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**Challenges in Defining a Radiologic and Hydrologic
Source Term for Underground Nuclear Test Centers,
Nevada Test Site, Nye County, Nevada**

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**CHALLENGES IN DEFINING A RADIOLOGIC AND HYDROLOGIC
SOURCE TERM FOR UNDERGROUND NUCLEAR TEST CENTERS,
NEVADA TEST SITE, NYE COUNTY, NEVADA**

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INTRODUCTION

The U.S. Department of Energy, Nevada Operations Office (DOE/NV) Environmental Restoration Division (ERD), is investigating subsurface contamination residual from 828 underground nuclear weapons tests conducted from 1955 to 1992 at the Nevada Test Site, Nye County, Nevada (Figure 1). The Underground Test Area (UGTA) Operable Unit was established by DOE/NV ERD to identify, characterize and potentially remediate groundwater impacted by testing. This process is expected to take many years and is being approached in a phased manner. The first phase relies primarily on existing data, is preliminary, and will assist in planning and prioritizing objectives for the remainder of the project.

An accurate assessment of the total radionuclide inventory present at the Nevada Test Site (NTS) includes all radioactive species produced by or remaining after underground nuclear explosions at the Nevada Test Site during the period 1955 to 1992. An inventory for 57 radionuclides, with half lives in excess of ten years, has been compiled for each of the experiments fired beneath the Nevada Test Site (Goishi et al., 1994). The inventory includes those radionuclides available for potential dispersal away from test centers and provides an estimate of the quantity of radionuclides underground at the NTS. However, not all radionuclides are equally available for transport. This is an important observation because the numerical models of groundwater flow and contaminant transport should be initiated with the amount of contamination available for transport. A necessary distinction must be drawn between the *radiologic source term* which includes all radioactive material remaining after a nuclear test and the *hydrologic source term* which includes only that radioactive material dissolved in or available for transport by groundwater. The radionuclide inventory reported by Goishi et al. (1994) represents the radiologic source term and does not represent the amount of radioactivity that is or ever will be dissolved in groundwater at NTS. Because different radioactive species are not equally available for solution and transport, the hydrologic source term is considerably less than the total radiologic source term.

Radionuclide species mobile in groundwater include 1) tritium, 2) conservative anions and neutral species such as ^{85}Kr , ^{99}Tc , ^{106}Ru , ^{36}Cl and ^{129}I and 3) less conservative cationic species including ^{125}Sb , ^{60}Co and ^{90}Sr and ^{137}Cs each with short lived gaseous precursors (^{90}Kr and ^{137}Xe respectively).

The following sections detail the approach used in calculating the radionuclide source term some of the limitations of estimating both the radiologic source term and the hydrologic source

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term for the Nevada Test Site. This paper summarizes a comprehensive evaluation of the radiologic and hydrologic source term for the Nevada Test Site by Smith et al. (1995).

