Development and application of models for the safety analysis of repositories with regard to the clearance of radioactive materials for landfilling

D. Weiss, A. Artmann, J. Larue, R. Roloff, H. Seher

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH

Abstract:

This paper describes the results of an assessment of the radiological impact of the disposal of Very Low Level Waste (VLLW) from NPP decommissioning on landfills without mixing with conventional wastes. The transport of pollutants by unsaturated water flow using the van Genuchten approach for saturated/unsaturated porous media was calculated with the programs SiWaPro DSS and SPRING. The release of the considered radionuclides from the waste body as well as the retardation inside the landfill is modelled by the so called two-site model and with the K_d-concept using K_d-values (distribution coefficients), where the K_d-values are an expression of inherent mobility of chemicals in soil. The models of the landfills, inert (German “Deponieklasse” DK 0), non-hazardous (DK I) and hazardous (DK II) are constructed on basis of relevant German technical standards. As radionuclides in a typical waste from decommissioning of nuclear facilities Ni-63, Sr-90, Cs-137, Pu-238, Pu-239/240, Am-241 and Uranium are considered.
The calculations show that only small concentrations of Uranium, Ni-63, Sr-90, Pu-238 and Pu-239/240 penetrate through the ground of an inert landfill. For all landfill types no release of Cs-137 and Am-241 is observed. The threshold of 10 µSv/a for a member of the public will not be exceeded in the long term.

1 INTRODUCTION

As a result of the German decision to phase out nuclear power, large quantities of Very Low Level Waste (VLLW) from NPP decommissioning are expected in the near future. In line with German legislation on radiation protection, such waste has recently been disposed of on landfills together with conventional waste as exempt waste. This will lead to a shortage of capacity of these landfills in the near future. Moreover, the landfill operators refuse more and more to accept exempt waste from the decommissioning of nuclear facilities. The specific activities for clearance for landfill disposal are given in the German Radiation Protection Ordinance /STV 08/. They were derived on the basis of an exposure of 10 µSv/a and based on defined mixing ratios with conventional waste.
Subsequently, GRS was asked by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) to assess the radiological impact of the disposal of such waste on landfills without mixing with conventional wastes.

2 TASKS AND OBJECTIVES

The assessment of the radiological impact of the disposal of such waste on landfills without mixing with conventional wastes is based on several requirements and assumptions:

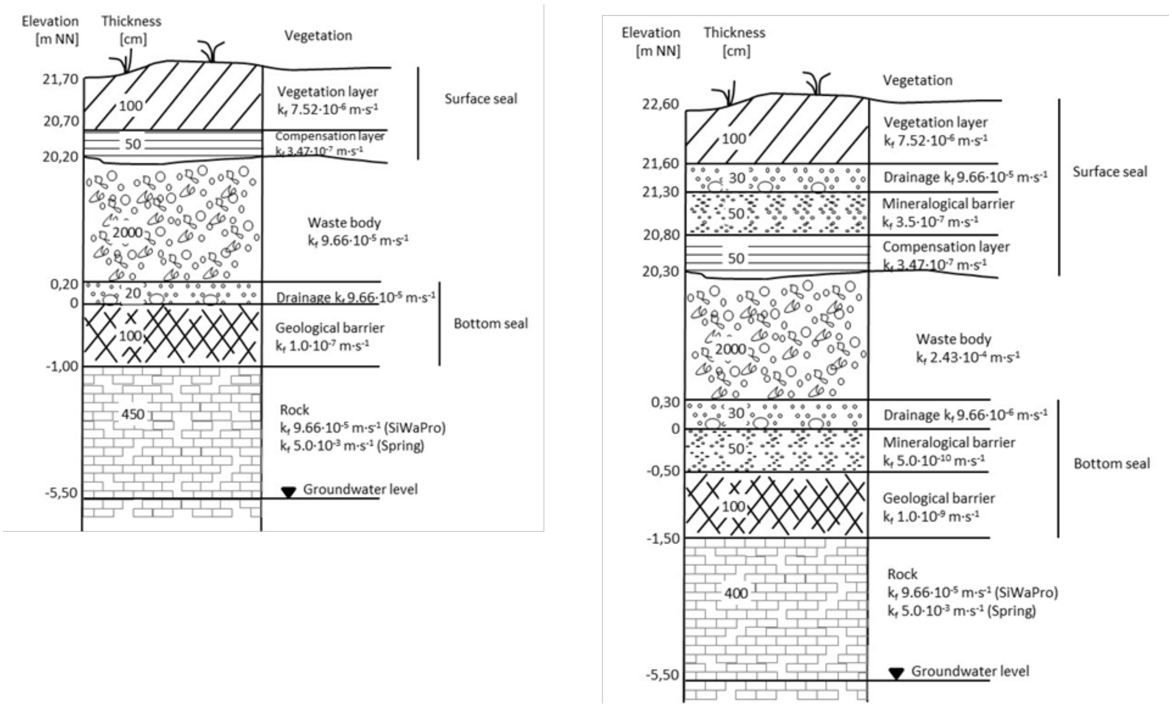
(1) The landfills are constructed on basis of relevant German technical standards. This requires a separate assessment for inert landfills (German “Deponieklasse” DK 0), non-hazardous landfills (DK I) and hazardous landfills (DK II).

