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SORPTION OF TRITIUM AND TRITIATED WATER ON CONSTRUCTION MATERIALS

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ABSTRACT

Sorption and desorption of tritium (HT) and tritiated water (HTO) on materials to be used in the construction of fusion facilities were studied. In *ca.* 24-hour exposures in argon or room air, metal samples sorbed 8-200 $\mu Ci/m^2$ (1 Ci = 3.7 x 10^{10} Bq) of tritium from atmospheres of 5-9 Ci/m^3 HT, and non-metallic samples sorbed 60-800 $\mu Ci/m^2$ from atmospheres of 14 Ci/m^3 HT. Sorption of HTO varied much more widely than HT sorption for different samples, ranging from 4 $\mu Ci/m^2$ for glass to 1 300 000 $\mu Ci/m^2$ for concrete samples, in 24-hour exposures to 1 Ci/m^3 HTO in room air. Time dependence of desorption in dry air showed a rapid initial process and a slower secondary process.

I. INTRODUCTION

The suitability of materials for use where they may contact elemental tritium (HT) and tritiated water (HTO) is determined in part by the sorption interactions of the materials with HT and HTO. A literature review[1] on the interactions of HT and HTO with a wide variety of materials has revealed that sorption on surfaces outside of tritium handling equipment has not been intensively studied; most of the systematic work has focused on metals.[2] The work reported here was carried out to determine the amounts of HT and HTO sorbed and desorbed by a variety of candidate materials for reactor halls and tritium handling equipment. Exposures to HT at 5-15 Ci/m^3 and to HTO at 1 Ci/m^3 were examined as typical concentrations that could be encountered in a major tritium release into an enclosure or room environment.

II. EXPERIMENTAL

The metal samples exposed to HT and HTO were planchets (disks) of aluminum, brass, copper, mild steel, tin-plated steel, galvanized steel and stainless steels (SS-304 and SS-316L). Some of the SS-304 and SS-316L planchets were polished to a mirror finish using metallographic equipment, the final abrasive being 0.05 μm Al_2O_3. Before one HTO exposure, some metal planchets were deliberately contaminated with oil.

The non-metallic building materials exposed to HT and to HTO were painted aluminum, Arborite, vinyl floor tile, porcelain tile, painted Gyproc and unpainted concrete. An oil-base semi-gloss paint with an undercoat of primer was used on the aluminum samples and an interior latex satin-finish paint was used on most Gyproc samples. The porcelain samples were glazed on one side only. The concrete samples were heated to *ca.* 80°C for *ca.* 15 minutes in an oven to drive off excess water after cutting, then cooled in room air for at least 24 hours to allow partial re-equilibration with the surrounding air.

Exposure conditions are summarized in Tables 1 and 2. Samples were exposed to *ca.* 10 Ci/m^3 HT (in the presence of *ca.* 100 ppm H_2), in either argon (Exposures 1-3) or room air. Assay of the atmosphere (using water bubblers and a CuO bed) indicated that small amounts of HTO (*ca.* 0.05% to 0.2% of the concentration of HT) were present in the HT exposure atmosphere. The exposure times varied from 22 hours to 68 hours. A maximum of 0.60% of available tritium was sorbed on the samples; this did not significantly affect the concentration determined for these exposures.

Air atmospheres contaminated with HTO were obtained by injection of an HT standard into a partially evacuated exposure chamber via a small CuO bed heated to 500°C. Assays indicated that over 90% of the HT was converted to tritiated water using this technique. The relative humidities

of the atmospheres were in the range 15-35%. For Exposure 6, about 85% of the HTO originally admitted to the chamber was sorbed on the samples during the 22-hour exposure; comparable proportions were sorbed in the other exposures.

