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Impact of the water flow rate in the tunnel on the release of radionuclides

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Keywords: Tunnel, backfill, radionuclide, release

Abstract

In performance assessment, it is assumed that the water flow rate in the deposition tunnels, back-filled with a sand-bentonite mixture is very small and that all the radionuclide transport in the tunnel occurs by diffusion. The impact of water flow in the deposition tunnel on the release of radionuclides is addressed by determining the release for different flow rates in the tunnel. It is found that the water flow rate in the tunnel has little influence on the release of radionuclide from the near-field, since the main transport resistance is not located in the tunnel. In general, the transport resistance in the small damage on the canister wall controls the release from the canister into the geosphere before the canister collapses. When the canister has collapsed, the transport resistance is mainly found in the bentonite around the canister in the deposition hole.

Sammanfattning

I säkerhetsanalys av förvaret för använt bränsle antas, att vattenflödet i tunnlarna, återfyllda med en blandning av sand och bentonit, är väldigt litet och att all transport av radionuklider sker genom diffusion. Effekterna av ett vattenflöde i tunneln (med avseende på transport av radionuklider) undersöks genom att bestämma radionuklidläckaget för flera olika vattenflöden. Man kan visa att vattenflödet i tunneln har en liten inverkan på läckaget av nuklider inom närområdet, då huvuddelen av transportmotståndet inte sker i tunneln. Allmänt sett gäller att de små hål (skada) som uppstått på kapselväggarna avgör utsläppet av nukliderna, och därmed läckaget till geosfären, innan kapseln slutligen kollapsar. När så sker, återfinns huvuddelen av motståndet i bentonitlagret som omger kapseln i deponeringshålet.

Executive summary

Canisters containing spent fuel will be deposited in bore-holes in the floors of tunnels at a depth of about 500 metres. In the deposition hole, the canister will be surrounded by highly compacted bentonite and the tunnel will be back-filled with a mixture of sand and bentonite. In the deposition tunnel, the water flow will be very small due to the low hydraulic conductivity of the sand-bentonite mixture.

The aim of this report is to address the impact of a possible water flow in the deposition tunnel back-filled with sand/bentonite. The radionuclide release from the near field is calculated for different flow rates (hydraulic conductivities) in the tunnel. The radionuclide release is calculated including all the possible pathways through which the nuclides may reach the flowing water. This is done using the compartment model NUCTRAN /Romero et al, 1995a,b/.

The results show that for the interval of flow rates used in the calculations, the radionuclide release depends on the transport properties, the nuclide half-lives, and the time when the peak is reached. For Sr-90, which is a slightly sorbing nuclide with a short half-life, the impact of the water flow rate is negligible. This radionuclide decays before it reaches the fracture zone intersecting the deposition tunnel. For the long-lived radionuclides, which show a high solubility, the maximum release is found directly after canister collapse. When the canister collapses, the concentration in the canister decreases rapidly. For the long-lived U-238, where the concentration in the canister is limited by the solubility, the peak is obtained after a very long time.

For the long-lived radionuclide I-129, a slight increase in the release is observed with increasing water flow rate in the tunnel. If the water flow increases to 1.0 m^3/year, the release increases by only 20% compared to the case without flow. It is the resistance through the bentonite that mainly controls the transport of I-129 from the canister.

For the long-lived radionuclide Cs-135, the release increases by a factor of two when the water flow increases from zero to 1.0 m^3/year in the tunnel. The greater increase in the release of Cs-135 than of I-129 is explained by the fact that the concentration of Cs-135 in the tunnel is increasing when the canister collapses. The concentration of I-129 in the tunnel has reached its maximum value before canister collapse.

For the long-lived U-238, the water flow rate in the tunnel has very little influence on the release. The concentration in the canister is constant during a very long time (several million years) since it is controlled by the solubility the uranium. This constant concentration in the canister means that a quasi steady state is reached in the bentonite surrounding the canister and in the sand-bentonite in the deposition tunnel.

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1 Introduction and background

In the Swedish concept of a final high-level waste repository, canisters containing spent fuel will be deposited in bore-holes in the floors of tunnels at a depth of about 500 metres. In the deposition hole, the canister will be surrounded by highly compacted bentonite and the tunnel will be back-filled with a mixture of sand and bentonite. Due to the very small hydraulic conductivity of the bentonite, the water flow around the canister will be very small and most of the transport will take place by diffusion through the bentonite. In the deposition tunnel, the water flow will be very small due to the low hydraulic conductivity of the sand-bentonite mixture /Push et al, 1991/. Nuclides escaping from the canister may reach the water flowing in the fractures through several paths. The most important ones are shown in Figure 1-1. In this concept, it is expected that the transport in the clay and sand-bentonite occurs by diffusion only.

In an earlier report /Moreno et al, 1995/, the release of radionuclides was studied in a deposition tunnel filled with gravel instead of sand-bentonite. It was found that the flow rate in the tunnel is controlled by the hydraulic conductivity of the fracture zones intersecting the drift and not by the conductivity of the backfill if this is rather high.

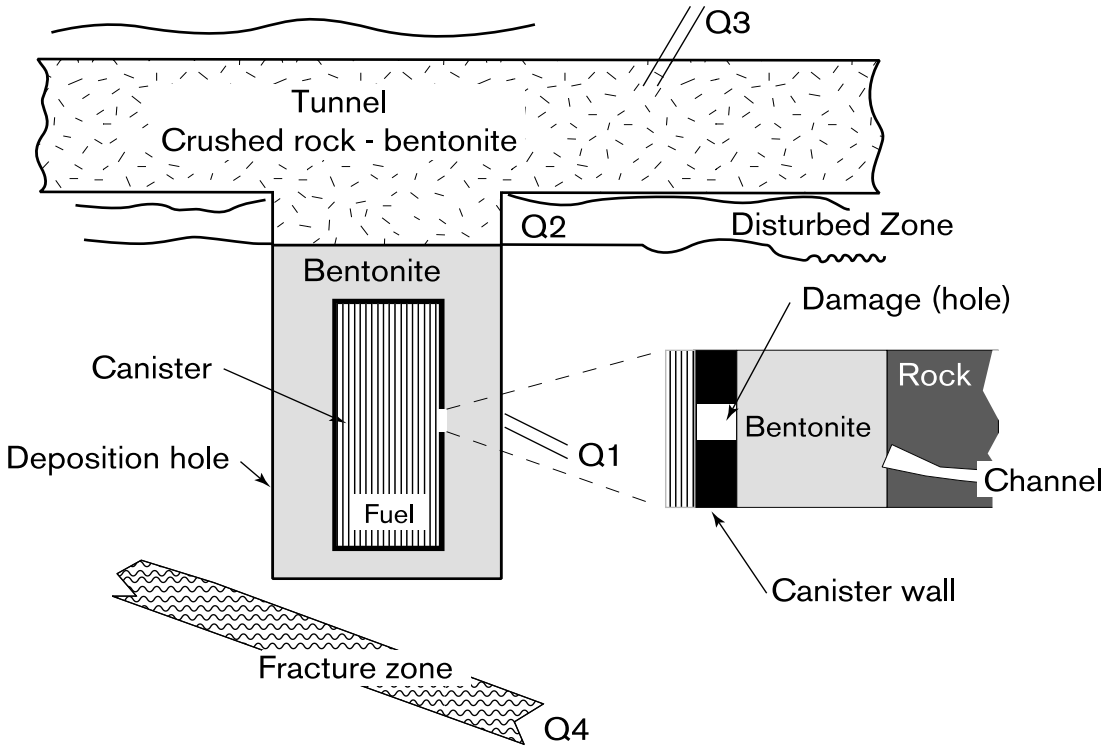

Figure 1-1. *Schematic view of the KBS-3 repository design, showing the small hole in the canister and the location of the various escape routes.*