(2) As radionuclides in a typical waste from decommissioning of nuclear facilities Ni-63, Sr-90, Cs-137, Pu-238, Pu-239/240, Am-241 and Uranium are considered.
(3) The migration of these radionuclides from the waste itself (source term) and the transport of the leachate in the groundwater from the landfill site are modelled for a period of some 100 years to meet the threshold of 10 µS/a for a member of the public.
(4) The pollutant release from the waste and the migration through technical barriers is predictably modelled by SiWaPro DSS /KPI 07/.

In addition the groundwater transport code SPRING /DEL 10/ is used to calculate the spreading of pollutants in groundwater.
SiWaPro DSS is a commercial available tool for predictable leachate calculations. It was developed in a project of the German Federal Ministry of Education and Research (BMBF). SiWaPro DSS only considers the transport inside the landfill until the pollutant reaches the groundwater body and was used to show the applicability for longer timespans of some 100 years. The radioactive decay of a radionuclide can be considered using a degradation function. SPRING is a well-known code for long term safety calculations on regional scales in the saturated and unsaturated zone. Within a special SPRING-package the transport of a full decay series can be considered. However in the presented calculations only uranium without decay within the observation time of some 100 years is used.

2.1 Landfill design

For the assessment of the three landfill types different soil profiles for inert (DK 0), Non-hazardous (DK I) and hazardous (DK II) landfills were developed by /SEH 11/. Figure 1 represents the soil profile of an inert landfill DK 0 (left) und for a Non-hazardous landfill DK I (right). A Non-hazardous (DK I) and a hazardous (DK II) landfill differ only in the absence of a bitumen layer or plastic liner in the mineralogical barrier of the bottom seal. The parameters are listed in the tables 1 and 2. Calculations for hazardous landfills were not made, but scenarios for a possible release could be derived from the results of the Non-hazardous landfill. The thickness and coefficients of hydraulic conductivity (k_f-values) of the bottom seals are taken from the specifications given in the German Disposal Ordinance /DepV 09/.



Inert landfill Non-hazardous landfill

Fig. 1 Soil profile of an inert landfill (DK) 0 (left) /SEH 11/ and for a Non-hazardous landfill DK I (right)

Tab. 1 Soil physical parameters used to model an inert landfill (DK 0)

No.	Layer	Thickness [m]	ϕ	$\theta_{w,r}$	α [1/m]	n	k_f [$m \cdot s^{-1}$]
1	Vegetation layer	1	0,41	0,04	6,743	1,28	$7{,}52 \cdot 10^{-6}$
2	Compensation layer	0,5	0,43	0	0,837	1,08	$3{,}47 \cdot 10^{-7}$
3	Waste body	20	0,39	0,03	3,022	2,38	$9{,}66 \cdot 10^{-5}$
4	Drainage layer	0,2	0,39	0,03	3,022	2,38	$9{,}66 \cdot 10^{-5}$
5	Geol. barrier	1	0,42	0	2,670	1,11	$1{,}0 \cdot 10^{-7}$
6	Rock	4	0,39	0,03	3,022	2,38	$9{,}66 \cdot 10^{-5}$

porosity ϕ, residual water content $\theta_{w,r}$, scale factor α, slope factor n und coefficient of hydraulic conductivity k_f.