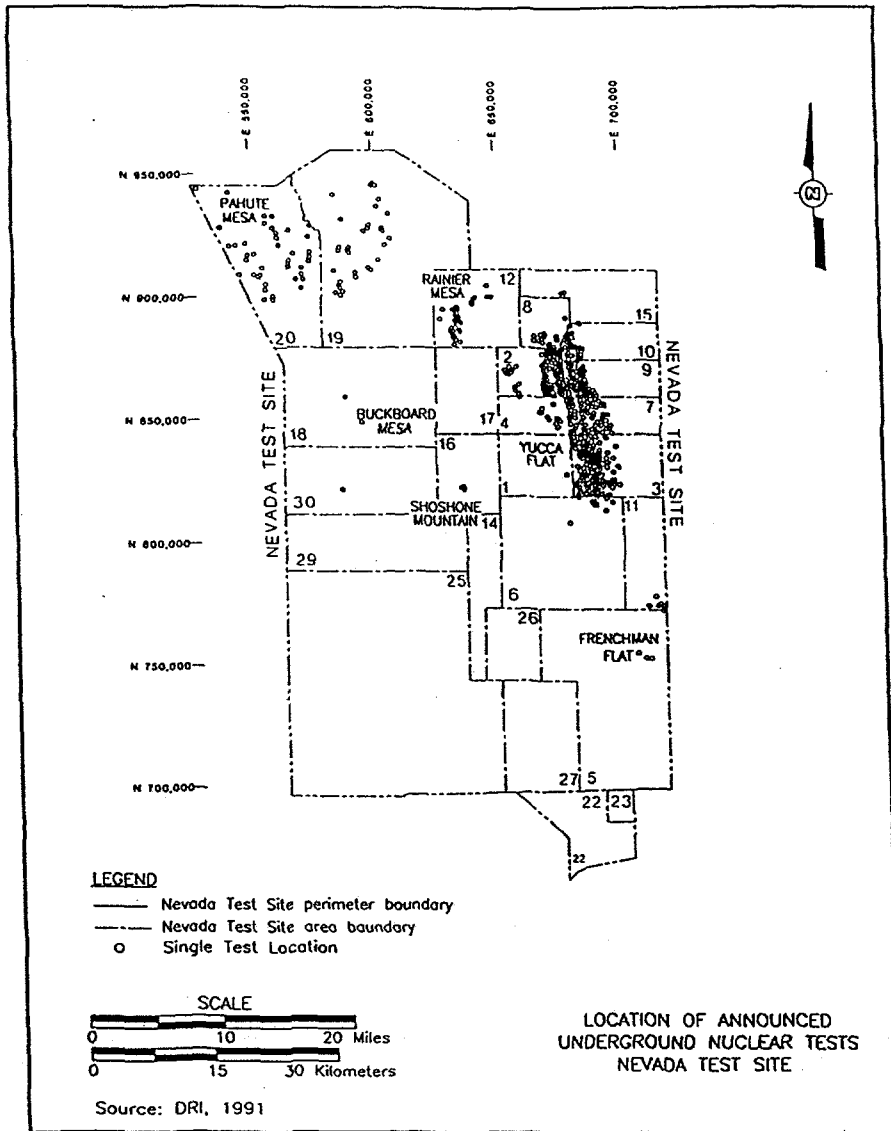


Figure 1

THE RADIONUCLIDE INVENTORY

Together the Chemical Sciences and Technology Division of the Los Alamos National Laboratory (LANL) and the Isotope Sciences Division of the Lawrence Livermore National Laboratory (LLNL) have completed an inventory of fifty four long-lived radionuclides residual from underground nuclear testing and three naturally occurring radionuclides (^{40}K , ^{232}Th and ^{238}U) common to the evolved volcanic rocks of southwestern Nevada (Goishi et al., 1994). Residual test derived radionuclides included in the source term inventory are: 1) residual fissile fuel and tracer materials, such as U isotopes, Pu isotopes, Am, and ^{244}Cm ; 2) fission products such as

^{137}Cs and ^{90}Sr ; 3) tritium (^3H) and 4) activation products induced by neutron capture by device parts, external hardware, and the surrounding geologic medium such as ^{14}C , ^{36}Cl , and ^{41}Ca . Radionuclides were excluded from the inventory if they were produced in such low amounts that if the *total* amount produced during a nuclear test were dissolved into a volume of water equal to the volume of the detonation cavity for the event and allowed to decay for 100 years the resulting aqueous concentration would be less than one-tenth of the maximum permissible concentration (MPC). MPCs proposed for drinking water by the U.S. Environmental Protection Agency (EPA) are listed in the Federal Register (vol. 56, no. 138, July 18, 1991). MPC's are listed in $\mu\text{Ci/mL}$; a μCi is 2.22×10^6 disintegrations per minute. For nuclides with no listed MPC, Goishi et al. (1994) conservatively assumed a value of $10^{-8} \mu\text{Ci/mL}$. The MPC of a nuclide listed in the EPA compilation is that concentration in drinking water which will impart a dose of 4 mrem/year to a person drinking an average of 2 liters of water per day.