The water flow rate in the deposition tunnel is controlled by the hydraulic conductivity in the tunnel only if a backfill with a low hydraulic conductivity is used, with a particle size of the backfill less than 0.1 mm in diameter. In those calculations, a water flow of 198 m^3/year was used in the tunnel. It was found that the release of radionuclides with a high diffusion coefficient in the bentonite, such as Cs-135, Cs-137 and Sr-90, increases if the tunnel is filled with sand or gravel instead of sand-bentonite. The release of the long-lived nuclides I-129 and U-238 is not influenced by the filling material used in the tunnel. For Pu-239 with high sorption in the bentonite and a half-life of 24 000 years, the release is not influenced by the choice of filling material in the tunnel.

The aim of this report is to study the effect of a possible water flow in the deposition tunnel back-filled with sand/bentonite. To investigate the importance of the hydraulic conductivity of the backfill in the deposition tunnel for the safety of the repository, the release from the near field is calculated for different flow rates (hydraulic conductivities) in the tunnel. The radionuclide release is calculated including all the possible pathways through which the nuclides may reach the flowing water. This is done using the compartment model NUCTRAN /Romero et al, 1995a,b/.

2 Preliminary calculations

The canisters containing the waste are deposited in bore-holes excavated in the floors of tunnels at a depth of about 500 metres. The bore-holes are filled with highly compacted bentonite and the deposition tunnel is back-filled with sand-bentonite. The hydraulic conductivity of the backfill is expected to be small /Push et al, 1991/. Therefore, the water flow in the tunnel will be very small. In this report, the radionuclide release is calculated for different water flow rates in the tunnel caused by a higher hydraulic conductivity of the sand-bentonite mixture than the expected low value. Before the determination of the radionuclide release, some preliminary calculations are carried out.

In these preliminary calculations some general results are addressed. The water flow in the tunnel back-filled with sand-bentonite is calculated for different values of the hydraulic gradient and hydraulic conductivity of the sand-bentonite mixture. The relative importance of radionuclide transport by the flowing water in the tunnel (advection) compared with transport by diffusion is also discussed.

2.1 Flow in the tunnel

Around the tunnel there is a zone with a higher hydraulic conductivity than the intact rock. According to Push et al /1991/, two zones may be distinguished, the blast-damaged zone with an expected hydraulic conductivity of about 10^{-7} m/s and the stress-influenced zone with a hydraulic conductivity of 10^{-8} m/s. For the sand-bentonite in the tunnel the expected value is 10^{-9} m/s.

The regional water flow in/around the repositor-y is a site-specific parameter, which is determined by the average hydraulic conductivity, the hydraulic gradient and other boundary conditions. The hydraulic conductivity is determined by hydraulic measurements and may vary over a wide interval. The water infiltration and the topography mainly determine the hydraulic gradient.

In these calculations, the hydraulic conductivity of the backfill is varied from 10^{-9} to 10^{-7} m/s. For the hydraulic gradient, values of 0.01 and 0.05 m/m are used. Table 2-1 shows the Darcy velocity (m^3/m^2year) in the tunnel for the different values of hydraulic conductivity. The water flow (m^3/year) is also shown, which is calculated for a cross section area of 12.6 m^2.

Table 2-1. Darcy velocity and water flow rate in the tunnel for different values of hydraulic conductivity and hydraulic gradient.

Hydraulic conductivity, m/s	Hydraulic gradient, m/m	Darcy velocity, m^3/m^2year	Water flow, m^3/year
$1.0 \cdot 10^{-9}$	0.01	0.00032	0.004
$1.0 \cdot 10^{-8}$	0.01	0.0032	0.04
$1.0 \cdot 10^{-7}$	0.01	0.032	0.4
$1.0 \cdot 10^{-9}$	0.05	0.0016	0.02
$1.0 \cdot 10^{-8}$	0.05	0.016	0.2
$1.0 \cdot 10^{-7}$	0.05	0.16	2.0

2.2 Radionuclide transport in the tunnel

Solutes in a porous medium may be transported by diffusion (molecular diffusion in the pores) or by advection (with the flowing water). If the water flow rate is very small, most of the transport takes place by diffusion. On the other hand, if the water flow rate is large, diffusion becomes negligible. Dispersion may however cause the spreading of the radionuclides when they are transported by the flowing water. The relative importance of the radionuclide transport that takes place by advection compared with the transport that takes place by diffusion will be addressed. Transport through a porous media may be written as:

$$\varepsilon \frac{\partial C}{\partial t} + (1-\varepsilon)\rho_s \frac{\partial C_s}{\partial t} + v_o \frac{\partial C}{\partial x} = v D_L \frac{\partial^2 C}{\partial x^2} \qquad (2\text{-}1)$$

where

C Concentration in the pore water, mol/m^3

C_s Concentration sorbed on the solid, mole/kg

D_L Longitudinal dispersion, m^2/s

t Time, s

v_o Darcy velocity, $m^3/m^2 s$

x Distance along the flow direction, m

ε Porosity

ρ Density, kg/m^3

For rather low concentrations, a linear isotherm for the sorption of the radionuclides on the solid may be assumed.

$$C_s = K_d C \tag{2-2}$$

Insertion of (2-2) in (2-1) leads to:

$$\left[\varepsilon + (1-\varepsilon)\cdot K_d \rho_s\right] \frac{\partial C}{\partial t} + v_o \frac{\partial C}{\partial x} = D_L \frac{\partial^2 C}{\partial x^2} \tag{2-3}$$

Equation (2-3) may be expressed as

$$\frac{\partial C}{\partial t} + \frac{v_o}{\varepsilon R}\frac{\partial C}{\partial x} = \frac{D_L}{\varepsilon R}\frac{\partial^2 C}{\partial x^2} \tag{2-4}$$

where R is a retardation coefficient defined as

$$R = \left[1 + \frac{(1-\varepsilon)}{\varepsilon} K_d \rho_s\right]$$

If it is assumed that the spreading of the solute take place only by molecular diffusion, the dispersion term may be replaced by the effective diffusivity, $\varepsilon \cdot D_p$. Transport by advection (flow) may then be compared with transport by diffusion by using the Peclet number, which is defined as,

$$Pe = \frac{v_o L}{D_e} \tag{2-5}$$

If the Peclet number is much larger than 1, transport by advection is important. For values of the Peclet number much less than 1, the transport by flow is negligible. Table 2-2 shows values of Peclet numbers calculated for water flow rates according to Table 2-1 and for an effective diffusion coefficient in the sand-bentonite of 10^{-10} m^2/s (see Table 3-3). These calculations are made for a porosity of 0.25 and a distance along the tunnel of 10 m.

