SKBF TECHNICAL REPORT
KBS
83-73

Uranium, thorium and radium in soil and crops — Calculations of transfer factors

Sverker Evans
Studsvik Energiteknik AB
Åke Eriksson
Swedish University of Agricultural Sciences

Sweden June 1983

SVENSK KÄRNBRÄNSLEFÖRSÖRJNING AB / AVDELNING KBS
Swedish Nuclear Fuel Supply Co/Division KBS
MAILING ADDRESS: SKBF/KBS, Box 5864, S-102 48 Stockholm, Sweden
Telephone 08-67 95 40

URANIUM, THORIUM AND RADIUM IN SOIL AND CROPS

- Calculations of transfer factors

Sverker Evans
Studsvik Energiteknik AB

Åke Eriksson
Swedish University of Agricultural Sciences,
Dept of Radioecology

Sweden June 1983

A list of other reports published in this series during 1983 is attached at the end of this report. Information on KBS technical reports from 1977-1978 (TR 121), 1979 (TR 79-28) 1980 (TR 80-26), 1981 (TR 81-17) and 1982 (TR 82-28) is available through SKBF/KBS.

Objekt nr 16.410

SKBF/KBS

Sverker Evans*)
Åke Eriksson*)

URANIUM, THORIUM AND RADIUM IN SOIL AND CROPS
- Calculations of transfer factors

ABSTRACT

The distribution of the naturally occuring radionuclides uranium, thorium and radium in soil, plant material and drainage water was evaluated. The plant/soil concentration factors showed that very small fractions of the nuclides were available for the plants. The water/soil concentration factors were calculated; the nuclide content in drainage water generally indicated very low leaching rates. The distribution of the radionuclides was utilized with the aim to obtain reliable concentration factors which in turn could be used to calculate the transfer of nuclides within the agricultural ecosystem. Dose calculations were performed using plant/soil concentration factors based on geometric mean values.

*) Swedish University of Agricultural Sciences,
Dept. of Radioecology

Approved by

Kristina Eyllander

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

1 INTRODUCTION

The dator code BIOPATH has been used to simulate the dynamic exchange of radionuclides within the biosphere /1/. Generally, these elements were assumed to reach the soil surface from a repository by the circulation of contaminated groundwater. Earlier calculations /2/ showed that a large part of the calculated total dose contribution to the critical group was derived from radium and uranium which entered the soil-plant food pathway. However, the reliability of the dose calculations was dependent upon the model design with regard to exposure pathways, selection of data and the introduction of approximations. The turnover rates of elements within the soil compartment and their subsequent transport to the crops and pasture were assessed using data obtained in other countries. Data valid for Swedish conditions concerning the exchange between water, soil and plant material and its dependence upon environmental factors were thus urgently needed.

The transport and accumulation of naturally occurring radionuclides in soil and plant material have been studied by the Department of Radioecology, the Swedish University of Agricultural Sciences /3/. At 37 sites on agricultural lands in and around the uranium mineralization at Ranstad, western Sweden, the inventories of uranium, thorium and radium in soils and crops were analyzed. The chemical and physical characteristics of the soils were determined with the purpose to investigate the variation of natural occurring nuclides in soils and crops and their correlation with local soil characteristics. The relationship between crop uptake and soil factors was also investigated.

In order to expand the investigation to comprise the distribution of radionuclides between soil and drainage water, a study was performed in cooperation with the Environmental Division at the Swedish University of Agricultural Sciences. Sampling and analysis of soil and drainage water from 16 research fields located in different parts of the country and sampling and analysis of growing and mature crops from 9 of these fields were carried out.

The objectives with this investigation was to study the relationship between nuclide contents in soil, drainage water and crops, with respect to soil factors. The distribution of naturally occurring radionuclides was utilized to obtain reliable concentration factors which in turn were used to calculate the transfer of nuclides within the agricultural ecosystem.

2 TRANSPORT OF RADIONUCLIDES IN SOIL AND CROPS

The principal processes that influence the transfer of radionuclides in the terrestrial food chain to man are

- migration in soil
- transfer to plants

The relative importance of the different exposure pathways to plant material - deposition on the leaves, resuspension and root uptake - varies depending on the specific radionuclide species and in which manner the contamination occurs.

2.1 Deposition

Considering a situation of continuous deposition of activity from the atmosphere, foliar intercep-

tion and retention are generally the dominant source of contamination of plant material /4, 5/. The values of 25 % for the interception factor and 14 days for the removal half-life appear to be a well-validated general value, considering a pasture yield of 0.1 kg m^{-2} (dry wt) /5/. Values suggested for leafy green vegetables and grain are given in Table 1.

2.2 Resuspension

The significance of this mechanism is greater for leafy plants which grow close to the soil surface. However, to quantitatively assess the contribution of this process to the total contamination of plants is difficult. 0.01 % of the dry grain weight is taken to be a typical quantity of soil on grain in U.K. /6/. However, the values can only be used to indicate the relative importance of this exposure pathway compared to deposition and root uptake.

2.3 Root uptake

Downward migration in soil is one of the principal mechanisms determining the time dependence of the uptake of long-lived radionuclides into plant material following the deposition of activity onto land. For most radionuclides, uptake by roots is assumed to be secondary in importance during conditions of continuous deposition. However, for long-lived nuclides that are absorbed from soil to a significant extent, e.g. Sr-90, Tc-99 and I-129, uptake by roots could dominate even during conditions of direct deposition when a sufficient buildup of activity in soil has occurred. Migration of radionuclides is also influenced by farming

activities that disturb the soil profile, which may enhance the root uptake pathway.

As sufficient data are lacking for the majority of elements with regard to the transfer between soil and different plant species, the transfer parameters have to be assumed independent of plant type. Data on uptake by roots tend to be in the form of concentration factors between plants and soil (Bq kg^{-1} plant material/Bq kg^{-1} soil) or transport coefficients (m^2 kg^{-1}). The transport coefficient gives that fraction of the activity per m^2 soil which is recovered in one kg of plant material.

3 INVESTIGATIONS BY THE DEPARTMENT OF RADIOECOLOGY

3.1 Area description

The 37 different sites used in the investigation by Eriksson and Fredriksson are described earlier /3/. Generally, the sampling surfaces constituted agricultural soils of different composition with regard to amounts of clay, organic matter and pH.

3.2 Sampling and sample treatment

In the investigation performed by Eriksson and Fredriksson /3/, sampling surfaces of 50 m^2 each were selected at every sampling locality. During the autumn 1979 samples of the top-soil (0-25 cm) and the sub-soil (25-50 cm) were collected, and during the summer 1980 samples of growing crops were collected from the same localities.

The contents of U-238, U-234, Th-230, Th-232 and Ra-226 were determined in crops and soils. Total

uranium in soils was determined by the delayed neutron technique, Th-232 and Ra-226 by radon emanation and gamma spectrometry. However, in soil, some fraction of the nuclides will be in the soil solution and easily available to plant roots while another fraction will be adsorbed onto surfaces and less available, with a third fraction incorporated in mineral structures and completely unavailable. In order to determine the accessibility of the nuclides by the plants, compared to the total radionuclide inventory of the soil, the soil samples were treated with different extraction agents. Uranium and thorium in soil extracted with hot 2 M HCl - which should release the amounts available during a longer time interval - and in plant material was determined by radiochemical separation and alphaspectrometry. Uranium and thorium extracted with ammonium oxalate - which should release the amounts of uranium and thorium from the soil which are readily available to the plants - was determined with similar technique. For radium, a solution of ammonium lactate and acetic acid (AL) was used as a soil extraction agent. Radium extracted from soil and in plant material was determined by a technique of radon emanation, absorption of radon in n-hexane and sampling of the hexane fraction after two weeks for liquid scintillation measurement of radon and daughters in equilibrium /3/.

3.3 Results

The results referred to below are mainly those derived by Eriksson and Fredriksson /3/ for the investigated 37 sites in SW Sweden.

3.3.1 Soil characteristics and radionuclide concentrations

The average contents of naturally occurring nuclides in the soil from two different depth layers are displayed in Table 2. Extraction with hot HCl will remove about 45 % of the total activity content of U-238 and 25 % of Th-232, on the average. For Ra-226, about 30 % of the total amount is extracted with ammonium lactate and acetic acid.

The soil characteristics will greatly influence the solubility of the radionuclides. The primary soil factors are the clay content and the amount of organic matter, while the concentration of phosphorous and the pH-level in the soil may be regarded as secondary characteristics. The content of colloids will enhance the capacity of the soil to retain radionuclides. In bedrock deposits, the highest concentrations of the naturally occurring radioactive compounds are found in shales with origin from clay minerals. It can be assumed that the ion-exchange capacity of clay together with a simultaneous sedimentation of mineral particles containing uranium and thorium will cause the elevated activity concentrations found, compared to other soil types. Eriksson and Fredriksson /3/ showed that there existed a certain connection between the measured uranium- and thorium concentrations and the contents of clay and organic matter in the soil. The concentration of Th-232 in the soil was strongly correlated to the clay content. For both Th-230 and Th-232, the connection between nuclide concentration and content of organic matter was weak, while it for uranium was strong. The difference between the behaviour of

uranium and thorium was explained by the higher solubility of the former nuclide. The HCl-soluble fractions of U-238 and U-234 showed a better correlation to the concentrations of clay and organic matter than the total contents of these two elements. This may be explained by the ion-exchange capacity of the soil.

The correlation between the total contents of Ra-226 and U-238 was strong; the soil characteristics contributed very little to the variation of the total activity content of radium. However, a strong tendency of pH to influence the amount of soluble radium in the soil was found. Treatment with ammonium lactate and acetic acid (AL) was supposed to release the fraction of radium that was readily available to the plants. At an increased pH, the ratio of Ra_{AL}/Ra_{total} decreased, and vice versa. This will imply an increased solubility of radium when pH is lowered. At the same time the fraction of soluble calcium may decrease. Thus, an increased acidification of the environment will cause a skewed Ra/Ca ratio and will imply an increased transport of radium to the crops.

The activity contents of uranium and radium in the soil mostly showed a lack of equilibrium. This skewed Ra-226/U-238 ratio may be due to differences in the transport downwards of uranium, thorium and radium caused by the physical and chemical properties of the soil. Clay and organic matter will decrease the transport of uranium relatively to that of radium. A high pH value, on the other hand, will enhance the transport of uranium, probably as carbonate complexes.

3.3.2 Radionuclide concentrations in plant material

The activity contents and variation of 40 crops are viewed in Table 3. The fraction of the nuclides in the soil which are available to the crops are assumed to be very small, and are coupled to other more or less soluble fractions in a complicated manner.The correlation between plant uptake of thorium and soil characteristics was shown to be insignificant /3/.

In the case of uranium, a certain connection was shown between plant uptake and soil characteristics. The uptake seemed to be dependent on the calcium content of the plant and the pH of the soil. An increased calcium content - that is, an increased uptake of minerals - will decrease the uptake of uranium, while an increased pH will cause an increased uptake of this radionuclide species by the plant. This dependence upon pH will suggest that the uptake of uranium by the plant occurs from a fraction bound as carbonate or silicate complexes. These fractions will increase when pH increases.

The inventory of radium in the plant material was related both to the radium content of the soil and to the uptake of calcium, since these two elements have similar chemical properties. The fraction of soluble radium in the soil was also affected by the pH. A positive correlation was found between the Ra/Ca-ratio of the plant and that of the soil. An increased pH however reduced the uptake rate.

The average concentration factors between plant and soil, using the total activity of the soil

(Table 4) and that extractable with HCl, demonstrates that very small fractions of the nuclides were available for the plants.

4 INVESTIGATIONS AT THE RESEARCH FIELDS

4.1 Area description

The locations and dominant soil types of the 16 research fields run by the Environmental Division are viewed in Fig 1. Other characteristics of the fields are described elsewhere /7/.

4.2 Sampling and sample treatment

During autumn 1980, water and soil samples were collected from the 16 experimental fields. Within each of the fields, 5 soil profiles containing 3 different depth levels (0-30, 30-60, and 60-90 cm) were collected. The 5 samples of each depth level were then combined into one. Water samples were collected also in spring 1981. During the summer 1981, growing crops were collected, and in the autumn the same year samples of mature crops were collected from 9 of the fields.