To conduct this inventory LLNL and LANL utilized data collected for the radiochemical diagnostics of underground nuclear tests. This data was derived from radiochemistry data files and data-bases resident at LANL and LLNL, test material reports, gas fill reports, nuclear design pre- and postshot reports, explosion codes and consultation with nuclear weapon design physicists. Because radionuclides of environmental significance are typically much longer-lived than those measured for weapon performance, the production of many radionuclides required new calculation. Fission products were determined from the fission split of fissile fuels. Actinides were determined from direct measurement of Pu, Am and Cm; U is diluted with natural uranium and its percentage was subtracted from the total for preshot uranium. Activation products were measured by monitoring the activation of ^{160}Tb which is a rare-earth element assumed to be homogeneously distributed in the geologic media adjacent to the working (firing) point together with device components modeled by explosion codes. Tritium was only measured on less than 20 underground nuclear tests; tritium was estimated by determining the thermonuclear yield of each nuclear stage by radiochemistry. The data were compiled on spreadsheets by event name, hole name, sponsoring laboratory, execution date, yield, depth of burial, cavity radius, lithology at the working point, static water level (SWL) and depth of the working point above or below the SWL and were extracted from containment data-bases resident at LLNL and LANL. The radionuclide concentrations are reported in curies corrected to January 1, 1994 and January 1, 2094. Each laboratory did the calculations for the tests it fielded. Maximum errors for the radionuclides inventoried are estimated to be approximately 30% for fission products, 20% for actinides, a factor of three for tritium and an order-of-magnitude for activation products. Table I is the total inventory of selected fission products, actinides and tritium for underground events fired below the SWL at the NTS together with a measure of the natural uranium introduced by the partial melting of evolved volcanic rocks.

TABLE I

^3H	^{85}Kr	^{99}Tc	^{137}Cs	^{235}U	^{239}Pu	Natural U
8.85×10^7	1.32×10^5	4.49×10^2	2.17×10^6	3.58	3.64×10^4	2.44×10^1

All activities reported in curies, decay corrected to January 1, 1994

Two radionuclide inventories were published. The first is an event-by-event inventory all fifty-seven inventoried radionuclides. In addition it contains a detailed explanation of how activity

values were calculated at Livermore and Los Alamos as well as a comparison of the results from each laboratory for six common events. Because this inventory compiles event and radiochemical data specific for each underground test as well as reveals nuclear weapon design information it is classified. A companion inventory has been prepared which gathers radionuclide data into five groups corresponding to geographic regions at the Nevada Test Site: Frenchman Flat, Yucca Flat, Rainier Mesa, Pahute Mesa 19 and Pahute Mesa 20 for events fired above and below the static water level. Because radiochemical data is combined for geographic areas of the Nevada Test Site and specific nuclear weapons design information is excluded, this version was prepared for unclassified release pending declassification by the Department of Energy. As of this writing, the second document remains classified.

THE RADIOLOGIC SOURCE TERM

The Goishi et al. (1994) radionuclide inventory excludes almost all radionuclides with half-lives less than 10 years, some of which (^{65}Zn , ^{106}Ru) are produced in great abundance in a nuclear event. Many of these nuclides have half-lives so short (microseconds to hours) that they have decayed to undetectable levels soon after zero (firing) time. Others are more stable, soluble and potentially could be transported by groundwater during time intervals less than 100 years. Table II is a list of radionuclides important for investigations of transport and modeling; it includes both long-lived radionuclides included in the inventory and short lived radionuclides omitted from the inventory.