To determine the time dependence of tritium release, the samples were removed from the exposure chamber in a fume hood, and transferred to Pyrex desorption chambers. Slow streams of room-temperature dry air (dew point lower than –20°C) were passed through the desorption chambers and into bubbler analysis trains that permitted independent analysis for HT and HTO desorbed from the samples. The air desorption period was typically six days. Several of the metal samples were thermally desorbed after the air desorption period by ramping from room temperature to temperatures of 600°C (for aluminum, brass and galvanized steel), or to 900°C at 5 K/min while passing a slow gas stream through the furnace tube into water bubblers. Leaching in water for two weeks was carried out on samples that were not thermally desorbed at the end of their air desorption periods. Leaching proved to be less effective than thermal desorption in removing HT from a sample of SS-304; thermal desorption of a sample at 900°C after leaching yielded approximately 10% of the total tritium desorbed from the sample (see Table 1, Exposure 3). This was considered acceptable within the reproducibility of the experimental data (see Exposure 1).

III. RESULTS

The samples, exposure conditions and results are given in Tables 1 and 2 for HT and HTO exposures, respectively. The amounts desorbed per unit geometric area are given in $\mu Ci/m^2$. The columns labelled A and F give the amounts of tritium desorbed during the air desorption and during the final desorption, respectively. The final desorption consisted of either a thermal treatment or a two-week leaching in water. The percentage of the total tritium that was desorbed in the HTO form is also given. For the tritium desorbed from the metallic samples after HT exposure, about 90% of the desorbed tritium was found to be in the form of HTO. This probably occurs by reactions on the surface, as found in other experimental studies.[2, 3, 4] A graphical representation of the time dependence of total tritium release from the metal samples from Exposure 3 is given in Figure 1. The assumption was made in all figures that tritium was completely desorbed from the samples by the air desorption and final desorption treatments, so that the figures were constructed in terms of tritium remaining on the sample after the given period of air desorption. Figures 2 and 3 present the data for desorption of HT and HTO, respectively, from the building materials in Exposures 4 and 5 as independent phenomena (see below). Figure 4 shows the time dependence of desorption of HTO from the samples in Exposure 6 (1.02 Ci/m^3 HTO in room air).

IV. DISCUSSION

A. *Amounts Sorbed - HT*

The amount of HT sorbed by metals with a wide variety of surface smoothness varied by only a factor of 10 or so. The main factor governing the amount of tritium sorbed seemed to be the "microscopic" smoothness of the surface; generally, the shiniest surfaces sorbed the least tritium, regardless of macroscopic scratches or grooves. As shown by data in Table 1, galvanized steel sorbed at least double the amount of HT of any other metal (112 $\mu Ci/m^2$ in Exposure 2), followed by brass, as-received SS-304, copper, mild steel, aluminum, tin-plated steel and polished SS-304 (8 $\mu Ci/m^2$ in Exposure 2). However, this order may well be different for different lots of metals, depending on the exact surface condition of each metal.

Careful mechanical polishing decreased the amount of tritium sorbed on SS-304 by a factor of five. The time dependence of desorption was similar for the polished and unpolished samples. It is noteworthy that the amount of tritium thermally desorbed from SS-304 in argon as HT (0.5 $\mu Ci/m^2$ for unpolished SS-304, 0.4 $\mu Ci/m^2$ for polished SS-304) did not significantly depend on the polishing, but the amount desorbed as HTO did (9.9 $\mu Ci/m^2$ for unpolished SS-304, 1.1 $\mu Ci/m^2$ for polished SS-304).

The ranking of samples where the amount of tritium sorbed per unit area is very similar ($\pm$ *ca.* 15%) must be done cautiously. For all metals, a large amount of tritium is desorbed during the first hour, as shown by the results in Figure 1, and the amount desorbed during the 0-10 minute sample handling period may be significant (e.g., the difference observed between the first and second sample of each type of metal in Exposure 1 may be due to handling time differences).

The non-metallic building materials are roughly comparable to the metals in the amount of HT sorbed. Porcelain tile and Gyproc sorbed significantly less HT than vinyl floor tile and Arborite; other investigators have also found that organic materials sorb significantly more HT than non-porous inorganic materials.[1] It is possible that the large amount of HTO desorbed from Gyproc is due to HT-HTO conversion of the sorbed HT (discussed further below). Porcelain is probably comparable in HT sorption ranking to unpolished SS-304 and brass.