The samples were treated in a similar way as those of the Ranstad investigation /3/.

4.3 Results

The primary data for the research fields regarding field locaties, soil characteristics and activity concentrations in soil water and crops are viewed in Fig 1 and Tables 5-15.

The two fields no 1 and 2 in the northern part of Sweden, have subsoils with low pH-values

which further decrease with increasing depth (Table 5). For most of the other fields the pH-values increase with the depth in the soil profile. Plant available phosphorus and potassium, as indicated by the P_{AL}- and K_{AL}- values in Tables 6a and 6b respectively, shows in some cases an enrichment in the plough layer due to fertilization and cultivation during a long time. P_{AL} thus indicates enrichment on fields no 6, 7, 8, 11, 12, 15 and 16; K_{AL} on fields no 1, 3, 6, 11, 14 and 15. K_{HCl} is an indicator on the clay content and Table 6b shows that soil profiles homogenous with regard to clay, silt and sand down to 90 cm depth are rare. The composition of the surface soil layers varies with depth depending on the glacial and post glacial geology. Generally the clay content increases with the depth. However, the soil profiles are rather homogenous in fields no 3, 13, 15 and 16 with low clay contents, and in fields no 4, 6, 8 and 12 with high clay contents. Also the concentrations of extractable Ca and Ra in the soil vary with soil depth (Table 5 and 7). To some extent this may depend on leaching and to some extent on the clay content, as indicated by K_{HCl} (Table 6b). The clay content also influences the concentration of uranium and thorium in the soil.

The relationships between radionuclide concentrations in water, soil and crops were calculated by means of linear regression analysis.

4.3.1 Water 1980 - water 1981

Water samples were collected from 8 fields in autumn 1980 and in spring 1981. For U-238 and U-234 consistent values were obtained (r = 0.95

and r = 0.90, respectively, cf. Table 16). For Th-230 and Th-232, low correlations were found for the two sampling occasions (r = 0.35 and r = 0.30, respectively), demonstrating that the content of thorium was variable as well as low.

4.3.2 Soil 1980 - water 1980

The relationship between radionuclide content in water and soil for the different research fields are viewed in table 17. For U-238 and U-234 the relation between soil and water showed an increased correlation for the different extraction treatments in the following order: amm. ox. > cold HCl > hot HCl. For the two Th nuclides, no correlation was obtained for any of the extraction treatments.

4.3.3 Soil and water 1980 - growing crops 1981

The correlation between the uranium content in soil and that of growing crop, as evaluated by the oxalate extraction, was comparatively high for such contexts (r = 0.7-0.8). The direct relationship between nuclide contents in soil and crop with regard to thorium and radium was weaker. The relationship between the uranium in water and that in the crops was also weak (Table 18).

A comparatively strong correlation between radionuclide content in soil and growing crops was found for U whereas no such relationship was found for Th and Ra (Table 18). The correlation between the nuclide contents in water and crops was weaker.

4.3.4 Soil and water 1980 - mature crops 1981

The mature crops were divided into vegetative and reproductive parts. For neither the soil-crop and water-crop systems, nor the vegetative or for the reproductive parts high correlations were found (Table 19).

The relative changes of the radionuclide concentrations from growing to mature crops are viewed in Table 20.

The changes seem to be dramatic on some locations and most certainly reflect the expansion of the root systems with the time into deeper horizons. Here the plant availability of the nuclides due to chemical conditions and concentrations differ from that in the shallow soil layers. The changes are thus partly due to root uptake from the deeper layers analyzed and partly due to layers below 90 cm depth.

To sum up, direct and simple relationships between the contents of U, Th or Ra in soil, water or crops from the research fields could not be established. Other characteristics such as the type of soil, pH and soil constituents may influence the distribution and transfer of the radionuclides. For Th, the solubility is probably dependent on the amount of organic acids present in the soil. Quotients between the quantities of radionuclides released with different extraction agents deviated considerably indicating a strong influence of soil characteristics on the degree of radionuclide solubility for different soil types. For U-238, the hot HCl/amm. ox. quotient decreased in the following sequence

sand > clay > till

while for Th

clay > till > sand.

4.3.5 Concentration factors (C_f)

The plant/soil concentration factors (Bq kg^{-1} crop/Bq kg^{-1} soil, dry wt) obtained for the different nuclides are displayed in Table 21-23. For Ra, the factor was about one order of magnitude higher than for U and Th. The calculated concentration factors for the mature crops and soils, based on dry weights, were used as transfer factors in the BIOPATH code. The plant/soil concentration factors were assumed to be in steady state. The C_f values obtained for the research fields, by Eriksson and Fredriksson /3/ and those used in the KBS-100 study /2/, are shown in Table 24. The soils from SW Sweden generally are less fertile and contain low amounts of calcium. The C_f values obtained from these fields are thus supposed to be less representative than those generated from the research fields, which are evenly distributed over the country.

For comparison, the C_f values from the research fields are calculated as arithmetic means. For U, the C_f value was raised a factor 6-7. For Th and Ra, the corresponding values were raised a factor 2 at the most for Th and a factor 13-120 for Ra.

However, when trying to find a C_f value of general applicability for Swedish soils, it might not be correct to use the arithmetic means. In order to examine which type of distribution the data obeyed, the C_f values for U-238 were plotted on lognormality probability paper

(Fig. 2). A straight line could reasonably fit the plotted data, which revealed a lognormal distribution. Thus, assuming lognormality for all nuclides, the data were logtransformed to produce a normal distribution having a mean value $\hat{\mu}$ and a standard deviation $\hat{\sigma}$.

$$\hat{\mu} = \sqrt[n]{x_1 \cdot x_2 \cdots x_n}$$

$$\hat{\sigma} = \sqrt{\frac{\sum_i (\ln x_i)^2 - \frac{(\sum_i \ln x_i)^2}{n}}{n-1}}$$

where

$\ln x_i$ = logarithm of i:th observation

n = number of observations

The geometric mean value for the various radionuclides was assumed to give a more reliable C_f value. The geometric mean values with their geometric standard deviations are shown in Table 25.

The water/soil concentration factors were calculated for the five radionuclides (Table 26). The nuclide content in drainage water generally indicated very low leaching rates of the naturally occuring nuclides. For Th, the leaching rate varied between <2-33 mBq l^{-1} ($\bar{x}$ = 7 mBq l^{-1}). For Ra, the values given were based on small samples and probably

overestimate the Ra-content. U showed a highly variable leaching rate with values ranging from 4 to 295 mBq l^{-1} ($\bar{x}$ = 93 mBq l^{-1}). For U, the water/soil concentration factors were strongly pH-dependant (Fig. 3). In most cases the leaching rate of U was low at pH 6-7 but increased considerably above that range. The water/soil C_f values, calculated as geometric means, are shown in Table 27.

4.3.6 Transport coefficients (T_c)

In order to assess the fraction of activity that was bound in the crop, transport coefficients were calculated of the form

$$T_c = \frac{C_f}{\text{soil weight } m^{-2}} \quad m^2\ kg^{-1}$$

Assuming a soil depth of 0.5 m, an average soil weight of 650 kg m^{-2} were used. The transport coefficients for harvested crops are displayed in Table 28. The values are comparable to those by Eriksson and Fredriksson /3/.

5 DOSE CONTRIBUTIONS FROM CONTAMINATED CROPS AND PASTURE

Radionuclides may reach the human populations directly through consumption of contaminated crops and indirectly through consumption of meat and milk produced by cattle stocks which use contaminated pasture as food. The diet of an individual is derived from a wide range of products, each representing a separate pathway for the transfer of elements through the environment. For simplicity in modelling, the major foodstuffs of vegetable origin have been grouped

into a limited number of categories, viz. green vegetables, root vegetables and cereals.

5.1 Dose equations

BIOPATH calculates the dose contribution to human individuals and populations from ingested cereals/root vegetables as follows:

- contribution from root uptake

  activity concentration in soil x concentration factor for cereals/root vegetables-soil

where the concentration factor is specified for each nuclide.The obtained value is multiplied with the early consumption of cereals/root vegetables and the dose factor for the nuclide, which will give the dose rate expressed as Sv yr^{-1}.

For green vegetables, several uptake routes are considered:

- contribution from root uptake

  activity concentration in soil x concentration factor for vegetables-soil

- contribution from deposition

  activity concentration in air x deposition velocity x the fraction of the activity that is retained on the leaves x average residence time on the leaves x the yield of the crop per m^2

- contribution from irrigation

  activity concentration in irrigation water x amount of water x the fraction of the activity that is retained on the leaves x average residence time on the leaves x the yield of the crop per m^2.

The sum of these contributions is multiplied with the annual consumption of vegetables and the dose factor for the nuclide, and gives the dose rate expressed as Sv yr^{-1}. The dose factor (Sv Bq^{-1}) used is the sum of the ICRP's weighted committed organ dose equivalents.

The deposition velocity is expressed in m day^{-1}. 75 % of the deposited activity is supposed to be retained on the leaves /5/.

The average residence time of deposited activity on the leaves is calculated as

$$\int_0^\infty e^{-\lambda t} dt = \frac{1}{\lambda}$$

where $\lambda = \frac{1n\ 2}{T_{\frac{1}{2}}}$ and $T_{\frac{1}{2}}$ = 14 days /5/.

Grazing animals are usually considered important in the transfer of activity to man because of the large surface area of pasture from which they obtain their food. The transfer of vegetation-bound activity to meat and milk may occur through the following pathways:

- root uptake and subsequent grazing

- deposition on the pasture and subsequent grazing.

The resulting dose calculations are formulated: activity concentration in soil x concentration factor for pasture-soil x daily consumtion rate and activity concentration in air x deposition rate x the fraction that is retained on the leaves x average residence time on the leaves x the yield of the pasture per m^2 x daily consumtion rate by the animal, respectively.

The sum of these contributions is multiplied with

- a distribution factor that gives the relation between the activity concentration in 1 kg of meat or milk, and the daily intake of activity by the animal

- the yearly consumtion of meat or milk

- the dose factor for the nuclide which will give the dose rate, expressed as Sv yr^{-1}.

The ratio between the activity concentration for the parent nuclide in 1 litre of milk or 1 kg of meat and the daily amount of activity ingested by a cow can be expressed as

$$\frac{\text{Bq } l^{-1}}{\text{Bq day}^{-1}} = \text{day } l^{-1}$$

Besides, the cow's consumption of contaminated water may further contribute to the total dose burden from meat and milk. Inadvertent consumption of soil together with grass by grazing animals

in another pathway that may be important. In the U.K., soil consumtion is estimated to be about 4 % of the dry matter intake for cattle /6/. In the absence of direct deposition, soil intake could contribute to the activity in meat and dairy products for several of the long-lived radionuclides.

5.2 Dose calculations

In order to evaluate the radiological consequences for man when using the C_f factors obtained in this study compared to those used in earlier investigations (2), a test was performed with the BIOPATH code.

A continous release of 1 Bq yr^{-1} of uranium, radium and thorium, respectively, into the Finnsjö area was simulated for a time period of $1 \cdot 10^5$ yr. Using the well case, the annual individual dose contribution from the intake of cereals was calculated (Table 29).

For both U-234 and U-238, the annual individual doses derived from the consumption of cereals were reduced to about 60 % of those earlier calculated. This pathway became equally important as the consumption of milk, after the water and meat consumption routes. The total internal dose was reduced with 2-3 %, compared to earlier calculations.

For Ra-226, on the other hand, the annual individual dose rate was enhanced by a factor 30 for the cereal consumption pathway. The contribution of this pathway to the total internal dose increased from 0.5 to 14 %, which made this route the 3rd most important after the consumption

of water and milk. However, the total internal dose was increased only by a factor 1.2.

For the two thorium nuclides, the annual individual doses derived from the cereal pathway decreased to around 10 % of that formerly calculated. From being a dominant contributor with 58 % to the total dose, this route was reduced to 17 %, passed by the intake of water and rootfruits.