TABLE II

<u>Nuclide</u>	<u>half-life (y)</u>	<u>MPC ($\mu\text{Ci/mL}$)*</u>	<u>main source(s) (FP = fission product)</u>
^3H	12.3	6.1×10^{-5}	device comp.; ^6Li (n, α) T
^{10}Be	1.6×10^6	---	^{10}B (n,p); ^9Be (n, γ)
^{14}C	5730	3.2×10^{-6}	^{14}N (n,p); ^{13}C (n, γ); ^{17}O (n, α)
$^{22}\text{Na}^{**}$	2.605	4.66×10^{-4}	^{23}Na (n,2n)
^{26}Al	7.3×10^5	---	^{27}Al (n,2n)
^{36}Cl	3.01×10^5	1.8×10^{-6}	^{35}Cl (n, γ); ^{39}K (n, α)
^{39}Ar	269	---	^{39}K (n,p); ^{38}Ar (n, γ)
^{41}Ca	1.03×10^5	---	^{40}Ca (n,g)
^{53}Mn	3.7×10^6	---	^{54}Fe (n,2n) $^{53}\text{Fe} \Rightarrow ^{53}\text{Mn}$
^{59}Ni	7.6×10^4	2.7×10^{-5}	^{58}Ni (n, γ)
$^{60}\text{Co}^{**}$	5.271	2.2×10^{-4}	^{59}Co (n, γ)
^{63}Ni	100	9.9×10^{-6}	^{62}Ni (n, γ), ^{64}Ni (n,2n), ^{63}Cu (n,p)
$^{65}\text{Zn}^{**}$	0.66	3.96×10^{-4}	^{64}Zn (n, γ)
^{79}Se	$\leq 6.5 \times 10^4$	---	^{78}Se (n, γ); ^{79}Br (n,p)
^{81}Kr	2.1×10^5	---	^{80}Kr (n, γ); ^{81}Br (n,p)
^{85}Kr	10.7	---	FP; ^{84}Kr (n, γ)
^{90}Sr	29.1	4.2×10^{-8}	FP

^{93}Zr	1.5×10^6	5.1×10^{-6}	FP; $^{92}\text{Zr} (n,\gamma)$; $^{94}\text{Zr} (n,2n)$
^{92g}Nb	3.6×10^7	----	$^{92}\text{Mo} (n,p)$; $^{93}\text{Nb} (n,2n)$
^{93m}Nb	16.1	1.0×10^{-5}	$^{93}\text{Nb} (n,n')$
^{94}Nb	2.0×10^4	7.1×10^{-7}	FP; $^{93}\text{Nb} (n,\gamma)$
^{93}Mo	~ 3500	----	$^{92}\text{Mo} (n,\gamma)$
^{98}Tc	4.2×10^6	----	$^{98}\text{Ru} (n,p)$
^{99g}Tc	2.13×10^5	3.8×10^{-6}	FP; $^{99}\text{Ru} (n,p)$
$^{106}\text{Ru}^{**}$	1.020	2.0×10^{-4}	FP
^{107}Pd	6.5×10^6	3.7×10^{-5}	FP; $^{106}\text{Pd} (n,\gamma)$
^{113m}Cd	14.1	----	FP
^{121m}Sn	~55	2.3×10^{-6}	FP; $^{120}\text{Sn} (n,\gamma)$
$^{125}\text{Sb}^{**}$	2.758	1.94×10^{-3}	FP
^{126}Sn	$\sim 1.0 \times 10^5$	2.9×10^{-7}	FP
^{129}I	1.57×10^7	2.1×10^{-8}	FP; $^{129}\text{Xe} (n,p)$
$^{134}\text{Cs}^{**}$	2.065	8.1×10^{-5}	FP
^{135}Cs	2.3×10^6	7.9×10^{-7}	FP
^{137}Cs	30.17	1.2×10^{-7}	FP; $^{137}\text{Ba} (n,p)$
^{146}Sm	1.03×10^8	----	FP; $^{147}\text{Sm} (n,2n)$
^{151}Sm	90	1.4×10^{-5}	FP; $^{150}\text{Sm} (n,\gamma)$
^{150}Eu	36	----	$^{151}\text{Eu} (n,2n)$
^{152}Eu	13.48	8.4×10^{-7}	$^{151}\text{Eu} (n,\gamma)$; $^{153}\text{Eu} (n,2n)$
$^{154}\text{Eu}^{**}$	8.59	6.7×10^{-7}	$^{153}\text{Eu} (n,\gamma)$
^{166m}Ho	1.2×10^3	----	FP; $^{165}\text{Ho} (n,\gamma)$
^{178m}Hf	31	----	$^{177}\text{Hf} (n,\gamma)$
^{186m}Re	2.0×10^5	----	$^{185}\text{Re} (n,\gamma)$; $^{186}\text{Os} (n,p)$
^{192m}Ir	$24. \times 10^1$	----	$^{191}\text{Ir} (n,\gamma)$; $^{193}\text{Ir} (n,2n)$
^{193}Pt	60	4.6×10^{-5}	$^{192}\text{Pt} (n,\gamma)$; $^{194}\text{Pt} (n,2n)$
^{205}Pb	1.5×10^7	----	$^{204}\text{Pb} (n,\gamma)$; $^{206}\text{Pb} (n,2n)$
^{210}Pb	22.3	1.0×10^{-9}	natural (RaA)
^{231}Pa	3.28×10^4	1.0×10^{-8}	natural; decay of device ^{235}U ; $^{232}\text{Th} (n,2n)$
^{232}Th	1.40×10^{10}	9.2×10^{-8}	natural and device component
^{232}U	70.	1.0×10^{-8}	device component; $^{233}\text{U} (n,2n)$
^{233}U	1.592×10^5	2.6×10^{-8}	device component; radiochemical tracer
^{234}U	2.46×10^5	2.6×10^{-8}	natural and device component
^{235}U	7.04×10^8	2.6×10^{-8}	natural and device component
^{236}U	2.342×10^7	2.7×10^{-8}	device comp.; $^{235}\text{U} (n,\gamma)$; $^{238}\text{U} (n,2n)^2$