The adhesive used to hold together the Arborite and vinyl floor tile samples in Exposure 5 sorbed significant amounts of HT; the HT concentration and the amounts of exposed surface were roughly the same for Exposures 4 and 5, the mass of each material present was doubled in Exposure 5, but the amount of HT sorbed by these two samples was more than double that sorbed in Exposure 4. The excess HT sorbed is 210 $\mu Ci/m^2$ for the Arborite sample and 243 $\mu Ci/m^2$ for the vinyl tile sample, using the area of both sides of the glue layer. This may be due to the contact cement only being aged 24 hours before the exposure was commenced, or it may be an effect of solvents from the contact cement on the materials.

A typical metal HT contamination value of 30 $\mu Ci/m^2$ corresponds to a coverage of 5.2×10^{15} H_2 molecules/m^2 (T/H: 0.060). Assuming complete dissociation of the H_2 molecules on the metal oxide surface and using an area of 0.052 nm^2 per hydroxyl group thus formed, a value of 9.6×10^{18} H_2 molecules/m^2 can be derived for monolayer coverage. Thus, assuming that the metals have smooth surfaces, about 5.4×10^{-4} monolayers of H_2 are present on the metal samples under the conditions used here.

B.   *Amounts Sorbed - HTO*

Unpainted concrete and Gyproc sorbed the most HTO of the samples studied, followed by paint on aluminum, Arborite, vinyl floor tile, porcelain, galvanized steel and the other metals in much the same order as for HT sorption, then glass. Of the two paints tested, the satin-finish latex paint used to paint the Gyproc sorbed more HTO than the semi-gloss oil-based paint used on the aluminum planchet. For the porcelain sample, the porous underside of the tile would be expected to sorb more HTO than the glazed surface. Porcelain (as used in construction) would probably behave similar to glass.

The amounts of HTO sorbed vary more widely than the amounts of HT sorbed for the materials studied; all HT sorption densities fall within two or three orders of magnitude, while the HTO sorption densities span five orders of magnitude. One major concern is the very high level of HTO sorption on unpainted concrete; Numata and co-workers have recently been investigating sorption and permeation of tritiated water vapor into concrete.[5] However, amounts of HTO sorbed

also vary more widely for any given material. For example, HTO on SS-304 varied from 58 to 340 μCi/m^2 for the three exposures, showing no particular correlation with exposure time, activity or specific activity, or residual HT concentration. This variability may be due to assay difficulties, slight variations in surface roughness or water or organic contamination of the sample surfaces. However, the overall ordering given above is reasonably valid.

A typical metal HTO contamination value of 50 μCi/m^2 corresponds to a coverage of 1.3 x 10^{19} tritiated water molecules/m^2 (T/H: 0.000 040). Using a value of 0.106 nm^2 for the molecular area for water,[6] a value of 9.5 x 10^{18} water molecules/m^2 can be derived for monolayer coverage. Thus, assuming no surface roughness, about 1.4 monolayers of tritiated water are present on the metal samples under the conditions used here.

If materials which sorb large quantities of HTO are present, it is difficult to determine accurately the amount of HTO present in the chamber atmosphere during HT exposures, because these small quantities of HTO are probably sorbed fairly rapidly. More HTO than HT was released by both Gyproc and Arborite in Exposure 4, and by Gyproc in Exposure 5, despite the much smaller amount of HTO available. These materials probably sorbed most of the HTO available in the chamber atmosphere; 2.34 μCi of HTO were available in the atmosphere ten minutes after the beginning of the exposure, and 0.31 μCi of HTO would be expected to form in the chamber by radiolytic means over the course of the 24-hour exposure, compared with the 2.54 μCi of HTO desorbed from the samples. The conversion of HT to HTO on these non-metallic materials probably occurred to only a minor extent, if at all. Exposures 4 and 5 were intended primarily as HT exposures, but the HTO present as an impurity in the tritiated standard allowed the measurement of some HTO desorption characteristics. The assayed HTO concentrations differed only by a factor of 1.7, but there are considerable differences in the amounts of HTO sorbed by similar samples in these two exposures. The HTO concentration difference may be larger than assayed, possibly because of assay difficulties such as sorption of HTO by sampling volume walls and valve packings.