Tab. 2 Soil physical parameters used to model an non-hazardous landfill (DK I)

No.	Layer	Thickness [m]	ϕ	$\theta_{w,r}$	α [1/m]	n	k_f [$m \cdot s^{-1}$]
1	Vegetation layer	1,0	0,41	0,04	6,743	1,28	$7{,}52 \cdot 10^{-6}$
2	Drainage layer	0,3	0,39	0,03	3,022	2,38	$9{,}66 \cdot 10^{-5}$
3	Mineralogical barrier	0,5	0,43	0	0,837	1,08	$3{,}50 \cdot 10^{-7}$
4	Compensation layer	0,5	0,43	0	0,837	1,08	$3{,}47 \cdot 10^{-7}$
5	Waste body	20	0,39	0,03	3,022	2,38	$2{,}43 \cdot 10^{-4}$
6	Drainage layer	0,3	0,39	0,03	3,022	2,38	$9{,}66 \cdot 10^{-5}$
7	Mineralogical barrier	0,5	0,43	0	0,837	1,08	$5{,}0 \cdot 10^{-10}$
8	Geol. barrier	1,0	0,42	0	2,670	1,11	$1{,}0 \cdot 10^{-9}$
9	Rock	4,0	0,39	0,03	3,022	2,38	$9{,}66 \cdot 10^{-5}$

porosity ϕ, residual water content $\theta_{w,r}$, scale factor α, slope factor n und coefficient of hydraulic conductivity k_f.

2.2 Processes to be modelled

The two programs SiWaPro DSS and SPRING can calculate the transport of pollutants by unsaturated water flow using the van Genuchten approach for saturated/unsaturated porous media. The release of the considered radionuclides from the waste body as well as the retardation inside the landfill is modelled by the so called two-site model of /SIM 94/ and with the K_d-concept using the K_d-values (distribution coefficients; they describe the sorptive behaviour in of chemicals soil and are an expression of their inherent mobility) given in table 3. The two-site model acounts for two surface sites where the sorption is rate and equilibrium controlled. For the equilibrium controlled sites the K_d-concept is used.

Tab. 3 Sorption coefficients of radionuclides /THI 04/

Element	K_d - waste body [l/kg]	K_d - barrier [l/kg]	K_d - soil [l/kg]	K_d - aquifer [l/kg]
Ni	10	10	1	0,1
Sr	1	10	0,1	0,1
Cs	10	100	10	1
U	10 / 235	10	1	0,1
Pu	10	10	1	0,1
Am	100	1000	100	10

2.3 Model parameters

As groundwater recharge a rate of 0.2 m/a is considered for the area of the landfill site. As comparison the groundwater recharge with respect to the landfill operations is taken from /THI 04/ (figure 2). The increase in groundwater recharge after the surface seal of the landfill is not functional anymore is linear or instantaneous.