²³⁸ U	4.47 x 10 ⁹	2.6 x 10 ⁻⁸	natural and device component
²³⁷ Np	2.14 x 10 ⁶	7.2 x 10 ⁻⁹	device component; radiochemical tracer; decay of ²³⁷ U
²³⁸ Pu	87.7	7.2 x 10 ⁻⁹	device component; radiochemical tracer; ²³⁹ Pu (n,2n)
²³⁹ Pu	2.410 x 10 ⁴	6.5 x 10 ⁻⁸	device component.; decay of ²³⁹ U
²⁴⁰ Pu	6.56 x 10 ³	6.5 x 10 ⁻⁸	device component
²⁴¹ Pu	14.4	----	device component
²⁴² Pu	3.75 x 10 ⁵	6.8 x 10 ⁻⁸	device component; radiochemical tracer
²⁴¹ Am	432.7	6.4 x 10 ⁻⁹	device component; radiochemical tracer; decay of ²⁴¹ Pu
²⁴³ Am	7.37 x 10 ³	6.5 x 10 ⁻⁹	device component; radiochemical tracer
²⁴⁴ Cm	18.1	1.0 x 10 ⁻⁸	radiochemical tracer

* MPC = Maximum Permissible Concentration from U.S. Environmental Protection Agency, Federal Register, v. 56, no. 138, July 18, 1991, p. 33050-33127.

** Short-lived radionuclides not included in the Goishi et al. (1994) inventory but important for transport and near-field modeling.

THE HYDROLOGIC SOURCE TERM

There are two approaches to defining a hydrologic source term for the NTS. The first involves collecting and analyzing impacted groundwater. The second relies on conversion of the radiologic source term to its hydrologic equivalent. Both approaches are limited.

Measuring the Hydrologic Source Term

Few samples and analyses exist for impacted groundwaters owing to the technical challenge and cost of obtaining data near test centers. Samples historically were collected from a variety of sources including dedicated satellite wells, exploratory wells and re-entry (post-shot) wells. Well completions were constructed for different purposes (geologic sampling, device emplacements, post-shot debris sampling) using drilling technologies appropriate at the time but not necessarily optimized for the collection of representative cavity or near-cavity water samples. In particular, drilling additives and lubricants often included prodigious quantities of clay minerals which, in the case of post-shot sampling, are forced into the hole with no return circulation. Clays have high sorptive capacity for radionuclides. In addition, many older well completions at the NTS were constructed with carbon steel which has severely corroded within a decade after construction (DOE, 1994). Secondary oxides also have a high sorptive capacity for radionuclides and will bias representative sampling.