6 CONCLUSIONS

The transfer of radionuclides through the terrestrial food web is complex; e.g. soil-to-plant concentration factors are extremely variable, which limits the usefulness of a single concentration factor to predict the uptake of a radionuclide species into crops from soil. The large uncertainty associated when predicting the uptake of radionuclides by plants may be reduced by considering the dominant crops and the soil types that are generally abundant in boreal areas.

The variations of the C_f values reflects the availability of the elements to be taken up by different crops. Very high U and Th uptakes were found in sugarbeet tops, compared to the rest of the investigated crops from the research fields. The C_f values for this crop was about 100 times that of barley in the same field.

The uptake of Ra, Th and U by the plants could be ranked in the decreasing order Ra > U > Th. This is in confirmity with the findings by Verkhovskaja et al /8/, who also stated, that the Ra content in plants in the autumn was several hundred times greater than in the

spring. However, such a large increase was not observed in our material.

The migration of Ra in soil should be briefly discussed. In soils most of the Ra is strongly sorbed. High Ca^{2+} concentrations causes Ra to be more permanently fixed to the soil, thus reducing the amount of exchangeable Ra and decreasing the amount available for plant uptake. However, although Ra absorption by plants is inversely proportional to the amount of alkaline earth elements present in mobile forms, Kirchmann et al /10/ found no relationship between the two ions. The reduction of Ra uptake was strongly dependant on the pH of the solution, which is influenced by the Ca concentration. Rusanova /9/ indicated that the most rapid desorption of Ra took place at pH 3 and that as the pH increased, desorption decreased. Thus, the migration of Ra in soils appears to depend on the Ca^{2+} concentration only in an indirect manner. The fractions of Ca and Ra leached from the research fields showed that the loss of Ca was 5-350 times higher than that of Ra /12/. This will probably result in an increasing Ra/Ca ratio in that part of the soil profile which is available for plant nutrient uptake.

7 REFERENCES

1 BERGSTRÖM U, EDLUND O, EVANS S, RÖJDER B
BIOPATH, a computer code for calculation of the turnover of radionuclides in the biopshere and the resulting doses to man.
STUDSVIK/NW-82/261 (1982).

2 BERGMAN R, BERGSTRÖM U, EVANS S
Dose and dose commitment from groundwaterborne radioactive elements in the final storage of spent nuclear fuel.
STUDSVIK/K2-79/92, KBS 100.

3 ERIKSSON Å, FREDRIKSSON L
Naturlig radioaktivitet i mark och grödor.
SLU-IRB-52 (1981).

4 CHADWICK R C, CHAMBERLAIN A C
Field loss of radionuclides from grass.
Atmospheric Environment 4, 51-56 (1970).

5 CHAMBERLAIN R C
Interception and retention of radioactive aerosols by vegetation.
Atmospheric Environment 4, 57-78 (1970)

6 SIMMONDS J R, LINSLEY G S, JONES J A
A general model for the transfer of radioactive materials in the terrestrial food chains.
NRPB-R89 (1979).

7 BRINK N, GUSTAFSON A, PERSSON G
Förluster av kväve, fosfor och kalium från åker.
Ekohydrologi 4 (1979). SLU.

8 VERKHOVSKAJA J N et al
The migration of natural radioactive elements under natural conditions and their distribution according to biotic and abiotic environmental components.
In: Radioecological concentration processes. Proc. Int. Symp. Stockholm, April 1966, B Åberg and F P Hungate (eds.). Pergamon, Oxford, pp. 313-328 (1967).

9 RUSANOVA G V
On the problem of studying the leaching processes and migration of radium in soils.
Soviet Soil Science 9, 85- (1962).

10 KIRCHMANN R et al
Absorption du Ra-226 par les plantes cultivées.
In: Proc. 1st Int. Congr. Radiation Protection, Rome, Sept 1966, W S Snyder (ed). Pergamon, Oxford (1968).

11 SIMMONDS J R, LINSLEY G S
A dynamic modeling system for the transfer of radioactivity in terrestrial food chains.
Nuclear Safety 22, 766-777 (1981).

12 ERIKSSON A
Studies on the content of uranium, thorium and radium in soils, crops and drainage water as influenced by soil qualities and by soil development and acidification processes.
ESNA 13th Annual Meeting, Brno, CSSR (1982).

NW3ASG

Table 1 Interception and retention parameters for leafy green vegetables and grain. From /11/

Crop	kg m^{-2} (dry wt)*	Interception factor*	Removal half-life (days)***
Leafy green vegetables	0.2	0.3	14
Grain	0.4	0.005**	30

* Parameter values are interrelated because of methods for derivation.

** Value relates to interception by grain seed, not the whole plant

*** These values are not recommended for Pu.

Table 2 Average contents of naturally occuring nuclides in the soil from 0 - 30 cm and 30 - 60 cm depth, respectively, expressed as $\bar{X} \pm$ SD (Bq kg^{-1} dry wt). Redrawn from /3/.

	Depth 0 - 25 cm	Depth 25 - 50cm
Total activity, Bq kg^{-1}		
U-238	69.9 ± 57.2	72.3 ± 61.6
Th-232	34.2 ± 21.1	40.1 ± 27.2
Ra-226	82.1 ± 96.2	73.7 ±100.6
Extraction with hot HCl, Bq kg^{-1}		
U-238	33.4 ± 28.3	34.9 ± 32.0
U-234	34.5 ± 27.4	35.9 ± 32.4
Th-230	9.3 ± 16.1	15.7 ± 15.9
Th-232	6.6 ± 10.4	11.4 ± 11.9
Extraction with ammonium lactate, and acetic acid (AL), Bq kg^{-1}		
Ra-226	18.3 ± 10.9	19.1 ± 12.1

Table 3 Activity contents and variation of 40 crops, expressed as mBq kg^{-1} (dry wt). From /3/.

Nuclide	Activity content, mBq kg^{-1}	
	$\bar{X}$	X_{min} - X_{max}
U-238	170	(30 - 1310)
U-234	226	(60 - 1540)
Th-230	148	(40 - 1680)
Th-232	97	(20 - 40)
Ra-226	1250	(330 - 5070)

Table 4 The average concentration factor for 40 crops and soils, using total activity concentrations and extractable activity concentrations of the soil, respectively. From /3/.

Nuclide	Activity content in soil	Concentration factor
Ra-226	total amount	$1.6 \cdot 10^{-2}$
U-238	- " -	$3.8 \cdot 10^{-3}$
Th-232	- " -	$3.8 \cdot 10^{-3}$
Ra-226	extractable amount	$6.6 \cdot 10^{-2}$
U-238	- " -	$1.0 \cdot 10^{-2}$
Th-230	- " -	$2.9 \cdot 10^{-2}$
Th-232	- " -	$2.6 \cdot 10^{-2}$

Table 5. Loss on ignition, pH and amounts of Ca extracted with AL in the soil profiles of the research fields.

Field no	Loss on ignition, %			pH_{aq}			Ca_{AL} mg/100 g soil		
	0-30 cm	30-60 cm	60-90 cm	0-30 cm	30-60 cm	60-90 cm	0-30 cm	30-60 cm	60-90 cm
1	10,8	2,2	2,0	6,3	4,4	3,6	340	100	110
2	3,3	3,4	2,0	5,9	6,2	4,3	130	85	65
3	10,6	2,3	1,2	6,8	7,8	8,2	520	360	975
4	4,9	1,4	1,5	6,3	6,6	6,9	215	120	105
5	4,1	1,0	1,2	5,9	6,3	6,6	135	105	135
6	3,9	2,7	2,1	7,9	8,3	8,5	1955	4725	8920
7	3,0	1,2	1,0	6,4	6,1	6,3	140	120	105
8	3,9	2,9	2,3	6,6	7,0	7,7	250	275	285
9	5,3	2,0	1,8	6,6	6,7	6,9	170	155	170
10	4,1	2,0	1,7	6,7	6,2	6,5	180	105	130
11	4,3	2,0	1,3	6,8	6,3	6,9	280	185	315
12	5,6	2,1	1,3	6,7	7,5	7,7	495	410	360
13	5,1	2,3	0	6,5	6,6	6,4	205	100	30
14	5,2	2,7	2,5	6,5	8,1	8,1	340	420	2275
15	4,1	0,4	0,2	7,3	8,1	8,3	570	1420	2230
16	2,7	2,1	1,7	7,8	8,0	8,2	775	885	1675

Table 6 a. Concentrations of phosphorous extracted with HCl and AL, respectively, in the soil profiles of the research fields

Field no	P_{HCl} mg/100 g dry soil			P_{AL}, mg/100 g dry soil		
	0-30 cm	30-60 cm	60-90 cm	0-30 cm	30-60 cm	60-90 cm
1	29	26	30	2,6	0,9	1,1
2	29	30	31	1,0	1,3	0,6
3	15	12	18	1,3	0,7	0,1
4	35	36	36	1,1	1,2	1,1
5	29	26	25	0,7	1,0	0,8
6	31	24	23	3,8	0,4	0,1
7	30	24	27	2,6	1,2	0,7
8	35	26	24	3,6	1,4	2,1
9	15	22	25	2,3	2,7	6,9
10	21	20	25	1,7	1,5	3,1
11	18	15	22	2,9	1,2	2,7
12	20	14	21	2,4	1,1	1,9
13	11	8	12	2,0	1,1	0,7
14	18	14	12	1,2	0,9	0,9
15	36	27	15	14,7	4,7	2,2
16	19	13	20	4,1	1,6	1,5

Table 6 b. Concentrations of potassium extracted with HCl and AL, respectively, in the soil profiles of the research fields.

Field no	K_{HCl}, mg/100 g soil			K_{AL}, mg/100 g soil		
	0-30 cm	30-60 cm	60-90 cm	0-30 cm	30-60 cm	60-90 cm
1	107	185	285	5,6	1,9	1,0
2	97	130	330	1,9	4,1	2,3
3	128	137	172	5,9	3,5	4,4
4	298	337	423	4,4	2,3	4,9
5	127	163	234	1,8	1,5	1,9
6	386	395	395	6,6	4,2	4,6
7	80	183	186	1,9	1,8	1,8
8	432	598	665	6,7	7,7	9,9
9	120	270	400	7,5	7,2	8,0
10	250	410	435	6,3	6,0	7,1
11	62	87	186	5,3	1,9	2,7
12	325	386	430	7,2	5,6	6,8
13	37	17	9	1,9	1,0	0,3
14	207	254	152	7,6	5,6	6,8
15	57	34	27	9,7	1,7	1,3
16	107	112	126	2,5	1,9	2,4

Table 7. Concentrations of Ca and Ra-226, extractable with 1 M NH_4Cl, and Ra-226/Ca ratios of samples from the soil profile.

Field no	Ca mg/100 g soil			^{226}Ra Bq/kg soil			^{226}Ra/Ca, Bq/g		
	0-30 cm	30-60 cm	60-90 cm	0-30 cm	30-60 cm	60-90 cm	0-30 cm	30-60 cm	60-90 cm
6	450	530	490	7,6	13,4	13,4	1,7	2,5	2,7
8	200	230	220	18,1	40,5	37,4	9,1	17,7	16,8
9	140	140	130	7,0	10,3	25,2	5,1	7,6	19,4
10	180	100	115	9,0	13,7	26,9	5,0	13,7	23,4
11	200	142	248	7,4	18,0	36,5	3,7	12,7	14,7
12	360	380	310	15,6	15,2	32,3	4,3	4,0	10,5
13	150	73	12	3,2	2,5	2,2	2,1	3,4	18,3
14	290	350	440	10,7	11,3	8,2	3,8	3,2	1,9
15	240	250	300	2,0	1,0	3,0	0,9	0,4	1,0
16	380	470	510	4,7	6,3	7,3	1,2	1,4	1,4

Table 8. U and Th levels in the drainage water from the research fields in October 1980 and spring 1981 (mBq l^{-1})

Field no	^{238}U		^{234}U		^{230}Th		^{232}Th	
	H 80	V 81	H 80	V 81	H 80	V 81	H 80	V 81
1	172	-	203	-	6	-	3	-
2	53	-	53	-	4	-	<2	-
3	5	-	8	-	2	-	2	-
4	6	-	12	-	<2	-	<2	-
5	4	-	7	-	3	-	3	-
6	183	180	180	224	3	5	3	7
7	4	-	8	-	4	-	<2	-
8	17	8	26	10	33	2	23	6
9	13	-	53	-	6	-	3	-
10	5	7	12	8	3	3	<2	5
11	295	203	274	203	7	4	5	4
12	266	160	284	161	4	16	6	19
13	6	4	9	6	<2	<2	2	3
14	44	59	41	62	5	5	2	8
15	146	139	188	152	4	<2	6	3
16	124	103	141	108	33	<2	21	<2

Table 9a. Concentrations of P, K and Ca and radium in drainage water from the research fields.