All the oil-contaminated metal planchets (except for brass) sorbed more HTO than their uncontaminated counterparts in the same exposure. However, the amount of HTO sorbed does not correlate simply with the amount of oil on the sample. The data imply that the roughness of the metal surface is still a major factor in determining HTO sorption on oil-contaminated surfaces.

More than 90% of the tritium released from the metal samples in air desorption after HT exposure is released as HTO. By contrast, most of the tritium released from vinyl floor tiles and porcelain tiles is in the form of HT. About 0.6 μCi of HTO (compared to 600 μCi of HT) was present in the chamber atmosphere during the HT exposures, so that some of the HTO desorbed from the metal samples may be due to sorbed HTO, but this is probably not a major contribution.

Conversion of HTO to HT does not occur to any significant extent on desorption from the samples in Exposure 6. The small amounts of tritium detected as HT are probably due to carry-through of HTO from the second HTO bubbler to the HT-designated bubblers.

C.   *Time Dependence of Room-Temperature Desorption*

Usually 40-60% of the tritium sorbed on metals was released in the first hour of desorption in a dry air stream, with a further 7-14% released in the next three hours. The non-metallic materials, except glass, were slower to release their sorbed tritium, with only 5-25% released in the first hour. Vinyl floor tiles and porcelain tile released their sorbed tritium more rapidly than Gyproc, concrete and Arborite. The desorption graphs (Figures 1-4) show rapid initial release rates for HT and HTO, followed by slower release rates. The rapid desorption may arise from a loosely-sorbed

layer, or even a boundary layer of "free" exposure atmosphere that was not removed during sample handling. The detection limit of the desorption apparatus corresponds to roughly 0.1 µL of the HT exposure atmosphere, which could easily remain on a high-surface-area sample.

Tritium was released more slowly from the second copper sample than from the first copper sample in Exposure 1 (22.5% compared to 43.0% in the first hour). One possible reason is a much slower air flow rate through the desorption chamber for the second copper sample. A dependence of tritium release rate on air flow rate is consistent with previous work and computer models,[3] and may arise from equilibration between sorbed and desorbed tritium in the desorption chamber.

D.   *Thermal Desorption*

Thermal desorption of metal samples in inert or reducing atmospheres gives rise to lower HTO conversion than room-temperature desorption in air, but the argon desorptions still gave rise to *ca.* 70% HTO and the H_2/He desorptions gave *ca.* 50% HTO. The predominance of HTO over HT is in agreement with other thermal desorption studies,[2] though less HTO was found in the present study. Thermal desorption of a sample of SS-304 after leaching indicates that 10% of the total tritium sorbed still remains on the metal, even after a two-week leaching period. This tightly-sorbed tritium is not significant in the modelling of air detritiation, but it may determine decommissioning requirements for facilities that have experienced acute releases of HT.

E.   *Effect on Release Cleanup*

An ideal cleanup time may be derived for a given tritium release, enclosure and air detritiation system by assuming that no tritium sorption or "soaking" occurs. If the total amount of tritium sorbed on the interior of the enclosure after the ideal cleanup time gave rise to an air concentration of less than the derived air concentration (DAC) for HTO, the sorbed tritium would have very little effect on the cleanup. The surface concentration required by this criterion depends on the shape and size of the volume being considered, and the DAC value. Using a DAC[8] of 20 µCi/m^3 and a volume of 10^5 m^3 (shaped as a 100 m x 100 m x 10 m enclosure), 80 µCi/m^2 is the criterion. Some surface contamination criteria currently in use (10 and 500 µCi/m^2 (refs. 9 and 10, respectively)) are similar in magnitude.