Table 2-2. Peclet number calculated for different Darcy velocities in the tunnel.

Darcy velocity, m^3/m^2year	Effective diffusion, m^2/year	Length, m	Peclet number
0.0003	0.0032	10.0	1
0.003	0.0032	10.0	10
0.03	0.0032	10.0	100

The results in Table 2-2 show that transport by advection may be an important mechanism for the transport of radionuclides in the tunnel even for small flow rates. Only for the smallest flow rate can transport by flow be ruled out. Moreover, the radionuclides that escape from the canister have to diffuse through the small region damaged on the canister wall, through the bentonite above and around the canister and finally through the sand-bentonite in the tunnel. Before the collapse of the canister, the radionuclide transport is controlled mainly by the transport resistance in the small damage on the canister wall. After canister collapse, the transport resistance through the bentonite in the deposition hole is the most important. This means that water flow in the tunnel may only slightly modify the radionuclide release through the tunnel.

3 Calculations

3.1 Calculated cases

The release into the geosphere takes place through the four pathways shown in Figure 1-1. Path Q1 represents a fracture intersecting the deposition hole, Q2 the disturbed zone around the deposition tunnel, Q3 a fracture intersecting the deposition tunnel and Q4 a fracture zone below the deposition hole. Radionuclides transported through the tunnel (by diffusion and advection) may reach fracture zones that intersect the deposition tunnel at a certain distance. For this reason, a canister cannot be deposited too close to a fracture zone.

According to the preliminary calculations, the water flux in the tunnel would be 0.032 m^3/m^2 year for a hydraulic gradient of 0.01 and a hydraulic conductivity of 10^{-7} m/s. Since the cross sectional area of the tunnel is about 12.6 m^2, the calculations were done with water flow rates varying from 0 to 1.0 m^3/year. It is expected, however, that the water flow in the tunnel is less than 1.0 m^3/year.

It is assumed that the canister is initially damaged, and that the damaged area is 1 mm^2 in size. The damage size is constant for the first 200 000 years. At this time, the canister collapses and the damage grows to a size of 0.3 m^2. This size is not crucial, since the resistance in the hole becomes negligible. At a given distance from the deposition borehole containing the canister, a fracture zone intersects the tunnel. Distances of 10 and 20 m between the deposition hole and this fracture zone are used in the calculations.

Table 3-1. Geometric and hydrological data used in the calculations.

	Values used
Water flux in the tunnel, m^3/year	0.00 – 0.0001 – 0.01 – 1.0
Tunnel cross-section area, m^2	12.6
Transport distance in the tunnel, m	10 – 20
Sand-bentonite porosity	0.25
Initial damage size, mm^2	1.0
Time for collapse, years	200 000
Damage size after collapse, m^2	0.3

3.2 Data used in the calculations

The release of the radionuclides escaping from the canister into the geosphere is determined by the transport properties of the materials that the nuclides encounter when they are transported through the canister damage, the deposition hole and the tunnel. This means that the diffusion coefficient and sorption constant of the radionuclides in these materials are important parameters. Half-lives also have a large influence on the release through the tunnel, short-lived radionuclides can decay to a negligible concentration before they reach the fracture zone intersecting the deposition tunnel. For some radionuclides, the solubility controls the release.

For these calculations, several radionuclides were chosen to cover a wide range of half-lives, and of sorption constants and diffusion coefficients in bentonite and sand-bentonite. Table 3-2 shows the half-lives and the solubilities for some radionuclides. The inventory in the canister is also shown, but in some cases the calculations are done for an inventory of one mole per canister.

Table 3-2. Half-life and inventory per canister and solubilities for some radionuclides.

	Half-life, years	Inventory, mole/canister	Solubility, mole/m^3
I-129	$1.57 \cdot 10^7$	2.22	High
Cs-135	$2.95 \cdot 10^6$	4.55	High
Cs-137	30.1	6.18	High
Sr-90	28.8	4.04	High
Pu-239	24 100	28.05	$2 \cdot 10^{-5}$
U-238	$4.47 \cdot 10^9$	5 603.00	$2 \cdot 10^{-4}$
Np-237	$2.10 \cdot 10^6$	8.95 (+Am-241)	$2 \cdot 10^{-5}$
Am-241	433	5.92	$2 \cdot 10^{-5}$
U-234	$2.45 \cdot 10^5$	2.03 (+Pu-238)	$2 \cdot 10^{-4}$
Th-230	$8.00 \cdot 10^4$	$1.1 \cdot 10^4$	$2 \cdot 10^{-7}$
Ra-226	1 602	$1.8 \cdot 10^8$	$2 \cdot 10^{-4}$

The values recommended by Andersson /1999/ are used for effective diffusion. For bentonite he recommends the values suggested by Yu and Neretnieks /1997/ and adjusted by Ochs /1997/. For diffusion in the rock, he recommends the values suggested by Ohlsson and Neretnieks /1997/ for high ionic strength. For sand-bentonite, the effective diffusivity recommended by Andersson /1999/ is $1 \cdot 10^{-10}$ m^2/s. These values are shown in Table 3-3.

For sorption constants, the recommendations of Andersson /1999/ are used. For bentonite, he recommends the values suggested by Yu and Neretnieks /1997/ and adjusted by Ochs /1997/. These are realistic values; the conservative ones are in general 10 times smaller. For the rock, they recommend the values suggested by Carbol and Engkvist /1997/ for saline water and reducing conditions when applicable. For sand-bentonite, Andersson /1999/ recommends the values for bentonite (realistic and for saline water) divided by 5. These sorption constants are shown in Table 3-4.

Table 3-3. Effective diffusion coefficients in bentonite, sand-bentonite and rock for the radionuclides.