The type and frequency of sample collection dramatically affects measured radionuclide concentrations. Without adequate purging and development of the well, water chemistry never stabilizes due to inadequate mixing within the well bore. Additionally, results from a field test at the DOE Hanford Reservation indicates that a well development ratio greater than 100 (volume of fluid removed divided by the volume of fluid lost during drilling) is required for a 1000-fold reduction in conservative (tritium), non-conservative (fluorescein) and indicator (total organic

carbon) drilling fluid tracer constituents; a ratio of greater than 1000 may be required for certain isotopes (^{129}I , ^{36}Cl , ^{14}C and others) (Graham and Johnson, 1991).

For these reasons, the UGTA Operable Unit has presently developed a near-field drilling strategy for the Nevada Test Site which incorporates techniques and materials to insure the return of representative groundwater samples and provide for long-term contaminant monitoring (DOE, 1995).

Estimating the Hydrologic Source Term

The hydrologic source term may alternately be calculated by converting the radiologic source term to its hydrologic equivalent. This approach involves applying attenuation factors derived from laboratory and field studies to a specific radiologic source term to estimate its hydrologic equivalent. The latter is complicated by incomplete knowledge of those factors which determine attenuation including initial distribution, sorption, solubility, matrix versus advective (fracture) transport and mobility as colloidal species.

Radionuclides deposited in the subsurface following a nuclear test are not equally available for groundwater transport. Several factors complicate the release function. The initial spatial and chemical distribution of radionuclides is heterogeneous. Some radionuclides are predominantly associated with the melt matrix and are only accessible to groundwater through slow processes such as glass dissolution. Other radionuclides are predominantly associated with surfaces and are accessible to groundwaters through fast processes such as ion exchange. Because melt debris is extremely heterogeneous in distribution and character, modeling the initial release of matrix-incorporated radioactivity is difficult (Smith, 1994). Similarly, because cavity debris is a heterogeneous mixture of particles of different sizes and compositions with poorly known surface properties, modeling the distribution and release of radioactivity condensed onto solid surfaces is also difficult.

As summarized by Borg (1976) and Smith (1993), the leaching of nuclear explosive melt debris is affected by composition, initial distribution of radionuclides, available surface area of the melt debris, chemistry (pH, Eh) of the leaching solution and the temperature of waters inside the cavity. The geochemical controls are variable from event to event, and over time for a single event. Radionuclides which are surface deposited rather than volume incorporated are more susceptible to leaching. Zones of prompt injection associated with high pressures accompanying detonation are particularly susceptible where short lived gaseous fission products, particularly ^{137}Xe and ^{90}Kr , are introduced and condense shortly after detonation. The contribution of surface deposited relative to volume incorporated radionuclides has yet to be quantified.

Interaction of radionuclides borne by groundwaters with the surrounding geologic media will significantly retard transport and dispersal. Much of the geology of the Nevada Test Site is composed of Tertiary tuffs and rhyolites and Quaternary alluvium which contain highly sorptive clay and zeolite phases. Sorption comprises a variety of physiochemical processes including ion exchange, adsorption and chemisorption and requires knowledge of the distribution of sorbing minerals neighboring each event cavity. Sorption is defined relative to the distribution coefficient, K_d , which is defined as:

$$K_d = \frac{(\text{amount of X within solid}) / (\text{weight of solid})}{(\text{amount of X within solution}) / (\text{volume of solution})}$$

Theoretically, the total retardation will be the sum of individual sorption coefficients multiplied by the abundance of the each sorbing phase:

$$\sum^n K_d = K_{d1}(\text{abundance 1}) + K_{d2}(\text{abundance 2}) + \dots + K_{dn}(\text{abundance n})$$

Groundwater composition, the oxidation state and specific radionuclide in solution, fluid temperature and the abundance, composition and cation exchange capacity of minerals comprising the host lithology determine a singular K_d for each underground event site (Ogard, 1984).