As can be seen from Exposures 1-3 in Table 1, all the metals except galvanized steel attain the 80 µCi/m^2 criterion or lower immediately after exposure to an HT concentration of 8 Ci/m^3 for *ca.* 24 hours. Of the other building materials exposed to HT, only porcelain tile attained levels lower than 80 µCi/m^2. In a normal release cleanup scenario, the ideal cleanup time is about 24 hours, during which time the air will be progressively detritiated. This will allow some desorption of tritium from the walls. Assuming that only as much tritium will desorb during the cleanup as desorbed in the first four hours of these desorptions with non-contaminated air, more than 50% of initial contamination will desorb from most metals. Thus, materials may fulfil tritium sorption criteria even if their sorption levels in this study are slightly higher.

In the *ca.* 1 Ci/m^3 HTO exposures, the metals which had visually "shiny" (smooth) rather than "matte" (rough) surfaces consistently attained the 80 µCi/m^2 criterion immediately after exposure. Over the course of five hours, the two metals surveyed desorbed 40-60% of their sorbed HTO, so that many of the other metals would probably also fall under the 80 µCi/m^2 level. Glass was the only non-metallic material which fulfilled the 80 µCi/m^2 criterion immediately after exposure, and it sorbed less than most metals. Because of their much higher contamination levels and slower HTO release rates, the other non-metallic materials would be expected to have a significant effect on the cleanup of a 1 Ci/m^3 HTO release.

V. CONCLUSIONS

Metals release about 8-200 µCi/m^2 of tritium after *ca.* 24 hours of exposure to atmospheres of 5-9 Ci/m^3 HT. About 30-50% of this tritium is released from the metal samples in the first hour of desorption. About 90% of the tritium desorbed from metal samples is in the form of HTO, probably because of conversion of HT to HTO by surface reactions. Polishing the surfaces of a metallic sample can markedly decrease the amount of tritium it sorbs. Non-metallic materials sorb about 60-800 µCi/m^2 of HT from 24 hours of exposure to atmospheres of 14 Ci/m^3 HT. In the first hour of desorption, 20-40% of the HT seems to be released from various non-metallic materials. In all cases, a rapid initial desorption is significant for the first four hours and a slower process governs the rest of a six-day desorption. Little conversion of HT to HTO occurs on non-metallic samples.

Sorption of HTO varies much more widely than HT sorption for different samples, ranging from 4 µCi/m^2 for glass to 1 300 000 µCi/m^2 for concrete, in a 24-hour exposure to 1 Ci/m^3 HTO in room air. Metal samples typically sorb slightly more HTO from the 1 Ci/m^3 HTO atmosphere than they sorb HT from the 8 Ci/m^3 HT atmospheres. Non-metallic samples (except glass) exhibit much higher amounts of HTO sorption than metals, and sorb comparable amounts of HT and HTO from an atmosphere with 13 Ci/m^3 HT and 0.02 Ci/m^3 HTO. Oil-contaminated metal samples sorb slightly more HTO than their oil-free counterparts. HTO desorbs more slowly than HT from non-metallic samples, with 4-30% of the HTO being desorbed in the first two hours. About 40-60% of HTO desorbs from metallic samples within two hours. HTO desorbs more rapidly in the first few hours than later in the desorption.

Porous and permeable materials such as Gyproc, concrete, and paint are not very suitable for surfaces that may come into contact with HT or HTO. The samples of porcelain tile used in this study did not perform much better than the other non-metallic materials. However, glass may be a better model material than half-glazed porcelain tile for most of the exposed surface of a wall lined with porcelain tiles; this favours the use of porcelain as a liner for concrete surfaces, due to its minimal HTO sorption and low HT-HTO conversion. The porous grouting used to hold porcelain tiles on the wall may sorb much more tritium than the tiles, unless suitably protected.