Radionuclide	D_e – bentonite m^2/s, (1)	D_e – rock m^2/s, (2)	D_e – s/b m^2/s, (3)
I	$3 \cdot 10^{-12}$	$1 \cdot 10^{-13}$	$1 \cdot 10^{-10}$
Cs	$6 \cdot 10^{-10}$	$1 \cdot 10^{-13}$	$1 \cdot 10^{-10}$
Sr	$5 \cdot 10^{-10}$	$1 \cdot 10^{-13}$	$1 \cdot 10^{-10}$
Pu	$3 \cdot 10^{-10}$	$1 \cdot 10^{-13}$	$1 \cdot 10^{-10}$
U	$5 \cdot 10^{-10}$	$1 \cdot 10^{-13}$	$1 \cdot 10^{-10}$
Np	$1 \cdot 10^{-09}$	$1 \cdot 10^{-13}$	$1 \cdot 10^{-10}$
Ra	$5 \cdot 10^{-10}$	$1 \cdot 10^{-13}$	$1 \cdot 10^{-10}$
Th	$7 \cdot 10^{-11}$	$1 \cdot 10^{-13}$	$1 \cdot 10^{-10}$

(1) Values suggested by Yu and Neretnieks /1997/ and adjusted by Ochs /1997/. They correspond to values for saline water. When values for oxidising and reducing conditions were available, the value for reducing conditions was taken (U and Np).

(2) Values recommended by Olhsson and Neretnieks /1997/. For high ion strength these values are equal to or smaller than $1 \cdot 10^{-13}$ m^2/s.

(3) Values proposed by Andersson /1999/.

Table 3-4. Sorption coefficients in bentonite, sand-bentonite and rock.

Radionuclide	K_d – clay m^3/kg, (4)	K_d – rock m^3/kg, (5)	K_d – s/b m^3/kg, (6)
I	0.00	0.00	0.00
Cs	0.05	0.05	0.01
Sr	0.01	0.0002	0.002
Pu	3.0	5.0	0.6
U	1.0	5.0	0.2
Np	3.0	5.0	0.6
Ra	0.01	0.02	0.002
Th	3.0	5.0	0.6

(4) Values taken from Yu and Neretnieks /1997/ and adjusted by Ochs /1997/ for saline water and reducing conditions when applicable. They are realistic values. Conservative values are, in general, 10 times smaller.

(5) Values recommended by Carbol and Engkvist /1997/ for saline water and reducing conditions when applicable.

(6) Values recommended by Andersson /1999/, values for bentonite (realistic and for saline water) divided by 5.

4 Results

4.1 Results for the base case

The distance between the deposition hole and the fracture zone intersecting the tunnel is assumed to be 10 m. The impact of water flow in the deposition tunnel is assessed by comparing the release with the release when there is not-flow in the tunnel. In this set of calculations, five radionuclides were chosen, namely, Cs-135, Sr-90, I-129, Ra-226 and U-238. For the first three radionuclides, the calculations were done for one mole since their solubilities are high. For U-238 an inventory of 5603 moles was assumed /Romero et al, 1995b/. The calculation for Ra-226 were done assuming an initial content of one mole in the canister. Ra-226 is a daughter nuclide in the 4n+2 chain. The release of Ra-226 is controlled by the transport of U-238 in the near field.

4.1.1 No flow in the deposition tunnel

The release through the four pathways shown in Figure 1-1 and the expected release through the tunnel into a fracture zone intersecting the deposition tunnel at a distance of 10 m are shown in Figure 4-1. The release into the fracture zone intersecting the tunnel occurs only by diffusion in this case.

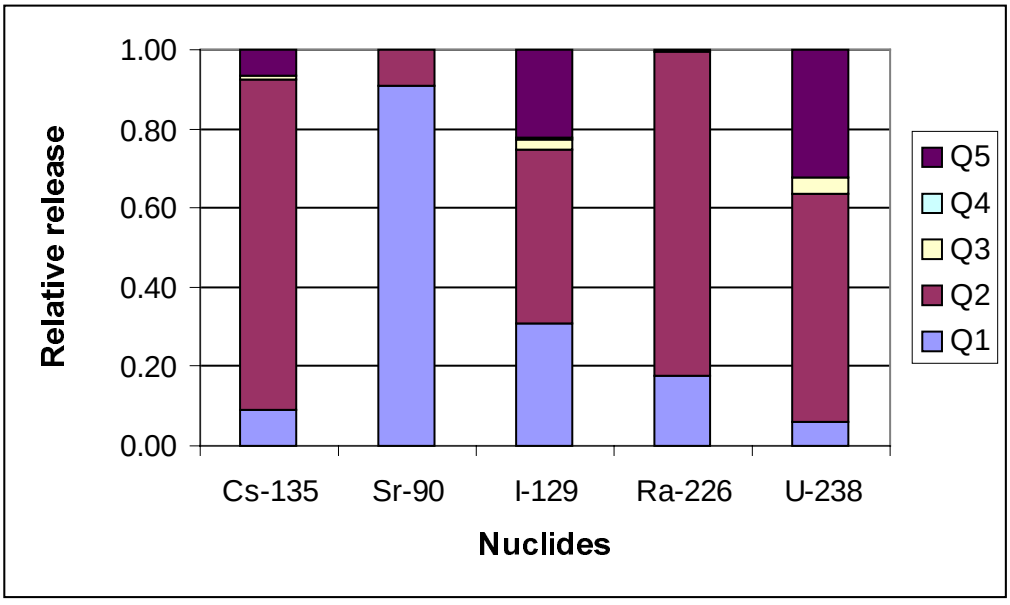

Figure 4-1. *Release through all pathways with no water flow in the tunnel. Path Q5 corresponds to diffusion into a fracture zone intersecting the tunnel at a distance of 10 m.*

According to Figure 4-1, for short-lived radionuclides the release is dominated by the path Q1, and the release in paths Q3, Q4 andQ5 is negligible. These radionuclides decay before they reach these paths. For the long-lived nuclides, the release through the path Q5 is significant. They have sufficient time to reach the fracture zone intersecting the tunnel. Path Q4 is negligible for all these radionuclides. Paths Q1 and Q2 are present for all the radionuclides.

4.1.2 Impact of the water flow rate in the deposition tunnel

Figure 4-2 shows the relative release of activity from the near field into the geosphere. The relative release is calculated in relation to the total release when there is no flow in the tunnel. Total release includes the release by the four paths shown in Figure 1-1 and the radionuclides transported through the tunnel into the fracture zone intersecting the tunnel.

For the water flow rate calculated, the results depend on the transport properties, on the nuclide half-lives, and on the time when the peak is reached. For Sr-90, which is a short-lived radionuclide, the impact of the water flow rate is negligible. This radionuclide decays before it reaches the fracture zone intersecting the deposition tunnel.

For the long-lived radionuclides, which show a high solubility, the maximum release is found directly after canister collapse. When the canister collapses, the concentration in the canister decreases rapidly. For the long-lived U-238, where the concentration in the canister is limited by the solubility, the peak is obtained after a very long time.