Studies at the CHESHIRE (U20n) event by Buddemeier and Hunt (1988) suggest that colloids in the range of 100,000 to 10,000 MWU (0.006 to 0.003 μm respectively) sorb radioactive Mn, Co, Cs, Ce and Eu species. Colloids are enriched in the CHESHIRE cavity relative to formation waters. X-ray diffraction studies indicate the colloids are composed of Ca-K feldspars and fine clays. Because high colloid concentrations may be characteristic of cavity waters in addition to CHESHIRE, colloids may potentially facilitate radionuclide migration throughout larger areas of the Nevada Test Site. Drilling and development activities may affect colloid generation, resuspension and transport. Similarly production of water from the sampling well may stress the aquifer and introduce abnormally high particulate loadings. Given these uncertainties, the role of colloids in radionuclide transport at NTS needs to be further investigated.

Time Scale

Borg et al. (1976) and Smith (1993) provide a review of controls affecting the transition between the radiological and hydrologic source terms. Important to this discussion is the time elapsed from zero time. The radionuclide source term is not static but will be affected by the radioactive decay of tritium, fission products and activation products (Borg et al., 1976). The decay of tritium is rapid and will decrease approximately one order of magnitude in 41 years and 5 orders of magnitude in 200 years. The decay of activation products produced in underground nuclear tests is even faster. At zero time plus 0.5 years, the activity per kiloton yield due to fission products is 30 times that due to activation products; the ratio increases to 88 at 25 years and 229 at 100 years. Hence elapsed time is important in elucidating the relative contributions of tritium, fission products and activation products to the source term.

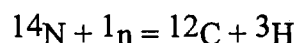
Recent Field Experience

The 1981 BASEBALL (U7ba) event cavity was drilled in 1994. Results from over seventy samples collected from side-wall core from one re-entry and one sidetrack hole confirm that the expected fractionation of volatile from refractory fission and activation products is preserved over the thirteen year interval since detonation (Thompson, 1995a). Lower boiling point species are dispersed throughout the cavity while refractory species are incorporated exclusively in the lower puddle region containing melt-glass. Tritium was analyzed from waters returned with the solids; tritium profiles are similarly preserved. As emphasized by Thompson (1995a), the

results from BASEBALL indicate that in regions of low groundwater flow, there may be only insignificant release and migration of radioactive material over ten years post-event. While these results have significant implication for radionuclide migration associated with single events on Yucca Flat, the controls have yet to be identified and cannot be extrapolated to a general case for the NTS.

TRITIUM

Tritium has a half-life of 12.43 years. It is produced naturally in the atmosphere by energetic reactions of cosmic rays with nitrogen by the following reaction:



It is also associated with nuclear weapons where it is both loaded on the device and produced in abundance by thermonuclear fuel burn. As an isotope of hydrogen, tritium can readily incorporate itself in the water molecule as HTO. Typically, 99.9% of the tritium occurs as molecular HTO. Enrichments in tritium values in NTS groundwaters above the precipitation threshold are highly diagnostic of waters impacted by subsurface nuclear weapons testing. Measurements of non-impacted groundwaters collected from NTS monitoring and water supply wells in 1992 and 1993 range between 0.3 and 60 pCi/L. By contrast, field tritium scans for groundwaters collected from "hot" wells near sites of subsurface detonations range from 5×10^2 to 8×10^7 pCi/L (Davisson et al., 1994, Thompson, 1995b).

For 100-200 years post-test, residual tritium in or near the saturated zone has the highest activity of any radionuclide with $t_{1/2} > 10$ years (Goishi et al., 1994). Because nearly all of the tritium is incorporated in the water molecule as HTO, tritium is an excellent measure of both the radiologic and hydrologic source terms. Tritium is conservative under saturated conditions and will not be depleted nor enriched in groundwater by chemical processes including ion-exchange, speciation, dissolution or precipitation. Because tritium is conservative, the abundance of other dissolved radionuclides may be normalized against the tritium concentration to identify a total hydrologic source term.