In agreement with the results of other investigators,[3] most samples sorbed more tritium from the HTO exposure atmospheres than from the HT atmospheres, even though the HT atmospheres had higher concentrations and specific activities. Also, in atmospheres containing HTO concentrations 1000 times less than the HT concentrations, the amount of HTO sorbed on some materials was greater than or similar to the amount of HT sorbed, and the HTO was usually desorbed more slowly. Thus, the more radiologically hazardous HTO both sorbs more readily and is more difficult to desorb than HT in most cases. This implies that recirculating atmosphere detritiation systems should have low re-emissions of HTO into the atmosphere in order to facilitate rapid cleanup of tritium releases.

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Table 1 - Tritium Sorption Data from HT Exposures

A = Air desorption   F = Final desorption

Material	Total T Desorbed ($\mu Ci/m^2$)	%HTO	A Total T (μCi)	F Total T (μCi)
Exposure 1 (5.2 Ci/m^3 HT in Ar for 68 h)(0.07% HTO)				
Al	28	95.0	0.063	0.004
Cu	36	91.0	0.075	0.010
brass	58	94.8	0.126	0.009
Al	26	85.2	0.048	0.012
Cu	27	82.6	0.038	0.025
brass	42	87.6	0.081	0.018
Exposure 2 (5.5 Ci/m^3 HT in Ar for 44 h)(0.10% HTO)				
tin-plated steel	11	89.2	0.026	0.002
galvanized steel	112	97.4	0.259	0.017
mild steel	22	91.4	0.042	0.012
SS-304	45	98.2	0.086	0.025
polished SS-304	8	92.8	0.017	0.004
Exposure 3 (8.7 Ci/m^3 HT in Ar for 22 h)(0.07% HTO)				
tin-plated steel	27	89.7	0.059	0.007
Al	31	94.7	0.073	0.003
galvanized steel	190	98.0	0.462	0.007
mild steel	35	95.7	0.085	0.001
SS-304	54	93.3	0.117	0.003
SS-304 thermal desorption after leaching:				0.013
Exposure 4 (13.8 Ci/m^3 HT in air for 24.5 h)(0.15% HTO)				
Arborite	196	71.5	0.285	0.167
vinyl floor tile	300	13.3	0.660	0.048
porcelain tile	63	14.6	0.176	0.003
Gyproc	562	98.6	0.863	1.26
Exposure 5 (13.6 Ci/m^3 HT in air for 25 h)(0.09% HTO)				
Arborite[a]	364	11.6	0.814	0.070
vinyl floor tile[a]	785	1.5	2.13	0.023
porcelain tile	67	5.0	0.184	0.006
painted Gyproc	139	88.3	0.166	0.360

[a]   Two thicknesses of sample glued together with contact cement.

Table 2 - Tritium Sorption Data from HTO Exposures

A = Air desorption   F = Final desorption

Material	Total T Desorbed (μCi/m^2)	%HTO	A Total T (μCi)	F Total T (μCi)
Exposure 6 (1.02 Ci/m^3 HTO in air for 22 h, at 33% relative humidity and 24°C)(1.5% HT)				
concrete	1 280 000	100.0	2 820	3 220
SS-304	56	99.7	0.100	0.039
painted Al	9 000	100.0	10.8	11.3
galvanized steel	173	99.5	0.266	0.163
vinyl floor tile	23 100	100.0	21.5	30.4
glass	4	96.4	0.006	0.004
tin-plated steel	5		b	0.011
Al	13		↓	0.032
mild steel	33			0.081
brass	36			0.089
Cu	24			0.058
Exposure 9 (0.61 Ci/m^3 HTO in air for 1.9 h, at 31.9% relative humidity and 25°C)(4.0% HT)				
tin-plated steel	53		b	0.130
Al	71		↓	0.176
SS-304	330			0.809
SS-316L	36			0.087
mild steel	126			0.312
galvanized steel	640			1.58
brass	240			0.595
Cu	121			0.298
painted Al	26 600			65.8
concrete	337 000			2 080
vinyl floor tile	19 400			44.5
porcelain tile	6480			16.9
Arborite	44 000			91.0
glass	16			0.031
painted Gyproc	268 000			1 100