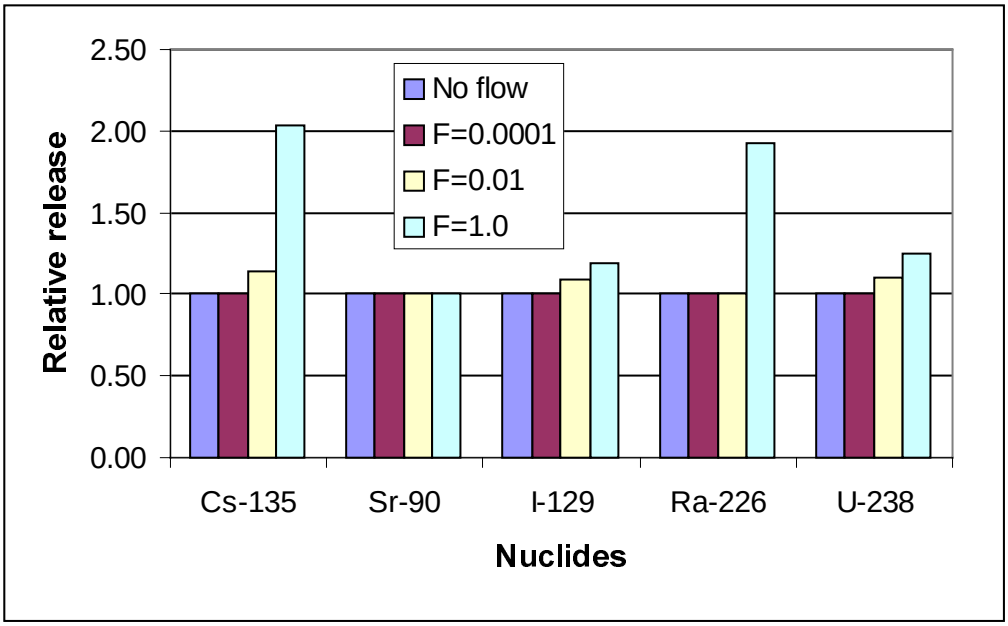

Figure 4-2*. Relative release rate for different water flow rates in the tunnel.*

For the long-lived radionuclide I-129, a slightly increase in the release is observed with increasing water flow rate in the tunnel. If the water flow is increased to 1.0 m^3/year, the release increases by only 20 % compared with the release without water flow. The transport of I-129 from the canister is controlled mainly by the resistance of the bentonite.

For the long-lived radionuclide Cs-135, the release is increased by a factor of two when the water flow in the tunnel is 1.0 m^3/year. The greater increase of Cs-135 than of I-129 can be explained by the fact that the concentration of Cs-135 increases in the tunnel when the canister collapses, whereas concentration of I-129 in the tunnel reaches its maximum value before canister collapse.

The water flow rate in the tunnel has very little influence on the release of the long-lived U-238. The concentration in the canister is constant over a very long time (several million of years) since it is controlled by the solubility of the uranium. This constant concentration in the canister means that a quasi steady state is reached in the bentonite surrounding the canister and in the sand-bentonite mixture in the deposition tunnel.

5 Discussion of the results. Uncertainties

The results presented in this report may be influenced by the selection of some of the parameters. In order to address this, calculations have been made using other values for some of the parameters. The time when the canister collapses is one important parameter determining the release from the near field. Before canister collapse, the release is controlled mainly by the transport resistance in the damage and secondarily by the resistance in the bentonite located in the deposition hole. After canister collapse, the transport is controlled by the bentonite in the deposition hole.

In these calculations, a distance of 10 m between the deposition hole and a fracture zone intersecting the deposition tunnel is used. In order to reduce the release into this fracture zone, a larger distance could be used. However, since the transport resistance in the damage and bentonite controls the release, no large reduction in the release is expected as a result of increasing the distance to the fracture zone.

Other important factor determining the release from the canister is the pattern follows by the damage growth. In the calculations is assumed that the damage size is constant under 200,000 years, at that time the canister collapse. Therefore, some calculations were performed assuming that the damage size grows linearly with the time, reaching a size of 0.1 m^2 at 200,000 years.

5.1 Time for canister collapse

In the base case, it is assumed that the canister collapses at $2.0 \cdot 10^5$ years. Here, the calculations are also performed for a collapse time of $2.0 \cdot 10^4$ years. The relative release in both cases is shown in Figure 5-1. These values are calculated as the ratio of the radionuclide release with a flow of 1.0 m^3/year in the tunnel to the release without water flow in the tunnel.

The results show that the effect of the water flow on the radionuclide release is slightly greater when the canister collapses earlier.

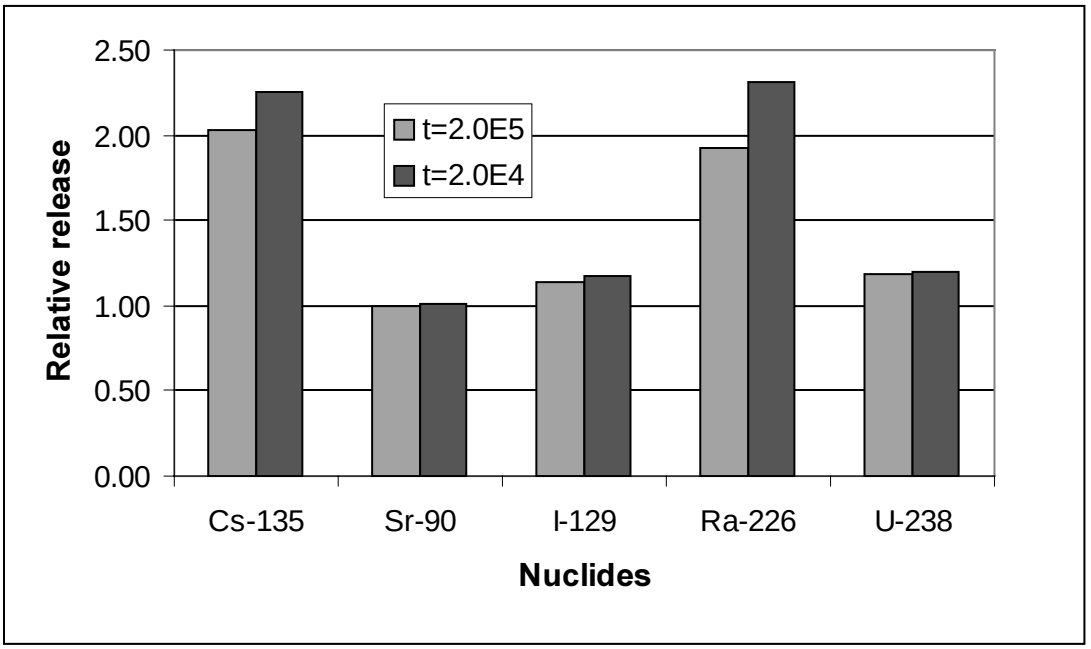

Figure 5-1. *Relative release due to water flow for two different times for canister collapse, $2.0 \cdot 10^4$ and $2.0 \cdot 10^5$ years.*

5.2 Distance to the fracture zone

The distance to the closest fracture zone intersecting the deposition tunnel is assumed to be 10 m in the base case. We explored, whether increasing this distance to 20 m has any effect on the release of radionuclides from the near field. The results are shown in Figure 5-2. They show that increasing the distance to the fracture zone has little impact on the release.