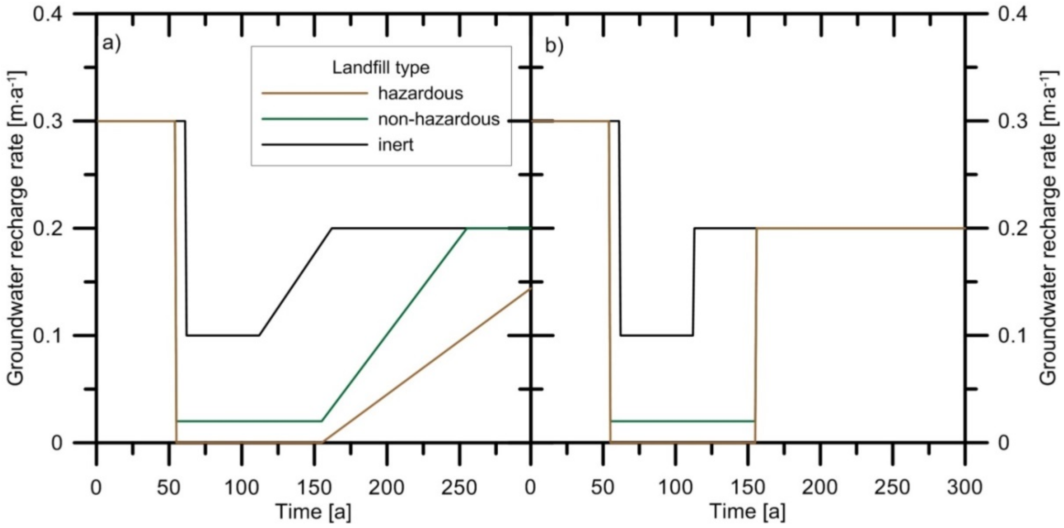


Fig. 2 Groundwater recharge for different land fill types with a linear increase (a) and an instantaneous increase (b) /THI 04/

2.3.1 Implementation for program codes

The landfill designs for a DK 0 and DK I are modelled as columns from the surface to the groundwater level in SiWaPro DSS.
For SPRING a regional model was built with a non-flow boundary in the south and west as well as a river in the north and east. A lake, a stream and three extraction wells are also present (figure 3). The landfill model is the same as given in figure 1 for SiWaPro DSS but extended to 3D (see figure 4).