CONCLUSIONS

The compilation of a radionuclide inventory for long-lived radioactive contaminants residual from nuclear testing provides a partial measure of the radiologic source term at the Nevada Test Site. The radiologic source term also includes potentially mobile short-lived radionuclides excluded from the inventory. The radiologic source term for tritium is known with accuracy and is equivalent to the hydrologic source term within the saturated zone. Definition of the total hydrologic source term for fission and activation products that have high activities for decades following underground testing involves knowledge and assumptions which are presently unavailable. Systematic investigation of the behavior of fission products, activation products and actinides under saturated or partially saturated conditions is imperative to define a representative total hydrologic source term. This is particularly important given the heterogeneous distribution of radionuclides within testing centers. Data quality objectives which emphasize a combination

of measurements and credible estimates of the hydrologic source term are a priority for near-field investigations at the Nevada Test Site.

BIBLIOGRAPHY

- Borg, I.Y., R. Stone, H.B. Levy and L.D. Ramspott, 1976, Information Pertinent to the Migration of Radionuclides in Ground Water at the Nevada Test Site, Part 1: Review and Analysis of Existing Information, Lawrence Livermore National Laboratory, UCRL-52078, Part 1.
- Buddemeier, R.W and J.R. Hunt, 1988, Transport of Colloidal Contaminants in Groundwater: Radionuclide Migration at the Nevada Test Site, Applied Geochemistry, v.3, p. 535-548.
- Davisson, M.L., J.M. Kenneally, D.K. Smith, G.B. Hudson, G.J. Nimz and J.H. Rego, 1994, Preliminary Report on the Isotope Hydrology Investigations at the Nevada Test Site: Hydrologic Resources Management Program, Lawrence Livermore National Laboratory, UCRL-ID-116122.
- Goishi, W., B. Esser, J. Meadows, N. Namboodiri, D. Smith, J. Wild, S. Bowen, P. Baca, L. Olivas, C. Geoffrion, J. Thompson and C. Miller, 1994, Total Radionuclide Inventory Associated with Underground Nuclear Tests Conducted at the Nevada Test Site 1955-1992 (U), Los Alamos National Laboratory, LA-CP-94-0222, SECRET-RESTRICTED DATA.
- Graham, D.L. and V.G. Johnson, 1991, Effects of Fluid Rotary Drilling on Hydrochemical Sampling Results from Deep Boreholes in Fractured Columbia River Basalt, Journal of Hydrology, v. 128, p. 171-212.
- Ogard, A.E., K. Wolfsberg, W.R. Daniels, J. Kerrisk, R.S. Runberg and K.W. Thomas, 1984, Retardation of Radionuclides by Rock Units along the Path to the Accessible Environment, Materials Research Society, Symposium Proceedings, Scientific Basis for Nuclear Waste Management VII, v. 26. p. 329-336.
- Smith, D.K., 1993, A Review of Literature Pertaining to the Leaching and Sorption of Radionuclides Associated with Nuclear Explosive Melt Glasses, Lawrence Livermore National Laboratory, UCRL-ID-113370.
- Smith, D.K., 1994, Characterization of Nuclear Explosive Melt Debris, Lawrence Livermore National Laboratory, UCRL-JC-119227 Preprint. Also in press, Radiochimica Acta.
- Smith, D.K., B.K. Esser and J.L. Thompson, 1995, Uncertainties Associated with the Definition of a Hydrologic Source Term for the Nevada Test Site, Lawrence Livermore National Laboratory, UCRL-ID-120322.
- Thompson, J.L., 1995a, Radionuclide Distribution in a Nuclear Cavity: The Baseball Event, Los Alamos National Laboratory, LA-UR-95-744.
- Thompson, J.L., 1995b, Laboratory and Field Studies Related to the Hydrologic Resources Management Program, October 1, 1993 - September 30, 1994, Los Alamos National Laboratory, LA-12917-PR.
- U.S. Department of Energy, Nevada Operations Office, 1994, Regulatory Acceptance of Well Construction Techniques at the Nevada Test Site, Draft, DOE/NV-XXX, UC-700, Las Vegas, NV.
- U.S. Department of Energy, Nevada Operations Office, 1995, Near Field Drilling Strategy, Draft, DOE/NV-XXX, UC-700, Las Vegas, NV.
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