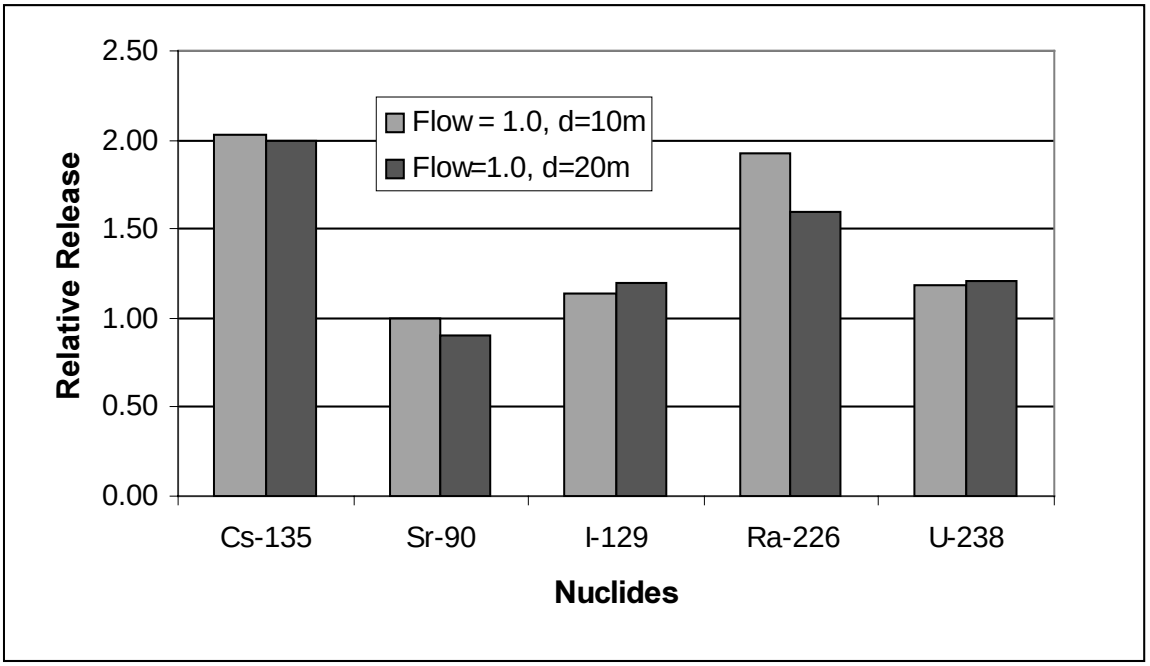

Figure 5-2. *Relative release for two different distances between the deposition hole and the fracture zone intersecting the deposition tunnel.*

5.3 Growth of the damage

In the base case, a step growth in the damage on the canister wall is assumed. This means that the size of the damage is kept constant for a certain time ($2.0 \cdot 10^5$ years) and that the canister then collapses. Calculations have also been performed assuming that the damage grows continuously from the initial damage size to a very large damage (0.1 m^2) in $2.0 \cdot 10^5$ years. The results are shown in Figure 5-3 and show that the pattern followed by the damage growth has only a slight influence on the radionuclide release from the near field.

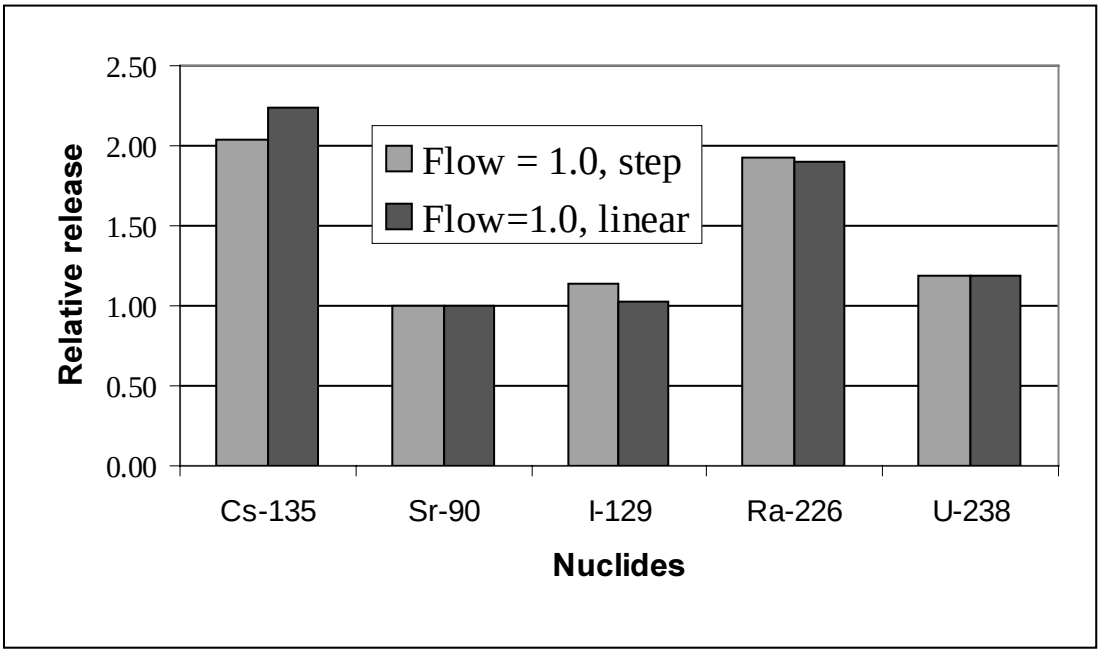

Figure 5-3. *Relative release as a function of the pattern of damage growth.*

5.4 Extreme water flow in the tunnel

Figure 4-2 shows that the relative release increases with increasing water flow in the tunnel. The release increases by a factor of two for some radionuclides when the water flow increases from 0.01 to 1.0 m^3/year. In order to test the impact of a high water flow rate, calculations were performed for a water flow rate of 10.0 m^3/year. Results show that the release increases only slightly (see Figure 5-4).