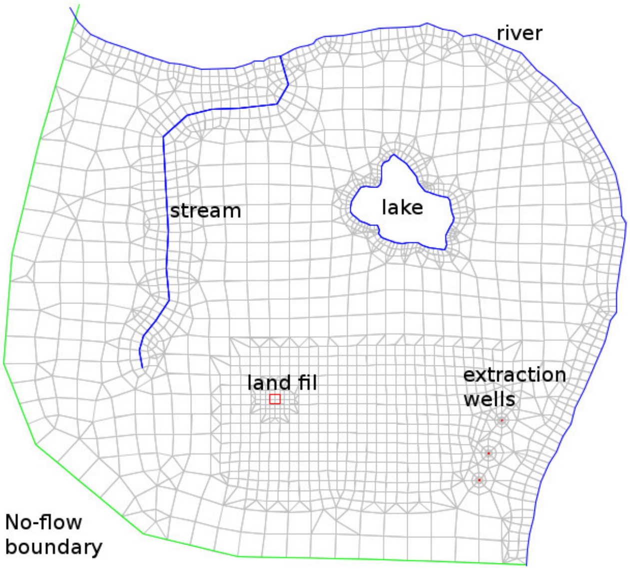


Fig. 3 Regional model for SPRING

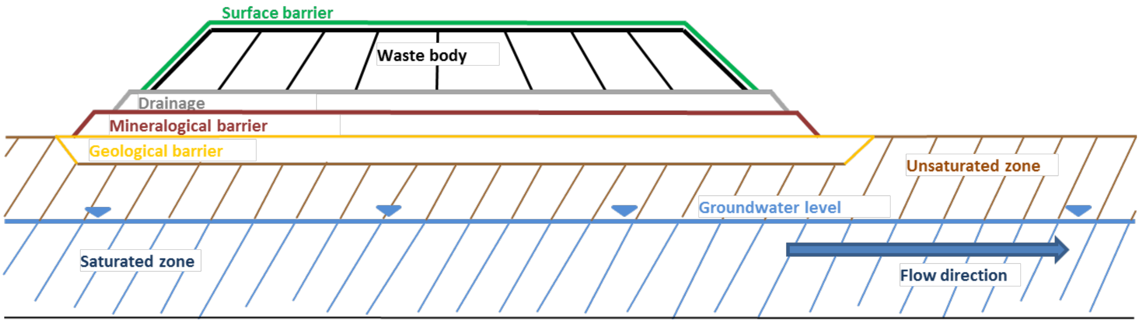


Fig. 4 Structure of the land fill model used in SPRING

3 SIMULATION OF POLLUTANT RELEASE AND MIGRATION THROUGH TECHNICAL BARRIERS

In the calculations with SiWaPro DSS a release of Uranium, Ni-63, Sr-90, Pu-238 and Pu-239/240 observed. As an example the concentration and mass flow of Sr-90 is presented in figure 5. The highest concentration is reached after 100 years. The decrease in concentration and mass flow can be explained by a radioactive decay with a half-live of 28,64 years.

No release of Cs-137 and Am-241 is observed in a time span of 800 years.

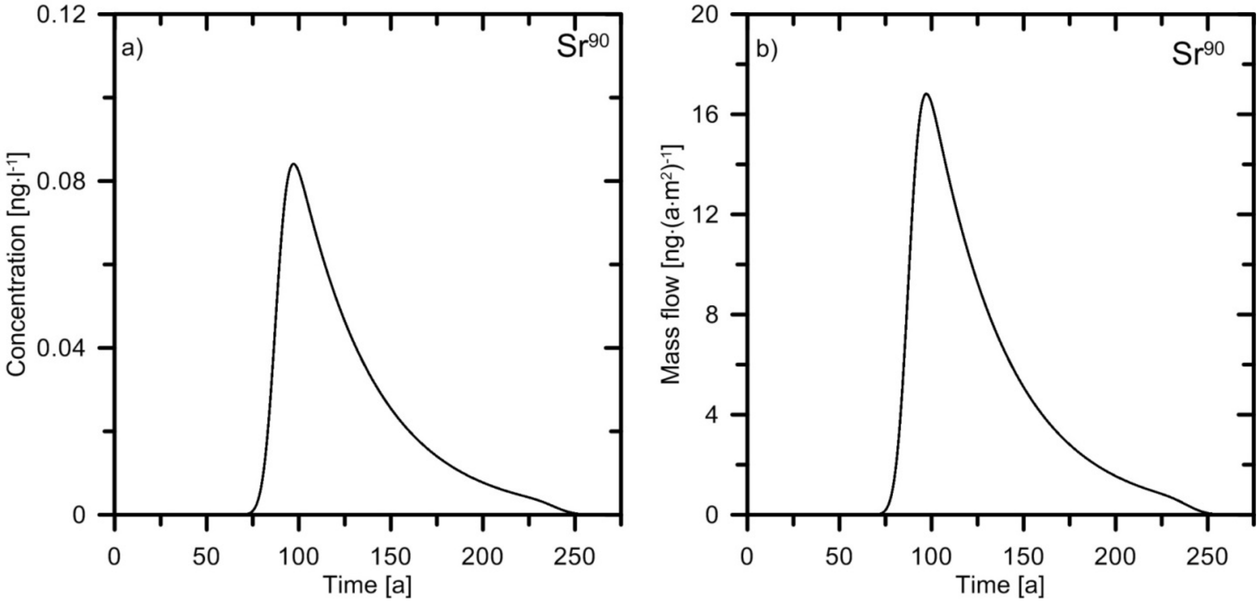


Fig. 5 Concentration and mass flow of Sr-90 from an inert landfill at the unsaturated/saturated zone interface

The calculations with SPRING only considered Uranium as non-decaying radionuclide. A release is observed for inert and non-hazardous landfill bodies within 800 years. For both landfills, inert and non-hazardous, a fully saturated water body is modelled above the bottom seal as shown in figure 6 and figure 7. Due to the low permeability inside the bottom seal the water transport is hindered. Above the bottom seal a drainage layer dewaters the landfill body to the sites where the water is treated during the observation period. Underneath the bottom seal the soil is unsaturated until the groundwater body is reached.