Field	P, mg/l		K, mg/l		Ca, mg/l		Ra, m Bq/l *)	
no	H 80	V 81	H 80	V 81	H 80	V 81	H 80	V 81
1	0,43		7,5		14,4		(50)	
2	1,05		15,3		18,5		(40)	
3	0,25		4,0		65,8		(40)	
4	0,93		5,3		8,6		(30)	
5	1,36		2,5		5,8		(30)	
6	0,31	0,43	1,4	1,5	41,0	76,2	(20)	(20)
7	0,43		7,7		37,4		(50)	
8	1,67	0,68	2,4	1,6	4,9	3,5	(40)	(50)
9	2,29		4,3		16,0		(30)	
10	0,43	0,56	2,6	1,5	35,6	9,9	(80)	(50)
11	0,50	0,25	21,0	1,4	48,0	58,8	(60)	(50)
12	1,18	0,31	3,7	2,6	41,5	54,4	(30)	(180)
13	0,37	0,37	6,3	5,2	35,5	18,8	(40)	(30)
14	1,36	0,37	4,3	3,8	73,7	58,8	(40)	(20)
15	0,93	1,74	35,4	20,0	83,8	54,8	(50)	(20)
16	1,61	0,50	1,0	1,0	62,4	68,4	(70)	(20)

*) The Ra values are based on analysis of only 1 l samples and are over-estimates; should be $\lesssim$ 20 mBq l^{-1}.

Table 9b. Ratio of Ra/Ca in drainage water (Bq g^{-1}) and OR-values (observed ratios) calculated as $(Ra/Ca)_{water}/(Ra/Ca)_{soil}$. The values of $(Ra/Ca)_{soil}$ are calculated as ratios of the amounts of Ra and Ca extracted with, on one hand AL, and on the other 1 M H_4NCl.

Field no	Ra/Ca_w Bq/g		OR-value: $Ra/Ca_w/Ra/Ca_s$			
			Ra/Ca_s AL		Ra/Ca_{sH_4NCl}	
	80	81	80	81	80	81
1	3,5		0,5			
2	2,2		0,2			
3	0,6		0,9			
4	3,5		0,4			
5	5,2		0,4			
6	0,5	0,3	2,6	1,4	0,2	0,1
7	1,3		0,1			
8	8,2	14,3	1,6	2,8	0,5	0,9
9	1,9				0,1	
10	2,2	5,1			0,1	0,2
11	1,3	0,9	0,3	0,2	0,08	0,06
12	0,7	3,3	0,2	1,04	0,07	0,3
13	1,1	1,6	0,02	0,03	0,06	0,09
14	0,5	0,3	1,0	0,6	0,3	0,2
15	0,6	0,4	1,1	0,6	0,6	0,4
16	1,1	0,3	1,7	0,5	0,8	0,2

Table 10. K, Ca and P concentrations of growing crops in July 1980.

Field no	Location	Crop	mg g^{-1} dry wt K	Ca	P
6	Sandbro	Turnip rape	23,0	19,2	8,3
8	Flinkesta	Barley	24,7	8,0	5,2
10	Karstorp	a W. wheat	24,2	5,0	2,9
		b "-	21,0	5,6	2,7
		c Turnip rape	33,3	26,9	5,5
		d W. wheat	14,5	3,6	2,1
		e "-	18,3	4,4	2,7
11	Hassla	"-	17,7	8,3	2,8
12	Stjärntorp	"-	18,8	3,8	2,5
13	Skottorp	Rape	23,1	19,0	3,9
14	Vettinge	a Rape	15,1	22,0	3,7
		b "-	23,1	4,2	2,5
		c Ley, 2nd cut	37,6	11,2	3,6
15	Kärrdala	a Barley	14,0	2,8	2,5
		b Sugar beets	41,9	10,8	4,9
16	Näsby gård	Rape	17,2	28,1	4,0

Table 11. Concentrations of K, Ca and P in harvested crops and oil plants in autumn 1980.

Field no	Crop	Product	mg g^{-1} dry wt K	Ca	P
6	Turnip rape	Straw	18,1	14,5	1,1
		Seed	8,9	6,4	3,2
8	Barley	Straw	11,7	4,0	1,8
		Grain	5,2	1,0	4,3
10	W. wheat	Straw	7,1	3,1	1,7
		Grain	5,4	0,6	4,4
	Turnip rape	Straw	18,3	20,1	2,0
		Seed	10,5	8,1	8,6
11	W. wheat	Straw	9,9	2,6	1,1
		Grain	3,3	0,6	3,0
12	W. wheat	Straw	10,3	3,0	1,3
		Grain	5,2	0,6	4,5
13	Rape	Straw	16,9	17,8	1,2
		Seed	9,5	5,3	8,6
14	Rape	Straw	9,6	2,2	1,1
		Seed	3,9	0,5	3,9
15	Sugar beet	Tops	76,9	22,2	5,5

Table 12. U, Th and Ra concentrations in harvested crops in July 1981.

Field no	Location		Crop	mBq kg^{-1} dry wt ^{238}U	^{234}U	^{230}Th	^{232}Th	^{226}Ra
6	Sandbro		Turnip rape	44	152	290	34	680
8	Flinkesta		Barley	52	68	22	11	450
10[x)]	Karstorp	a	W. wheat	50	54	19	13	1170
		b	"	204	164	147	196	1080
		c	T. rape	113	94	64	27	590
		d	W. wheat	53	105	55	26	920
		e	"	58	74	43	94	610
11	Hassla		"	178	135	27	28	740
12	Stjärntorp		"	83	200	9	12	1120
13	Skottorp		Rape	43	59	28	24	950
14	Vettinge	a	"	86	80	40	41	650
		b	W. wheat	32	69	30	23	820
		c	Ley	192	205	224	217	1020
15	Kärrdala	a	Barley	65	68	17	22	670
		b	Sugarb., tops	6650	6840	2154	2966	5150
16	Näsby g-d		Rape	66	66	55	49	630

x) large, elongated field

Table 13. Concentrations of U, Th and Ra in harvested crops from the research fields in autumn 1981.

Field no	Crop	Product	mBq kg^{-1} dry wt				
			^{238}U	^{234}U	^{230}Th	^{232}Th	^{226}Ra
6	Turnip rape	Straw	41	191	70	30	840
		Seed	148	150	78	50	180
8	Barley	Straw	112	118	138	91	1840
		Grain	139	100	50	29	530
10	W. wheat	Straw	102	207	124	110	1100
		Grain	72	81	44	12	630
10	Turnip rape	Straw	114	114	59	71	670
		Seed	113	94	82	60	540
11	W. wheat	Straw	155	160	77	38	1940
		Grain	126	192	73	9	720
12	W. wheat	Straw	58	53	60	47	1840
		Grain	98	70	27	15	580
13	Rape	Straw	97	252	110	32	850
		Seed	184	135	53	16	200
14	W. wheat	Straw	189	219	189	234	1180
		Grain	101	168	74	236	570
15	Sugar beet	Tops	763	765	679	846	1870

Table 14. The Ra/Ca ratio in growing crops (July 1981) and harvested crops (autumn 1981), respectively.

Field no		Crop	$^{226}Ra/Ca$, mBq g^{-1} July 81	Autumn 81 Straw	Autumn 81 Seed, grain
6		Turnip rape	35	58	28
8		Barley	56	460	530
10	a	W. wheat	234		
	b	"	193	355	1050
	c	Turnip rape	22	33	67
	d	W. wheat	256		
	e	"	139		
11		"	89	746	1200
12		"	295	613	967
13		Rape	50	48	38
14	a	Rape	30		
	b	W. wheat	195	536	1140
	c	Field	91		
15	a	Barley	239		
	b	Sugar beet	477	84	
16		Rape	22		

Table 15. OR-values $(Ra/Ca)_{crop}/(Ra/Ca)_{soil} \times 10^{-3}$.
Assumptions: An evenly distributed uptake of Ra and Ca from the soil profiles down to a depth of 60 cm in July 1981 and down to 90 cm in autumn 1981.

Field no	Crop	Ra/Ca	crop/Ra/Ca$_{H_4NCl}$		Ra/Ca	crop/Ra/Ca$_{AL}$	
		July	Straw	Grain	July	Straw	Grain
6	Turnip rape	17	26	12	116	230	111
8	Barley	5	35	40	12	96	111
10	a W. wheat	32					
	b "-	27	37	110			
	c Turnip rape	3	4	7			
	d W wheat	35					
	e "-	19					
11	W wheat	16	104	167	26	203	326
12	"	72	118	186	98	200	316
13	Rape	20	13	10	10	6	5
14	a Rape	9			22		
	b W wheat	56	197	419	139	586	1246
	c Field	26			65		
15	a Barley	432			160		
	b Sugar beet	862	129		321	87	
16	Rape	17			28		

Table 16. Relationship between radionuclide content in drainage water samples from the research fields, collected in autumn 1980 and spring 1981, respectively.
r = correlation coeff.
a, b = constants

Nuclide	r	a	b
U-238	0.95	12.89	0.68
U-234	0.90	12.71	0.71
Th-230	0.35	8.24	- 0.14
Th-232	0.30	5.76	- 0,20

Table 17. Relationship between radionuclide content in soil and drainage water from the research fields in autumn 1980. Radionuclide content in soil = average values of three depth levels.

Extraction with hot 2-M HCl

Nuclide	r	a	b
U-238	0.02	0.08	$8 \cdot 10^{-5}$
U-234	0.03	0.10	$-1 \cdot 10^{-4}$
Th-230	0.05	0.01	$-2 \cdot 10^{-5}$
Th-232	0.05	0.01	$3 \cdot 10^{-5}$

Extraction with cold 2-M HCl

Nuclide	r	a	b
U-238	0.65	$1 \cdot 10^{-3}$	0.01
U-234	0.57	0.01	$4 \cdot 10^{-3}$
Th-230	0.20	0.01	$6 \cdot 10^{-4}$
Th-232	0.24	$4 \cdot 10^{-3}$	$7 \cdot 10^{-4}$

Extraction with ammonium-oxalat

Nuclide	r	a	b
U-238	0.82	- 0.03	0.03
U-234	0.71	- 0.02	- 0.02
Th-230	0.26	0.01	$1 \cdot 10^{-3}$
Th-232	0.10	0.01	$-5 \cdot 10^{-4}$

Table 18. Relationship between radionuclide content in soil (autumn 1980) and growing crop (1981), and drainage water and growing crop (1981), respectively. From the research fields. Soil samples extracted with ammonium oxalate (U, Th) and AL (Ra) respectively.