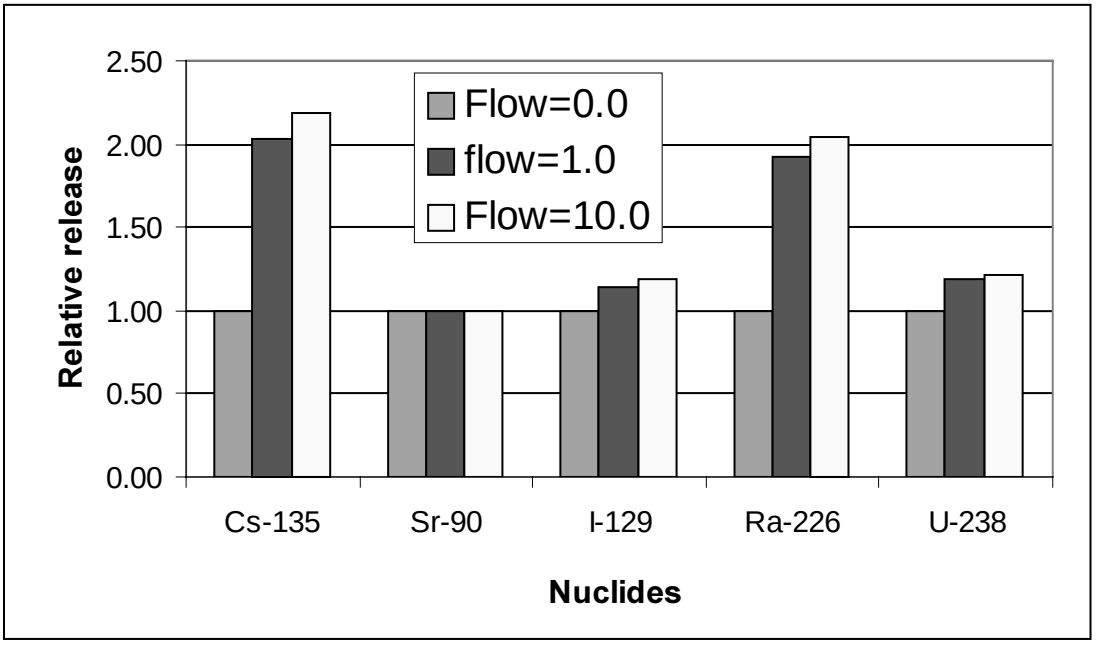

Figure 5-4. *Relative release rate as a function of the water flow rate in the tunnel. A high flow rate is included for the sake of comparison.*

6 Conclusions

The impact of water flow in the deposition tunnel backfilled with sand-bentonite is addressed in the report. Different flow rates in the tunnel were simulated.

A wide interval of water flow rates was used in the simulations. It is expected that the water flow rate in the tunnel is less than 1 m^3/year, since the interval for the hydraulic conductivity of the sand-bentonite mixture and the hydraulic gradient are very conservative. For the diffusion and sorption data, the values recommended by Andersson /1999/ were used.

The results shown that the water flow rate in the tunnel has little influence on the release of radionuclides into the geosphere, since the main transport resistance is not located in the tunnel. In general, the transport resistance at the damage site controls the release from the canister into the geosphere before canister collapses. When the canister has collapsed, the transport resistance is found mainly in the bentonite in the deposition hole.

The assumptions regarding the time when the canister collapses, the pattern followed by the damage growth and the distance to the closest fracture zone do not significantly modify the impact of the water flow in the tunnel.

7 References

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Appendix A

Results for the base case

Radionuclide releases in the case where a fracture zone intersects the deposition tunnel at a distance of 10 m is shown in figures below.