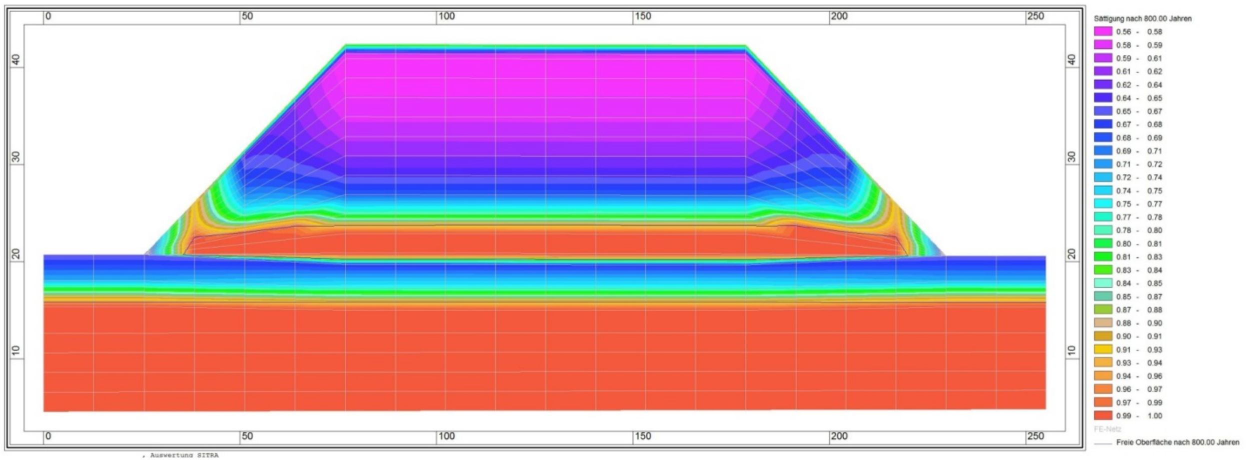


Fig. 6 Saturation of inert landfill body after 800 years

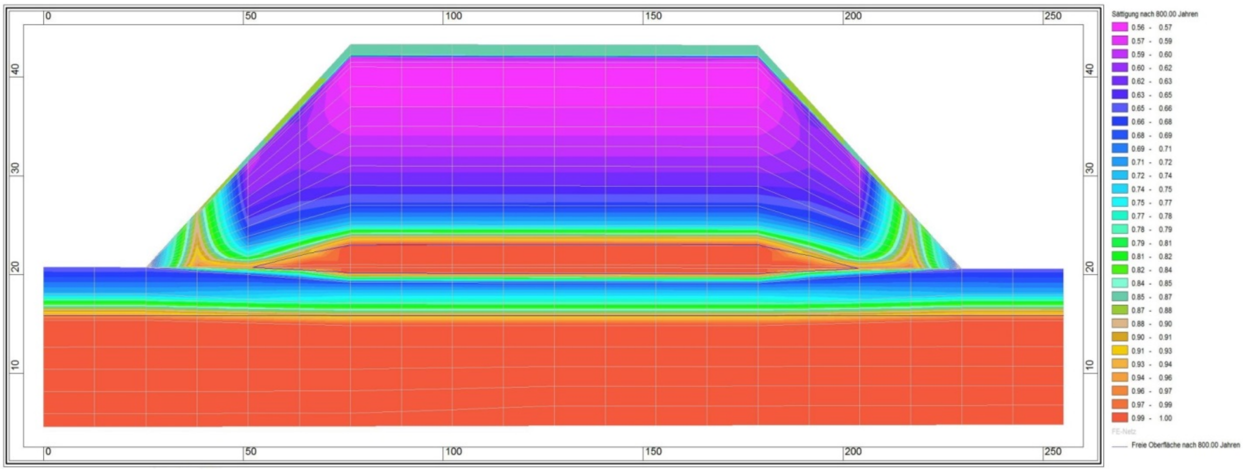


Fig. 7 Saturation of non-hazardous landfill body after 800 years

3.1 Preliminary results

Only a small concentration of Uranium, Ni-63, Sr-90, Pu-238 and Pu-239/240 penetrates through the ground of an inert landfill without technical barriers. For non-hazardous landfills and hazardous landfills with technical barriers, the mass transport is lowered by a factor of 10. However a breakthrough can still be modelled. For all landfill types no release of Cs-137 and Am-241 is observed.