Soil - crop

Nuclide	n	r	a	b
U-238	10	0.66	43.28	0.01
U-234	10	0.81	48.64	0.01
Th-230	10	0.35	113.43	- 0.02
Th-232	10	0.01	30.87	$3 \cdot 10^{-4}$
Ra-226	9	0.03	777.90	$- 3 \cdot 10^{-3}$

Water - crop

Nuclide	n	r	a	b
U-238	10	0.46	53.04	0.24
U-234	10	0.65	63.72	0.37
Th-230	10	0.03	64.40	- 0.55
Th-232	10	0.26	35.75	- 1.07
Ra-226	10	0.66	637.50	2.53

Table 19. Relationship between radionuclide content in soil and mature crops (autumn 1981), and groundwater (spring 1981) and harvested crops (autumn 1981). Division into reproductive parts (grain) and vegetative parts (straw). Soil samples extracted with ammonium oxalate (U, Th) and AL (Ra

Soil - crop

Vegetative parts

Nuclide	n	r	a	b
U-238	9	0.20	121.20	$-2 \cdot 10^{-3}$
U-234	9	0.48	211.17	- 0.01
Th-230	9	0.32	133.49	- 0.01
Th-232	9	0.03	78.59	$1 \cdot 10^{-3}$
Ra-226	7	0.30	424.90	0.09

Reproductive parts

Nuclide	n	r	a	b
U-238	9	0.10	126.62	$-8 \cdot 10^{-4}$
U-234	9	0.41	107.45	$5 \cdot 10^{-3}$
Th-230	9	0.55	81.86	- 0.01
Th-232	9	0.28	118.41	- 0.03
Ra-226	7	0.14	662.62	- 0.02

Water - crop

Vegetative parts

Nuclide	n	r	a	b
U-238	9	0.20	117.20	- 0.11
U-234	9	0.22	176.86	- 0.15
Th-230	9	0.22	117.11	- 1.97
Th-232	9	0.42	106.72	- 5.80
Ra-226	9	0.52	990.66	5.19

Reproductive parts

Nuclide	n	r	a	b
U-238	9	$3 \cdot 10^{-4}$	122.61	$1 \cdot 10^{-4}$
U-234	9	0.45	106.16	0.21
Th-230	9	0.56	75.35	- 2.18
Th-232	9	0.01	54.07	- 0.15
Ra-226	9	0.35	421.26	1.29

Table 20. The relative change of radionuclide concentration in growing/harvested crops 1981.

1. Relative change in vegetative parts

Location no	Crop	Δ concentration (%) U-238	U-234	Th-230	Th-232	Ra-226
6	T. rape	- 7	+ 26	- 76	- 12	+ 24
8	Barley	+ 115	+ 74	+ 527	+ 727	+ 309
10	Wheat	+ 12	+ 109	+ 88	+ 34	+ 16
10	T. rape	+ 1	+ 15	- 11	- 13	- 29
11	Wheat	- 13	+ 19	+ 185	+ 36	+ 162
12	"	- 30	- 74	+ 567	+ 292	+ 64
13	Rape	+ 126	+ 327	+ 293	+ 33	- 11
14	Wheat	+ 491	+ 217	+ 530	+ 917	+ 44
15	Sugar beet tops	- 89	- 89	- 68	- 71	- 64

2. Relative change in reproductive parts

Location no	Crop	Δ concentration (%) U-238	U-234	Th-230	Th-232	Ra-226
6	T. rape	+ 236	- 1	- 73	+ 47	- 74
8	Barley	+ 167	+ 47	+ 127	+ 164	+ 18
10	Wheat	- 21	- 18	- 33	- 85	- 33
10	T. rape	± 0	- 5	+ 24	- 27	- 43
11	Wheat	- 29	+ 42	+ 170	- 68	- 3
12	"	+ 18	- 65	+ 200	+ 25	- 48
13	Rape	+ 328	+ 129	+ 89	- 33	- 79
14	Wheat	+ 216	+ 144	+ 147	+ 926	- 30
15	Sugar beet tops	- 89	- 89	- 68	- 71	- 64

Table 21. Uranium concentration factors C_f [(Bq kg^{-1} crop/Bq kg^{-1} soil, dry wt) x 10^{-3}] for growing and mature crops. C_f values calculated with the assumption that an evenly distributed uptake of nuclides will occur from the soil profile; up to July down to 60 cm soil depth and up to autumn down to 90 cm depth. Soil extraction with hot 2 M HCl and ammonium oxalate, respectively.

Site	Crop	Nuclide	$Cf_{(HCl)} \cdot 10^{-3}$			$Cf_{(ox)} \cdot 10^{-3}$		
			Growing crop July	Mature crop Straw	Grain	Growing crop July	Mature crop Straw	Grain
6	Turnip rape	U-238	1.19	1.45	5.27	14.35	11.88	42.92
		U-234	3.71	5.88	4.61	11.27	22.70	17.83
8	Barley	U-238	1.06	2.14	2.66	10.17	20.72	25.72
		U-234	1.30	2.12	1.79	11.25	17.94	15.20
10	W. wheat	U-238	2.32	1.09	0.76	117.69	48.28	34.17
		U-234	1.76	2.08	0.81	72.85	75.89	29.89
10	Turnip rape	U-238	1.28	1.21	1.20	65.19	53.58	53.11
		U-234	1.01	1.14	0.94	41.46	41.60	34.31
11	W. wheat	U-238	2.99	2.56	2.08	14.26	12.38	10.06
		U-234	2.39	2.76	3.32	11.61	13.89	16.68
12	W. wheat	U-238	1.16	0.93	1.57	8.08	6.34	10.72
		U-234	2.58	0.81	1.07	19.76	6.12	8.09
13	Rape	U-238	0.71	1.78	3.38	27.85	82.30	156.12
		U-234	0.89	4.23	2.26	31.91	160.87	86.18
14	W. wheat	U-238	1.92	11.46	6.12	24.75	130.65	69.81
		U-234	4.18	12.87	9.87	41.89	123.40	94.66
15	Sugarbeet	U-238	535.42	73.22	.00	2958.35	457.49	.00
	tops	U-234	564.74	64.87	.00	2400.00	410.76	.00

Table 21. (Cont.)

Site Crop	Nuclide	$Cf_{(HCl)} \cdot 10^{-3}$			$Cf_{(ox)} \cdot 10^{-3}$		
		Growing crop July	Mature crop Straw	Grain	Growing crop July	Mature crop Straw	Grain
Extreme values	U-238	0.71-2.99	0.93-11.46	0.76-6.12	8.08-117.69	6.34-130.65	10.06-156.12
	U-234	0.89-4.18	0.81-12.87	0.81-9.87	11.25- 72.86	6.12-160.87	8.09- 86.18
Arithmetic mean*) ± SD	U-238	1.6 ± 0.7	2.8 ± 3.5	2.9 ± 1.9	35.3 ± 38.0	45.8 ± 43.2	50.3 ± 47.4
	U-234	2.2 ± 1.2	4.0 ± 4.0	3.1 ± 3.0	30.3 ± 21.6	57.8 ± 57.2	37.9 ± 33.6

*) Sugar beet tops not included in mean value.

Table 22. Thorium concentration factors C_f [(Bq kg^{-1} crop/Bq kg^{-1} soil, dry wt) x 10^{-3}] for growing and mature crops. C_f values calculated with the assumption that an evenly distributed uptake of nuclides will occur from the soil profile; up to July down to 60 cm soil depth and up to autumn down to 90 cm depth. Soil extraction with hot 2 M HCl and ammonium oxalate, respectively.

Site	Crop	Nuclide	$Cf_{(HCl)} \cdot 10^{-3}$			$Cf_{(ox)} \cdot 10^{-3}$		
			Growing crop July	Mature crop Straw	Grain	Growing crop July	Mature crop Straw	Grain
6	Turnip rape	Th-230	11.94	2.74	3.05	140.97	100.45	111.94
		Th-232	2.27	1.63	2.71	19.61	44.86	74.78
8	Barley	Th-230	0.77	3.90	1.41	5.57	38.16	13.83
		Th-232	0.37	2.66	0.84	4.26	42.50	13.54
10	W. wheat	Th-230	9.05	5.23	1.85	71.50	72.00	25.54
		Th-232	11.33	4.37	0.47	109.20	69.06	7.53
10	Turnip rape	Th-230	3.94	2.48	4.46	32.62	35.25	48.61
		Th-232	1.55	3.82	3.38	16.54	45.57	38.66
11	W. wheat	Th-230	2.63	5.48	5.20	6.59	20.56	19.49
		Th-232	5.38	5.25	1.24	20.09	25.21	5.97
12	W. wheat	Th-230	0.22	1.31	0.58	1.76	14.49	6.52
		Th-232	0.38	1.31	0.41	3.73	16.55	5.28
13	Rape	Th-230	11.36	34.08	16.42	14.36	70.96	34.19
		Th-232	17.23	16.64	8.32	11.31	25.29	12.64
14	W. wheat	Th-230	4.01	19.31	7.55	11.67	168.46	65.95
		Th-232	3.28	24.22	24.43	10.01	327.94	330.74
15	Barley, sugarbeet tops	Th-230	3.02	308.57[a]	97.26[b]	12.58	1861.47[a]	586.78[b]
		Th-232	5.98	609.07[a]	173.72[b]	33.00	4613.77[a]	1316.00[b]

a) Sugar beet tops July 1981 b) Sugar beet tops Autumn 1981

Table 22. (Cont.)

Site	Crop	Nuclide	$Cf_{(HCl)} \cdot 10^{-3}$			$Cf_{(ox)} \cdot 10^{-3}$		
			Growing crop July	Mature crop Straw	Grain	Growing crop July	Mature crop Straw	Grain
Extreme values		Th-230	0.22-11.94	1.31-19.31	0.58-16.42	1.76-140.97	14.49-168.46	6.52-111.94
		Th-232	0.37-17.23	1.31-24.22	0.41-24.43	3.73-109.20	16.55-327.94	5.28-330.74
Arithmetic mean*) ± SD		Th-230	5.5 ± 4.7	9.3 ± 11.5	5.1 ± 5.1	35.6 ± 48.3	65.0 ± 50.9	40.8 ± 34.6
		Th-232	5.2 ± 6.0	7.5 ± 8.4	5.2 ± 8.2	24.3 ± 34.9	74.6 ± 103.7	61.6 ± 111.5

*) Sugar beet tops not included in mean value.

Table 23. Radium concentration factors C_f [(Bq kg^{-1} crop/Bq kg^{-1} soil, dry wt) x 10^{-3}] for mature crops.
Soil concentration: Mean value of 3 depth levels.
Soil extraction with AL

Site	Crop	$C_f \cdot 10^{-3}$	
		Straw	Grain
6	Turnip rape	72	15
8	Barley	140	39
11	W. wheat	200	72
12	"-	140	44
13	Rape	80	19
14	W. wheat	130	64
15	Sugarbeet tops	140	-
	Extreme values	72-200	15-64
	Arithmetic mean ± SD	130 ± 43	42 ± 23

Table 24. Plant/soil concentration factors obtained in this study, compared to earlier investigations.

Nuclide	$C_f \cdot 10^{-3}$		
	Ref 2	Ref 3	this study*)
Uranium	2.5	3.8	1.3 ± 1
Thorium	4.0	3.8	0.9 ± 0.9
Radium	0.3	16	12 ± 6

*) Arithmetic mean ± 1 SD.
Values compensated for soil extraction efficiencies: U 45 % (HCl); Th 18 % (HCl); Ra 28 % (AL).

Tabe 25. Concentration factors for plant/soil (dry wt). Mature crop, grain. Corrected for soil extraction efficiencies. Geometric mean values (X_m), geometric standard deviations (Sg), and 95 % confidence limits.

Nuclide	n	$X_m \cdot 10^{-3}$	Sg	95 % conf inf $\cdot 10^{-3}$
U-238	8	1.05	0.72	0.54 - 2.03
U-234	8	0.94	0.84	0.66 - 1.33
Th-230	8	0.59	1.06	0.53 - 0.66
Th-232	8	0.37	1.44	0.18 - 0.77
Ra-226	6	10.14	0.64	4.15 - 24.76

Table 26. Concentration factors C_f [(Bq l^{-1} water/Bq kg^{-1} soil) x 10^{-3}] for drainage water and soil for 60-90 cm soil depth. Soil extraction with hot 2 M HCl and ammonium oxalate, respectively (U, Th), and AL and 1 M NH_4Cl, respectively (Ra).