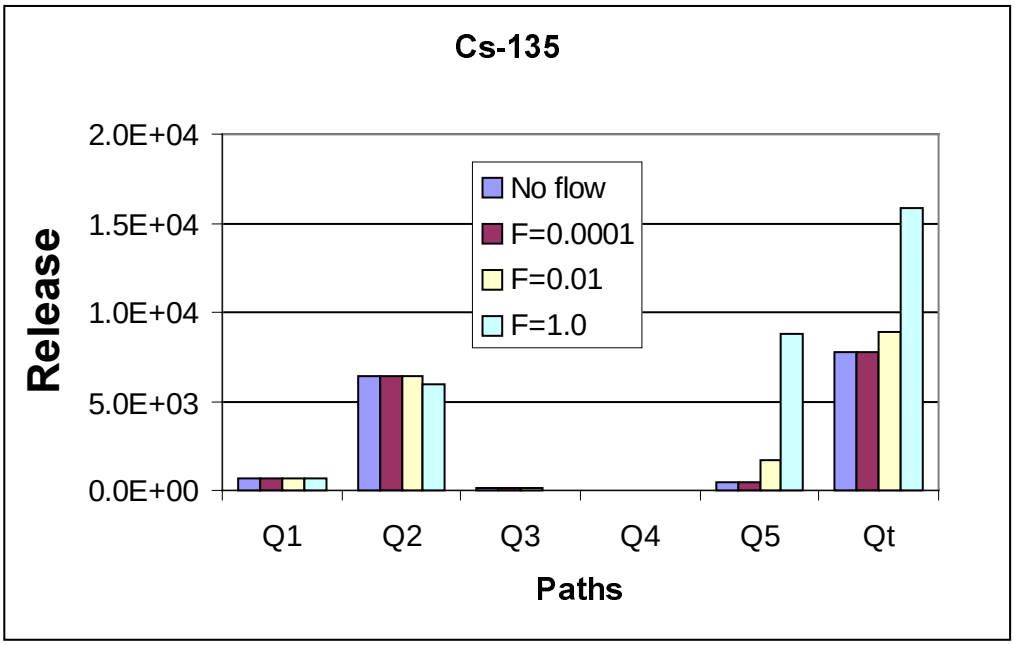

Figure A-1. *Release of Cs-135 through the different pathways.*

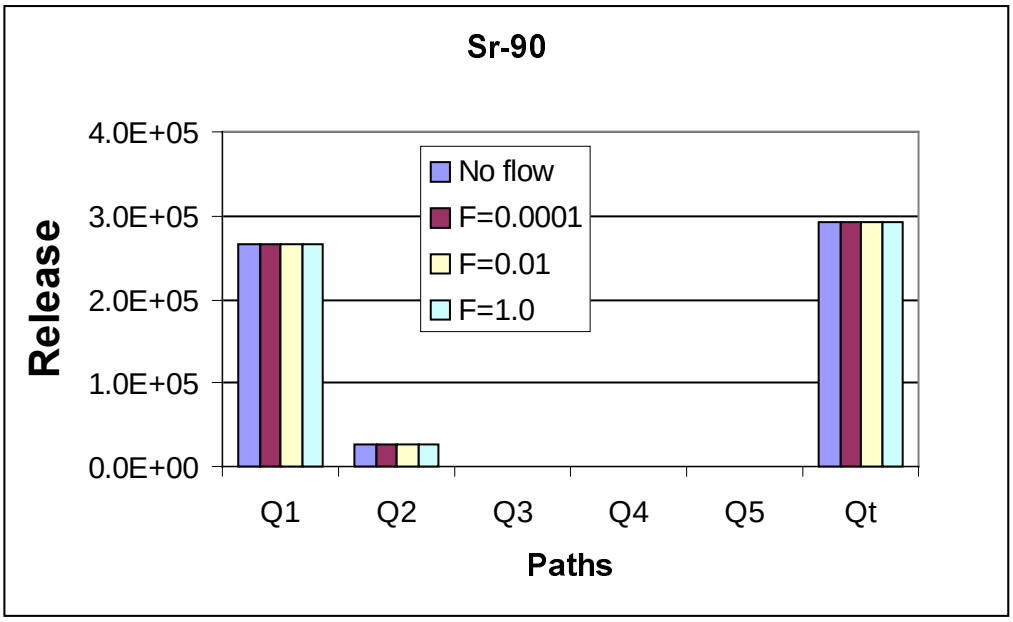

Figure A-2. *Release of Sr-90 through the different pathways.*

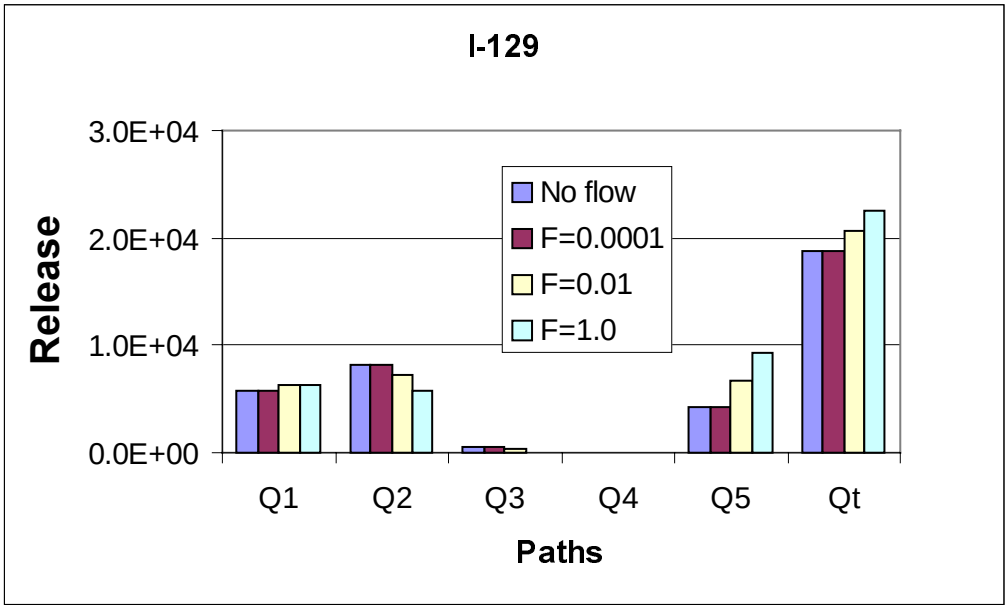

Figure A-3. *Release of I-129 through the different pathways.*

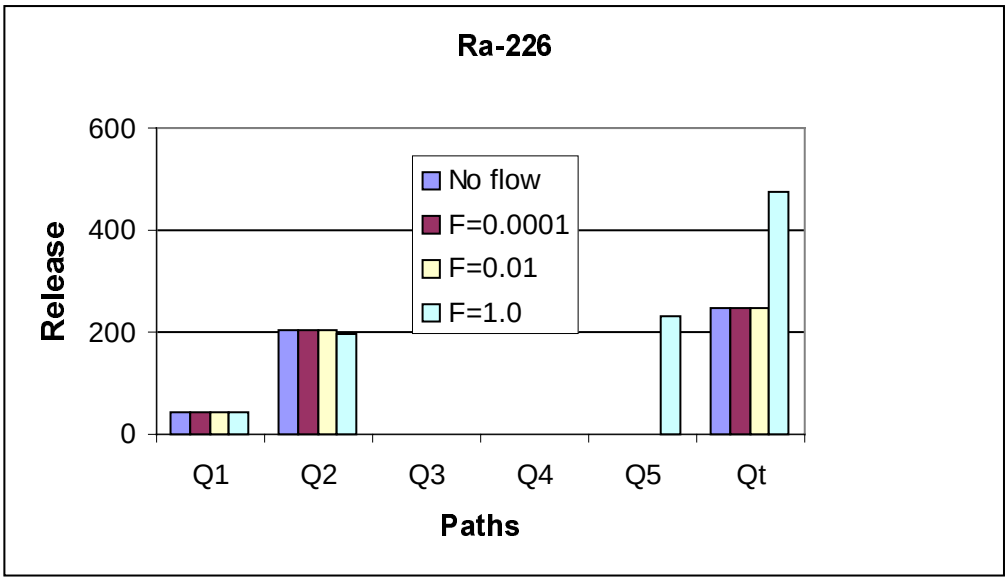

Figure A-4. *Release of Ra-226 through the different pathways.*

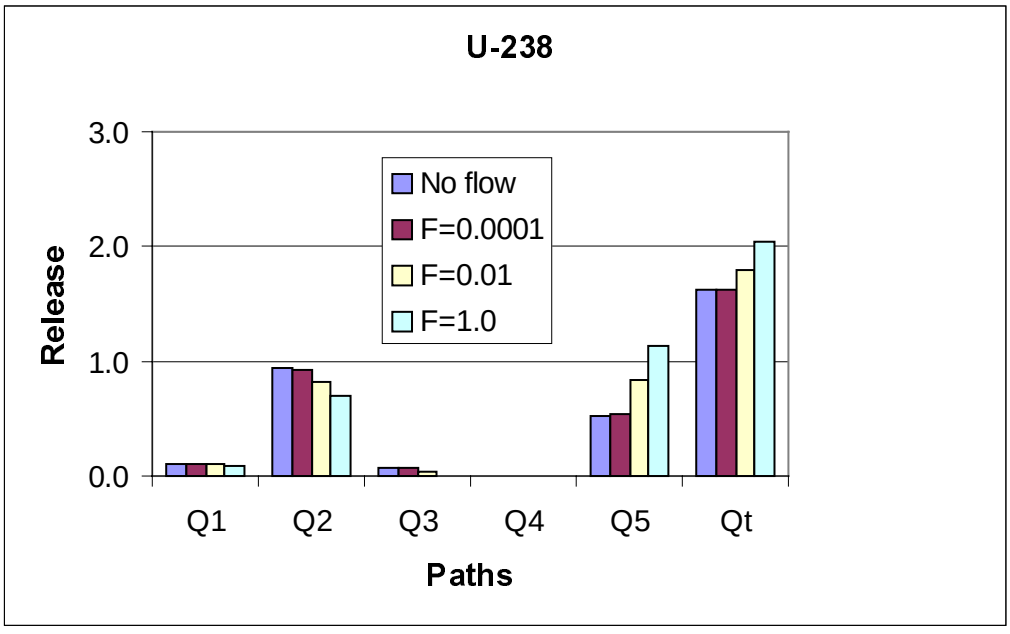

Figure A-5. *Release of U-238 through the different pathways.*