4 CONCLUSIONS AND PERSPECTIVE

The threshold of 10 µSv/a for a member of the public will not be exceeded in the long term if VLLW from NPP decommissioning is disposed of on non-hazardous landfills (DK I) and hazardous landfills (DK II) constructed on the basis of German technical standards for conventional landfills.
There are still some open questions to be answered in follow-up studies, e.g. on the licensing conditions, inclusion of further relevant long-lived radionuclides, the dose limit for landfill workers, and the radiological consequences of possible inadvertent intrusions at the site.
The presented calculations don't include an uncertainty analysis. Some parameters (e.g. thickness and k_f-values of landfill bottom seals) are given by Ordinances where the value is taken as fixed. For other parameters (e.g. sorption K_d-values and rates) the exact values are not known. Therefore the K_d-value in the waste body is varied for Uranium between 10 and 235 l/kg (see table 3) but the results are not presented here. Further parameter variations could be performed in follow-up studies.

5 LITERATURE

/DEL 10/ Delta h: Spring 4.0 - Benutzerhandbuch. Delta h: Witten, 2010.

/DepV 09/ Deponieverordnung (DepV) vom 27. April 2009 (BGBl. I S. 900), zuletzt geändert am 24. Februar 2012 (BGBl. I S. 212).

/KPI 07/ KP Ingenieurgesellschaft für Wasser und Boden mbH, TU Dresden, Institut für Abfallwirtschaft und Altlasten: BMBF-Förderschwerpunkt „Sickerwasserprognose": SiWaPro DSS - Entwicklung eines computergestützten Beratungssystems zur Sickerwasserprognose. Gemeinsamer Schlussbericht. KP Ingenieurgesellschaft für Wasser und Boden mbH, TU Dresden, Institut für Abfallwirtschaft und Altlasten, 2007.

/SEH 11/ Seher, H., Larue, J., Weiß, D.: Auswahl und Eignungsprüfung herkömmlicher Deponiemodelle für längere Betrachtungszeiträume. GRS Bericht zum AP 3 des Vorhabens 3610S50004 "Anwendung und (Weiter)-entwicklung von Modellen für Endlagersicherheitsanalysen auf die Freigabe radioaktiver Stoffe zur Deponierung", Gesellschaft für Anlagen und Reaktorsicherheit (GRS) mbH: GRS-Köln, August 2011.

/SIM 94/ Šimůnek, J., Vogel, T., van Genuchten, M. T.: The SWMS_2D code for simulating water flow and solute transport on two-dimensional variably saturated media, Version 1.1. Research Report No. 132, U.S. Slinінity Laboratory, USDA, ARS: Riverside, Ca, 1994.

/STV 08/ Verordnung über den Schutz vor Schäden durch ionisierende Strahlen (Strahlenschutzverordnung - StrlSchV), in der Fassung vom 20. Juli 2001 (BGBl. I S. 1714; 2002 I S. 1459), zuletzt geändert durch Artikel 2 des Gesetzes vom 29. August 2008 (BGBl. I S. 1793).

/THI 04/ Thierfeldt, S., Wörlen, S.: Spezifische Fragestellungen für die Fortentwicklung von Datensätzen für die Freigrenzen, Freigabe von Oberflächenkontaminationen. Fortentwicklung des radiologischen Modells für die Berechnung von Freigabewerten für die Freigabe zur Beseitigung. Endbericht zu AP2/AP3 des BMU Vorhabens StSch 4279 - BS-Nr. 0107-01, 233 Seiten, Brenk Systemplanung: Aachen, 2004.