Site no	Year	C_f - Uranium			C_f - Thorium			C_f - Radium	
		Isotope	HCl	Ox	Isotope	HCl	Ox	AL	H_4NCl
1	1980	238	6.53	41.95	230	0.50	0.88	6.32	
		234	7.40	36.90	232	0.24	0.57		
2	1980	238	2.28	12.61	230	1.05	0.80	6.77	
		234	2.04	9.81	232	0.71	0.42		
3	1980	238	0.42	6.25	230	0.29	2.22	6.34	
		234	0.55	4.21	232	0.44	5.00		
4	1980	238	0.17	2.06	230	0.06	0.47	2.91	
		234	0.34	2.30	232	0.08	0.74		
5	1980	238	0.10	0.78	230	0.07	1.36	1.54	
		234	0.14	0.97	232	0.08	1.57		
6	1980	238	9.63	39.78	230	0.10	10.00	1.18	1.49
		234	7.82	37.50	232	0.08	10.00		
	1981	238	9.47	39.13	230	0.17	16.66	1.18	1.49
		234	9.73	46.66	232	0.20	23.33		
7	1980	238	0.14	0.93	230	0.13	2.35	4.38	
		234	0.26	1.70	232	0.08	1.11		
8	1980	238	0.27	2.78	230	0.48	10.64	2.73	1.06
		234	0.40	3.25	232	0.45	14.37		
	1981	238	0.13	1.31	230	0.02	0.64	3.42	1.33
		234	0.15	1.25	232	0.11	3.75		
9	1980	238	0.11	3.82	230	0.05	3.75		1.19
		234	0.50	15.58	232	0.02	2.14		

Table 26. (Cont.)

Site no	Year	C_f - Uranium			C_f - Thorium			C_f - Radium	
		Isotope	HCl	Ox	Isotope	HCl	Ox	AL	H_4NCl
10	1980	238	0.04	1.28	230	0.01	2.30		2.97
		234	0.10	2.55	232	0.01	1.53		
	1981	238	0.06	1.79	230	0.01	2.30		1.85
		234	0.06	1.70	232	0.01	3.84		
11	1980	238	4.74	23.41	230	0.13	2.18	4.41	1.64
		234	4.49	24.24	232	0.15	2.77		
	1981	238	3.26	16.11	230	0.07	1.25	3.67	1.36
		234	3.33	17.96	232	0.12	2.22		
12	1980	238	5.39	35.46	230	0.05	1.33	2.63	0.92
		234	5.76	42.38	232	0.11	2.60		
	1981	238	3.24	21.33	230	0.22	5.33	15.78	5.57
		234	3.26	24.02	232	0.35	8.26		
13	1980	238	0.13	7.50	230	0.23	1.81	2.89	18.18
		234	0.17	7.50	232	0.25	2.85		
	1981	238	0.08	5.00	230	0.23	1.81	2.17	13.63
		234	0.11	5.00	232	0.37	4.28		
14	1980	238	2.69	23.15	230	0.19	7.14	3.20	4.87
		234	2.26	19.52	232	0.04	6.66		
	1981	238	3.61	31.05	230	0.19	7.14	1.60	2.43
		234	3.42	29.52	232	0.19	26.66		
15	1980	238	18.71	132.72	230	0.29	4.44	3.96	16.66
		234	16.78	170.90	232	0.43	10.00		
	1981	238	17.82	126.36	230	0.14	2.22	1.58	6.66
		234	13.57	138.18	232	0.21	5.00		

Table 26. (Cont.)

Site no	Year	C_f - Uranium			C_f - Thorium			C_f - Radium	
		Isotope	HCl	Ox	Isotope	HCl	Ox	AL	H_4NCl
16	1980	238	13.93	112.73	230	2.94	41.25	6.48	9.58
		234	15.49	94.00	232	3.68	35.00		
	1981	238	11.57	93.63	230	0.17	2.50	1.85	2.73
		234	11.86	72.00	232	0.35	3.33		

Table 27. Concentration factors (C_f) for water/soil. Geometric mean values (X_m^f), geometric standard deviations (Sg), and 95 % confidence limits.

Nuclide	n	$X_m \cdot 10^{-3}$	Sg	95 % conf inf $\cdot 10^{-3}$
U-238	25	0.39	2.11	0.09 - 1.74
U-234	25	0.47	1.87	0.13 - 1.64
Th-230	25	0.02	1.50	0.01 - 0.05
Th-232	25	0.02	1.31	0.01 - 0.03
Ra-226	25	0.68	0.65	0.29 - 1.61

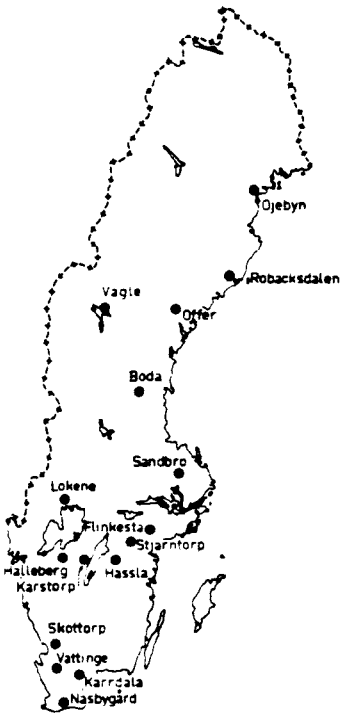
Tabell 28. Transport coefficients ($m^2\ kg^{-1}$) for harvested crops. Soil concentration: mean value of 3 depth levels. Soil extraction with ammonium oxalate (U, Th) and AL (Ra).

Local	Crop	U-238		U-234		Th-230		Th-232		Ra-226	
		Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain
6	Turnip rape	$8\cdot10^{-6}$	$3\cdot10^{-5}$	$3\cdot10^{-5}$	$2\cdot10^{-5}$	$8\cdot10^{-5}$	$8\cdot10^{-5}$	$3\cdot10^{-5}$	$4\cdot10^{-5}$	$1\cdot10^{-5}$	$2\cdot10^{-5}$
8	Barley	$3\cdot10^{-5}$	$4\cdot10^{-5}$	$3\cdot10^{-5}$	$2\cdot10^{-5}$	$4\cdot10^{-5}$	$2\cdot10^{-5}$	$4\cdot10^{-5}$	$2\cdot10^{-5}$	$2\cdot10^{-4}$	$8\cdot10^{-5}$
10	W. wheat	$8\cdot10^{-5}$	$4\cdot10^{-5}$	$8\cdot10^{-5}$	$4\cdot10^{-5}$	$1\cdot10^{-4}$	$4\cdot10^{-5}$	$4\cdot10^{-5}$	$4\cdot10^{-6}$	-	-
10	Turnip rape	$8\cdot10^{-5}$	$8\cdot10^{-5}$	$4\cdot10^{-5}$	$4\cdot10^{-5}$	$4\cdot10^{-5}$	$8\cdot10^{-5}$	$4\cdot10^{-5}$	$3\cdot10^{-5}$	-	-
11	W. wheat	$2\cdot10^{-5}$	$3\cdot10^{-5}$	$2\cdot10^{-5}$	$2\cdot10^{-5}$	$3\cdot10^{-5}$	$3\cdot10^{-5}$	$4\cdot10^{-5}$	$8\cdot10^{-6}$	$3\cdot10^{-4}$	$1\cdot10^{-4}$
12	W. wheat	$8\cdot10^{-6}$	$2\cdot10^{-5}$	$8\cdot10^{-6}$	$1\cdot10^{-5}$	$2\cdot10^{-5}$	$8\cdot10^{-6}$	$2\cdot10^{-5}$	$8\cdot10^{-6}$	$2\cdot10^{-4}$	$8\cdot10^{-5}$
13	Rape	$1\cdot10^{-4}$	$2\cdot10^{-4}$	$2\cdot10^{-4}$	$1\cdot10^{-4}$	$8\cdot10^{-5}$	$4\cdot10^{-5}$	$3\cdot10^{-5}$	$2\cdot10^{-5}$	$1\cdot10^{-4}$	$3\cdot10^{-5}$
14	W. wheat	$2\cdot10^{-4}$	$1\cdot10^{-4}$	$2\cdot10^{-4}$	$2\cdot10^{-4}$	$2\cdot10^{-4}$	$8\cdot10^{-5}$	$2\cdot10^{-4}$	$2\cdot10^{-4}$	$2\cdot10^{-4}$	$8\cdot10^{-5}$
15	Sugarbeet tops	$4\cdot10^{-4}$	-	$4\cdot10^{-4}$	-	$8\cdot10^{-4}$	-	$2\cdot10^{-3}$	-	$2\cdot10^{-4}$	-
extreme values		$8\cdot10^{-6}$ - $2\cdot10^{-4}$	$2\cdot10^{-5}$ - $2\cdot10^{-4}$	$8\cdot10^{-6}$ - $2\cdot10^{-4}$	$1\cdot10^{-5}$ - $2\cdot10^{-4}$	$2\cdot10^{-5}$ - $2\cdot10^{-4}$	$8\cdot10^{-6}$ - $8\cdot10^{-5}$	$3\cdot10^{-5}$ - $2\cdot10^{-4}$	$4\cdot10^{-6}$ - $2\cdot10^{-4}$	$1\cdot10^{-4}$ - $3\cdot10^{-4}$	$2\cdot10^{-5}$ - $8\cdot10^{-5}$
range		$2\cdot10^{-4}$	$2\cdot10^{-4}$	$2\cdot10^{-4}$	$1\cdot10^{-4}$	$2\cdot10^{-4}$	$8\cdot10^{-5}$	$2\cdot10^{-4}$	$2\cdot10^{-4}$	$2\cdot10^{-4}$	$8\cdot10^{-5}$
mean value (sugarbeet tops not included)		$8\cdot10^{-5}$	$8\cdot10^{-5}$	$8\cdot10^{-5}$	$8\cdot10^{-5}$	$8\cdot10^{-5}$	$4\cdot10^{-5}$	$8\cdot10^{-5}$	$4\cdot10^{-5}$	$2\cdot10^{-4}$	$8\cdot10^{-5}$

Table 29 Annual individual dose contributions from uranium, thorium and radium, respectively, from the consumption of cereals. For further details, see text.

Nuclide	C_f		Annual individual dose (Sv yr^{-1})	
			dose contr. from cereals	Σ internal dose
U-234	$2.5 \cdot 10^{-3}$	(2)	$3.9 \cdot 10^{-15}$	$9.4 \cdot 10^{-14}$
	$9 \cdot 10^{-4}$	*)	$1.5 \cdot 10^{-15}$	$9.2 \cdot 10^{-14}$
U-238	$2.5 \cdot 10^{-3}$	(2)	$3.5 \cdot 10^{-15}$	$8.4 \cdot 10^{-14}$
	$1.1 \cdot 10^{-3}$	*)	$1.5 \cdot 10^{-15}$	$8.2 \cdot 10^{-14}$
Th-230	$4.0 \cdot 10^{-3}$	(2)	$3.98 \cdot 10^{-13}$	$6.80 \cdot 10^{-13}$
	$6 \cdot 10^{-4}$	*)	$5.9 \cdot 10^{-14}$	$3.42 \cdot 10^{-13}$
Th-232	$4.0 \cdot 10^{-3}$	(2)	$2.17 \cdot 10^{-12}$	$3.60 \cdot 10^{-12}$
	$4 \cdot 10^{-4}$	*)	$2.01 \cdot 10^{-13}$	$1.63 \cdot 10^{-12}$
Ra-226	$3 \cdot 10^{-4}$	(2)	$2.5 \cdot 10^{-15}$	$5.04 \cdot 10^{-13}$
	$1.0 \cdot 10^{-2}$	*)	$8.2 \cdot 10^{-14}$	$5.83 \cdot 10^{-13}$

*) This study



Location		Soil type
1	Öjebyn	till, fine sand, sandy clay loam
2	Röbäcksdalen	sandy clay loam, clay
3	Vagle	clay till, very fine sand, sil
4	Offer	till, very fine sand, silt, clay
5	Boda	fine sand. silt, varved clay
6	Sandbro	sandy till, very fine sand, clay
7	Lökene	fine sand, sandy clay loam, silt
8	Flinkesta	block, till, gravel, varved clay
9	Hälleberg	fine sand, clay
10	Karstorp	clay, varved clay
11	Hassla	fine sand, sandy clay loam, clay
12	Stjärntorp	till, very fine sand, silt, clay
13	Skottorp	sand, fine sand, clay
14	Vättinge	clay
15	Kärrdala	stony sand, sand, clay
16	Näsbygård	sandy clay till, loamy till, peat

Figure 1 Map of the experiment fields and soil types. Redrawn from / /.

