use of standard conversion factors proposed in MCNP4C /2/. The calculated about 100 mGy/h agrees quite well with the radiation levels presented in /1/. Note that the present result represents the average dose rate over the total copper/bentonite boundary, while the results in /1/ represent dose rates in two certain location on the copper surface. Note that the maximum radiation level in /1/ is about a factor of five higher than the calculated average over the surface.

Table 3-1. Calculated average gamma dose rate radial outside copper shield (Total copper surface: 12.1 m^2).

E_max [MeV]	γ_DR [mGy/h]	Err. [%]
0.01	1.35E-01	34.6%
0.1	2.76E+00	5.9%
0.5	5.93E+01	3.8%
1	3.30E+01	5.2%
2	3.87E+00	5.8%
3	9.03E-04	14.6%
5	4.29E-05	16.1%
6	5.71E-06	31.2%
total	**9.90E+01**	**3.9%**

3.2 Electrons

The calculated flow of secondary electrons out from the copper surface, and the correspon-ding average current density, is shown in Table 3-2. The current density seems to be very small compared to naturally occurring current densities due to corrosion phenomenon.

Table 3-2. Calculated average flow of electrons through copper surface (Total copper surface: 12.1 m^2).

E_max [MeV]	Electrons through surface [e/s]	Current [A/m2]	Err. [%]
0.01	9.31E+07	1.23E-12	22.00%
0.1	1.07E+09	1.41E-11	6.81%
0.3	1.15E+09	1.51E-11	5.57%
1	4.38E+08	5.78E-12	6.62%
3	6.66E+06	8.79E-14	10.65%
6	3.36E+02	4.43E-18	9.11%
total	**2.75E+09**	**3.63E-11**	**4.34%**

The calculated average flux of secondary electrons at the copper surface is presented in Table 3-3. The electron flux is recalculated to radiation dose to water at the copper surface from stopping power calculated with the ESTAR code /3/, see Figure 3-1. The calculated average electron dose rate, about 150 mGy/h, is comparable to the calculated average gamma dose rate of about 100 mGy/h, see Table 3-1. Note that these dose rates should not be added, but is in principal two different calculations of the same dose rate. The reason for performing the calculation of contribution from secondary electrons is a better representation of the local material conditions at the copper/bentonite interface. The calculation results show, however, that the two different assessments of radiation dose are very close to each other.

Table 3-3. Calculated average flux of electrons and electron dose rate at copper surface (Total copper surface: 12.1 m^2).

E_max [MeV]	Electron flux [e/cm2/s]	electron_ DR] [mGy/h	Err. [%]
0.01	1.29E+03	1.74E+01	24.32%
0.1	1.73E+04	8.85E+01	8.60%
0.3	2.04E+04	3.77E+01	9.26%
1	7.68E+03	9.43E+00	10.60%
3	7.99E+01	8.13E-02	11.75%
6	3.88E-03	3.97E-06	10.60%
total	**4.68E+04**	**1.53E+02**	**5.98%**

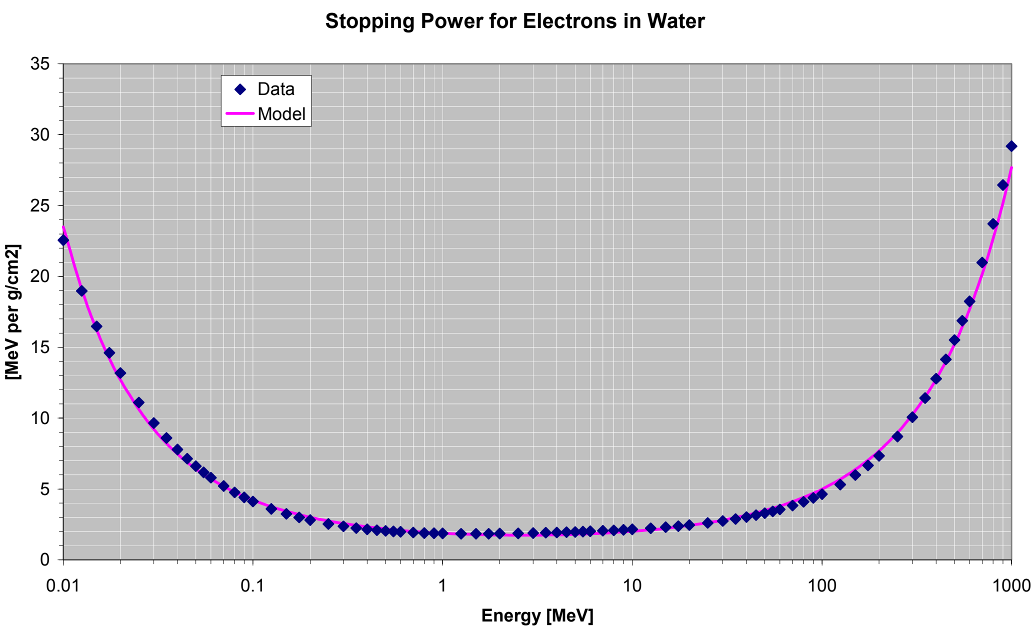

***Figure 3-1**. Stopping power for electrons in water calculated with the ESTAR code /3/ (Calculated data points and least-square fit).*

4 Discussion and summary

- Calculated gamma radiation dose rate outside the copper canister is compared to the calculated dose rate from secondary electrons. The two determinations result in rather similar dose rate levels. The results show, that the influence of the local conditions at the surface is rather small, and that the radiation dose to water outside the copper surface is reasonably well determined by the gamma dose rate.
- The secondary electrons means a net current leaving the copper canister. The current density is, however, very small compared to naturally occurring currents due to corrosion processes.

5 References

/1/ Klas Lundgren,
”*Kontroll av strålskärmsberäkningar för kopparkapsel*”,
ALARA Engineering Rapport 97-0028R (oktober 1998).

/2/ ”*MCNP4C – Monte Carlo N-Particle Transport Code System*”,
Oak Ridge National Laboratory CCC-700/MCNP4C (July 2000).

/3/ M J Berger, ”*ESTAR, PSTAR, and ASTAR: Computer programs for calculating stopping-power and range tables for electrons, protons, and helium ions*”,
U.S. Department of Commerce, NISTIR 4999 (December 1992).

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