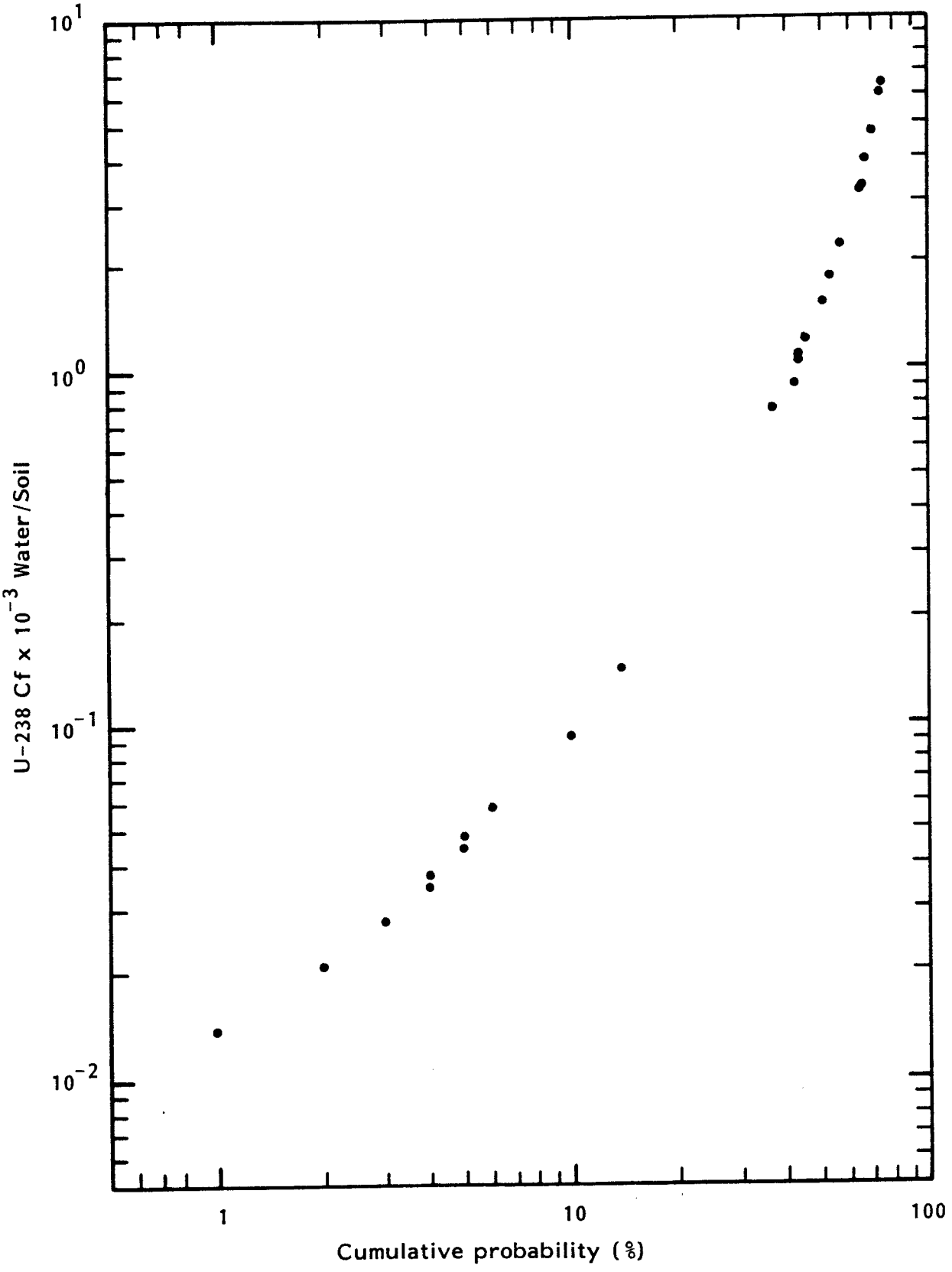


Figure 2 Lognormal probability plot of water/soil C_f values for U-238 from the research fields.

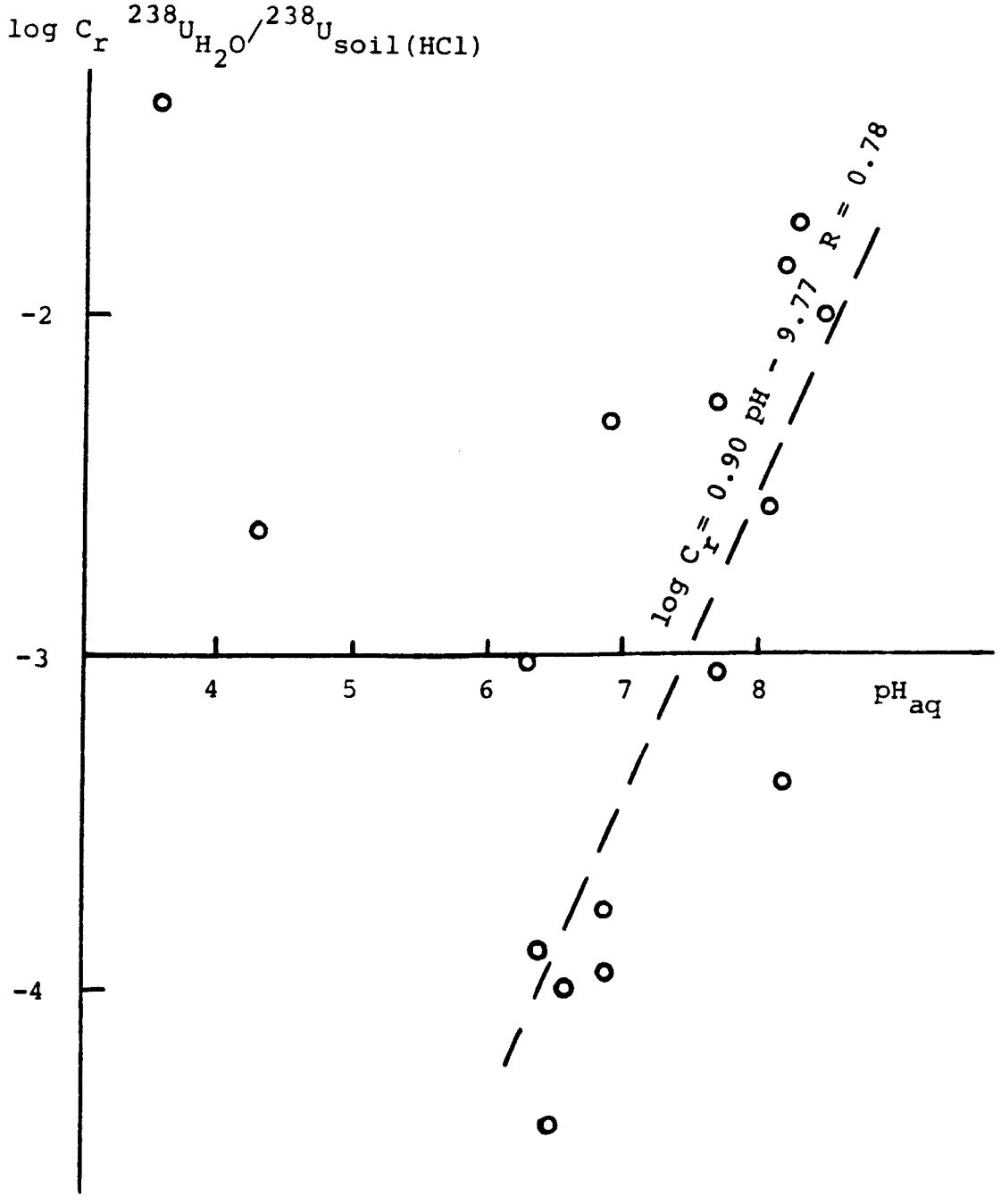


Figure 3 Relationship found between pH-level in the soil layer 60-90 cm and C_r-values calculated on basis of the ^{238}U-content in drainage water and that in the soil layer 60-90 cm extractable with hot 2 M HCl. From (12).

List of KBS's Technical Reports

1977–78
TR 121
KBS Technical Reports 1 – 120.
Summaries. Stockholm, May 1979.

1979
TR 79–28
The KBS Annual Report 1979.
KBS Technical Reports 79-01 – 79-27.
Summaries. Stockholm, March 1980.

1980
TR 80–26
The KBS Annual Report 1980.
KBS Technical Reports 80-01 – 80-25.
Summaries. Stockholm, March 1981.

1981
TR 81–17
The KBS Annual Report 1981.
KBS Technical Reports 81-01 – 81-16.
Summaries. Stockholm, April 1982.

TR 82–28
The KBS Annual Report 1982.
KBS Technical Reports 82-01 – 82-27.

1983
TR 83–01
Radionuclide transport in a single fissure A laboratory study
Trygve E Eriksen
Department of Nuclear Chemistry
The Royal Institute of Technology
Stockholm, Sweden 1983-01-19

TR 83–02
The possible effects of alfa and beta radiolysis on the matrix dissolution of spent nuclear fuel
I Grenthe
I Puigdomènech
J Bruno
Department of Inorganic Chemistry
Royal Institute of Technology
Stockholm, Sweden, January 1983

TR 83–03
Smectite alteration
Proceedings of a colloquium at State University of New York at Buffalo, May 26–27, 1982
Compiled by Duwayne M Anderson
State University of New York at Buffalo
February 15, 1983

TR 83–04
Stability of bentonite gels in crystalline rock – Physical aspects
Roland Pusch
Division Soil Mechanics, Univeristy of Luleå
Luleå, Sweden, 1983-02-20

TR 83–05
Studies in pitting corrosion on archeological bronzes – Copper
Åke Bresle
Jozef Saers
Birgit Arrhenius
Archaeological Research Laboratory
University of Stockholm
Stockholm, Sweden 1983-01-02

TR 83–06
Investigation of the stress corrosion cracking of pure copper
L A Benjamin
D Hardie
R N Parkins
University of Newcastle upon Tyne
Department of Metallurgy and engineering Materials
Newcastle upon Tyne, Great Britain, April 1983

TR 83–07
Sorption of radionuclides on geologic media – A literature survey.
I: Fission Products
K Andersson
B Allard
Department of Nuclear Chemistry
Chalmers University of Technology
Göteborg, Sweden 1983-01-31

TR 83–08
Formation and properties of actinide colloids
U Olofsson
B Allard
M Bengtsson
B Torstenfelt
K Andersson
Department of Nuclear Chemistry
Chalmers University of Technology
Göteborg, Sweden 1983-01-30

TR 83–09
Complexes of actinides with naturally occurring organic substances – Literature survey
U Olofsson
B Allard
Department of Nucluear Chemistry
Chalmers University of Technology
Göteborg, Sweden 1983-02-15

TR 83–10
Radilysis in nature: Evidence from the Oklo natural reactors
David B Curtis
Alexander J Gancarz
New Mexico, USA February 1983

TR 83–11
Description of recipient areas related to final storage of unreprocessed spent nuclear fuel
Björn Sundblad
Ulla Bergström
Studsvik Energiteknik AB
Nyköping, Sweden 1983-02-07

TR 83–12
Calculation of activity content and related propeties in PWR and BWR fuel using ORIGEN 2
Ove Edlund
Studsvik Energiteknik AB
Nyköping, Sweden 1983-03-07

TR 83–13
Sorption and diffusion studies of Cs and I in concrete
K Andersson
B Torstenfelt
B Allard
Department of Nuclear Chemistry
Chalmers University of Technology
Göteborg, Sweden 1983-01-15

TR 83–14
The complexation of Eu (III) by fulvic acid
J A Marinsky
State University of New York at Buffalo
Buffalo, NY 1983-03-31

TR 83–15
Diffusion measurements in crystalline rocks
Kristina Skagius
Ivars Neretnieks
Royal Institute of Technology
Stockholm, Sweden 1983-03-11

TR 83–16
Stability of deep-sited smectite minerals in crystalline rock – chemical aspects
Roland Pusch
Division of Soil Mechanics, University of Luleå
Luleå 1983-03-30

TR 83–17
Analysis of groundwater from deep boreholes in Gideå
Sif Laurent
Swedish Environmental Research Institute
Stockholm, Sweden 1983-03-09

TR 83–18
Migration experiments in Studsvik
O Landström
Studsvik Energiteknik AB
C-E Klockars
O Persson
E-L Tullborg
S Å Larson
Swedish Geological
K Andersson
B Allard
B Torstenfelt
Chalmers University of Technology
1983-01-31

TR 83–19
Analysis of groundwater from deep boreholes in Fjällveden
Sif Laurent
Swedish Environmental Research Institute
Stockholm, Sweden 1983-03-29

TR 83–20
Encapsulation and handling of spent nuclear fuel for final disposal
1 Welded copper canisters
2 Pressed copper canisters (HIPOW)
3 BWR Channels in Concrete
B Lönnerbeg, ASEA-ATOM
H Larker, ASEA
L Ageskog, VBB
May 1983

TR 83–21
An analysis of the conditions of gas migration from a low-level radioactive waste repository
C Braester
Israel Institute of Technology, Haifa, Israel
R Thunvik
Royal Institute of Technology
Stockholm, Sweden November 1982

TR 83–22
Calculated temperature field in and around a repository for spent nuclear fuel
Taivo Tarandi, VBB
Stockholm, Sweden April 1983

TR 83–23
Preparation of titanates and zeolites and their uses in radioactive waste management, particularly in the treatment of spent resins
Å Hultgren, editor
C Airola
Studsvik Energiteknik AB
S Forberg, Royal Institute of Technology
L Fälth, University of Lund
May 1983

TR 83–24
Corrosion resistance of a copper canister for spent nuclear fuel
The Swedish Corrosion Research Institute
and its reference group
Stockholm, Sweden April 1983

TR 83–25
Feasibility study of electron beam welding of spent nuclear fuel canisters
A Sanderson, T F Szluha, J L Turner, R H Leggatt
The Welding Institute Cambridge
The United Kingdom April 1983

TR 83–26
The KBS UO_2 leaching program
Summary Report 1983-02-01
Ronald Forsyth, Studsvik Energiteknik AB
Nyköping, Sweden February 1983

TR 83–27
Radiation effects on the chemical environment in a radioactive waste repository
Trygve Eriksen
Royal Institute of Technology, Stockholm
Arvid Jacobsson
Univerisity of Luleå
Luleå, Sweden 1983-07-01

TR 83–28
An analysis of selected parameters for the BIOPATH-program
U Bergström
A-B Wilkens
Studsvik Energiteknik AB
Nyköping, Sweden 1983-06-08

TR 83–29
On the environmental impact of a repository for spent nuclear fuel
Otto Brotzen
Stockholm, Sweden april 1983

TR 83–30
Encapsulation of spent nucler fuel – Safety Analysis
ES-konsult AB
Stockholm, Sweden April 1983

TR 83–31
Final disposal of spent nuclear fuel – Standard programme for site investigations
Compiled by
Ulf Thoregren
Swedish Geological
April 1983

TR 83–32
Feasibility study of detection of defects in thick welded copper
Tekniska Röntgencentralen AB
Stockholm, Sweden April 1983

TR 83–33
The interaction of bentonite and glass with aqueous media
M Mosslehi
A Lambrosa
J A Marinsky
State University of New York
Buffalo, NY, USA April 1983

TR 83–34
Radionuclide diffusion and mobilities in compacted bentonite
B Torstenfelt
B Allard
K Andersson
H Kipatsi
L Eliasson
U Olofsson
H Persson
Chalmers University of Technology
Göteborg, Sweden 1983-12-15

TR 83–35
Actinide solution equilibria and solubilities in geologic systems
B Allard
Chalmers University of Technology
Göteborg, Sweden 1983-04-10

TR 83–36
Iron content and reducing capacity of granites and bentonite
B Torstenfelt
B Allard
W Johansson
T Ittner
Chalmers University of Technology
Göteborg, Sweden April 1983

TR 83–37
Surface migration in sorption processes
A Rasmuson
I Neretnieks
Royal Institute of Technology
Stockholm, Sweden March 1983

TR 83–38
Evaluation of some tracer tests in the granitic rock at Finnsjön
L Moreno
I Neretnieks
Royal Institute of Technology, Stockholm
C-E Klockars
Swedish Geological
Uppsala April 1983

TR 83–39
Diffusion in the matrix of granitic rock Field test in the Stripa mine. Part 2
L Birgersson
I Neretnieks
Royal Institute of Technology
Stockholm, Sweden March 1983

TR 83–40
Redox conditions in groundwaters from Svartboberget, Gideå, Fjällveden and Kamlunge
P Wikberg
I Grenthe
K Axelsen
Royal Institute of Technology
Stockholm, Sweden 1983-05-10

TR 83–41
Analysis of groundwater from deep boreholes in Svartboberget
Sif Laurent
Swedish Environmental Research Institute
Stockholm, Sweden 1983-06-10

TR 83–42
Final disposal of high-levels waste and spent nuclear fuel – foreign activities
R Gelin
Studsvik Energiteknik AB
Nyköping, Sweden May 1983

TR 83–43
Final disposal of spent nuclear fuel – geological, hydrogeological and geophysical methods for site characterization
K Ahlbom
L Carlsson
O Olsson
Swedish Geological
Sweden May 1983

TR 83–44
Final disposal of spent nuclear fuel – equipment for site characterization
K Almén, K Hansson, B-E Johansson, G Nilsson
Swedish Geological
O Andersson, IPA-Konsult
P Wikberg, Royal Institute of Technology
H Åhagen, SKBF/KBS
May 1983

TR 83–45
Model calculations of the groundwater flow at Finnsjön, Fjällveden, Gideå and Kamlunge
L Carlsson
A Winberg
Swedish Geological, Göteborg
B Grundfelt
Kemakta Consultant Company,
Stockholm May 1983

TR 83–46
Use of clays as buffers in radioactive repositories
Roland Pusch
University of Luleå
Luleå May 25 1983

TR 83–47
Stress/strain/time properties of highly compacted bentonite
Roland Pusch
University of Luleå
Luleå May 1983

TR 83–48
Model calculations of the migration of radio-nuclides from a respository for spent nuclear fuel
A Bengtsson
Kemakta Consultant Company, Stockholm
M Magnusson
I Neretnieks
A Rasmuson
Royal Institute of Technology, Stockholm
May 1983

TR 83–49
Dose and dose commitment calculations from groundwaterborne radioactive elements released from a repository for spent nuclear fuel
U Bergström
Studsvik Energiteknik AB
Nyköping, Sweden May 1983

TR 83–50
Calculation of fluxes through a repository caused by a local well
R Thunvik
Royal Institute of Technology
Stockholm, Sweden May 1983

TR 83–51
GWHRT – A finite element solution to the coupled ground water flow and heat transport problem in three dimensions
B Grundfelt
Kemakta Consultant Company
Stockholm, Sweden May 1983

TR 83–52
Evaluation of the geological, geophysical and hydrogeological conditions at Fjällveden
K Ahlbom
L Carlsson
L-E Carlsten
O Duran
N-Å Larsson
O Olsson
Swedish Geological
May 1983

TR 83–53
Evaluation of the geological, geophysical and hydrogeological conditions at Gideå
K Ahlbom
B Albino
L Carlsson
G Nilsson
O Olsson
L Stenberg
H Timje
Swedish Geological
May 1983

TR 83–54
Evaluation of the geological, geophysical and hydrogeological conditions at Kamlunge
K Ahlbom
B Albino
L Carlsson
J Danielsson
G Nilsson
O Olsson
S Sehlstedt
V Stejskal
L Stenberg
Swedish Geological
May 1983

TR 83–55
Evaluation of the geological, geophysical and hydrogeological conditions at Svartboberget
K Ahlbom
L Carlsson
B Gentzschein
A Jämtlid
O Olsson
S Tirén
Swedish Geological
May 1983

TR 83–56
I: Evaluation of the hydrogeological conditions at Finnsjön
L Carlsson
G Gidlund
II: Supplementary geophysical investigations of the Stärnö peninsula
B Hesselström
Swedish Geological
May 1983

TR 83–57
Neotectonics in northern Sweden – geophysical investigations
H Henkel
K Hult
L Eriksson
Geological Survey of Sweden
L Johansson
Swedish Geological
May 1983

TR 83–58
Neotectonics in northern Sweden – geological investigations
R Lagerbäck
F Witschard
Geological Survey of Sweden
May 1983

TR 83–59
Chemistry of deep groundwaters from granitic bedrock
B Allard
Chalmers University of Technology
S Å Larson
E-L Tullborg
Swedish Geological
P Wikberg
Royal Institute of Technology
May 1983

TR 83–60
On the solubility of technetium in geochemical systems
B Allard
B Torstenfelt
Chalmers University of Technology
Göteborg, Sweden 1983-05-05

TR 83–61
Sorption behaviour of well-defined oxidation states
B Allard
U Olofsson
B Torstenfelt
H Kipatsi
Chalmers University of Technology
Göteborg, Sweden 1983-05-15

TR 83–62
The distribution coefficient concept and aspects on experimental distribution studies
B Allard
K Andersson
B Torstenfelt
Chalmers University of Technology
Göteborg, Sweden May 1983

TR 83–63
Sorption of radionuclides in geologic systems
K Andersson
B Torstenfelt
B Allard
Chalmers University of Technology
Göteborg, Sweden 1983-06-15

TR 83–64
Ion exchange capacities and surface areas of some major components and common fracture filling materials of igneous rocks
B Allard
M Karlsson
Chalmers University of Technology
E-L Tullborg
S Å Larson
Swedish Geological
Göteborg, Sweden May 1983

TR 83–65
Sorption of actinides on uranium dioxide and zirconium dioxide in connection with leaching of uranium dioxide fuel
B Allard
N Berner
K Andersson
U Olofsson
B Torstenfelt
Chalmars University of Technology
R Forsyth
Studsvik Energiteknik AB
May 1983

TR 83–66
The movement of radionuclides past a redox front
I Neretnieks
B Åslund
Royal Institute of Technology
Stockholm, Sweden 1983-04-22

TR 83–67
Some notes in connection with the studies of final disposal of spent fuel. Part 2
I Neretnieks
Royal Institute of Technology
Stockholm, Sweden May 1983

TR 83–68
Two dimensional movements of a redox front downstream from a repository for nuclear waste
I Neretnieks
B Åslund
Royal Institute of Technology
Stockholm, Sweden 1983-06-03

TR 83–69
An approach to modelling radionuclide migration in a medium with strongly varying velocity and block sizes along the flow path
I Neretnieks
A Rasmuson
Royal Institute of Technology
Stockholm, Sweden May 1983

TR 83–70
Analysis of groundwater from deep boreholes in Kamlunge
S Laurent
Swedish Environmental Research Institute
Stockholm, Sweden May 1983

TR 83–71
Gas migration through bentonite clay
Roland Pusch
Thomas Forsberg
University of Luleå
Luleå, Sweden May 31, 1983

TR 83–72
On the thermal conductivity and thermal diffusivity of highly compacted bentonite
Sven Knutsson
University of Luleå
Luleå, Sweden October 1983

TR 83–73
Uranium, thorium and radium in soil and crops – Calculations of transfer factors
Sverker Evans
Studsvik Energiteknik AB
Åke Eriksson
Swedish University of Agricultural Sciences
Sweden June 1983

TR 83–74
Fissure fillings from Gideå, central Sweden
Eva-Lena Tullborg
Swedish Geological
Sven Åke Larson
Geological Survey of Sweden
Gothenburg, Sweden August 1983