Table 2 - Tritium Sorption Data from HTO Exposures (Cont'd)

A = Air desorption   F = Final desorption

Material	Total T Desorbed (μCi/m^2)	%HTO	A Total T (μCi)	F Total T (μCi)
Exposure 10 (2.97 Ci/m^3 HTO in air for 3.2 h, at 18.5% relative humidity and 23°C)(8.6% HT)				
tin-plated steel	42		b	0.103
Al	63		↓	0.155
SS-304	128			0.317
SS-316L	39			0.098
mild steel	162			0.400
galvanized steel	500			1.22
brass	330			0.807
Cu	80			0.197
concrete	237 000			1 070
vinyl floor tile	18 800			45.0
porcelain tile	23 900			63.0
Arborite	65 000			134
glass	47			0.090
painted Gyproc	357 000			1 460
polished SS-304	57			0.140
polished SS-316L	14			0.036
oil-contaminated		mass of oil (g)		
tin-plated steel	94		0.0005	0.231
Al	91		0.0011	0.226
SS-304	320		0.0016	0.782
SS-316L	98		0.0008	0.243
brass	149		0.0006	0.369
Cu	202		0.0026	0.500
polished SS-316	56		0.0002	0.138

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bAir desorption was not carried out on these samples.
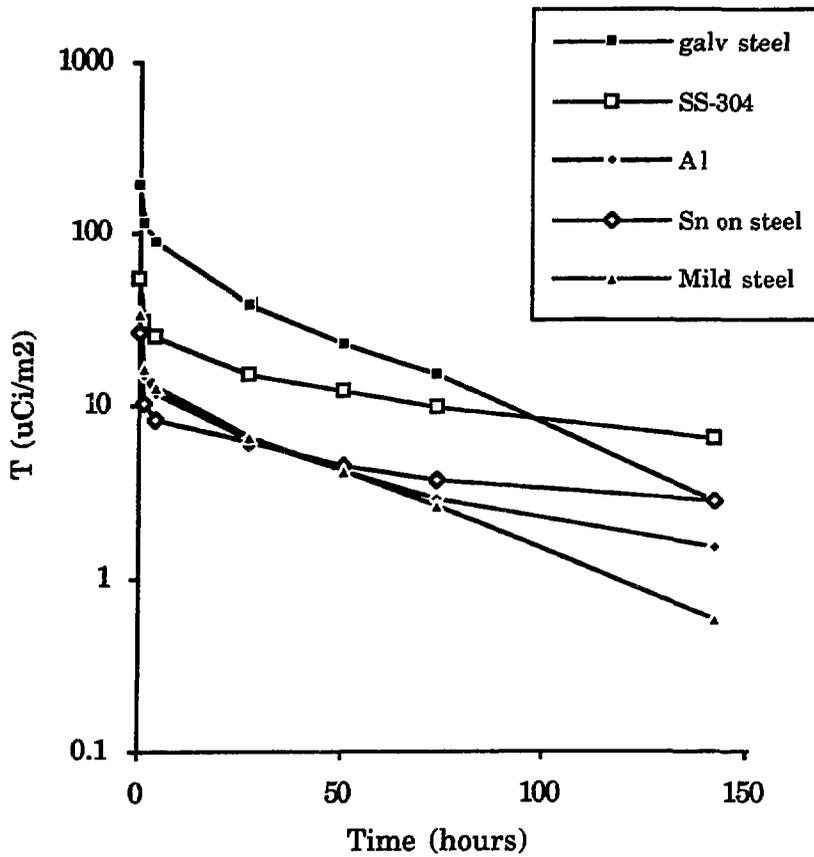
Figure 1 - Total Tritium (HT and HTO) Sorbed Versus Time for Metal Samples.
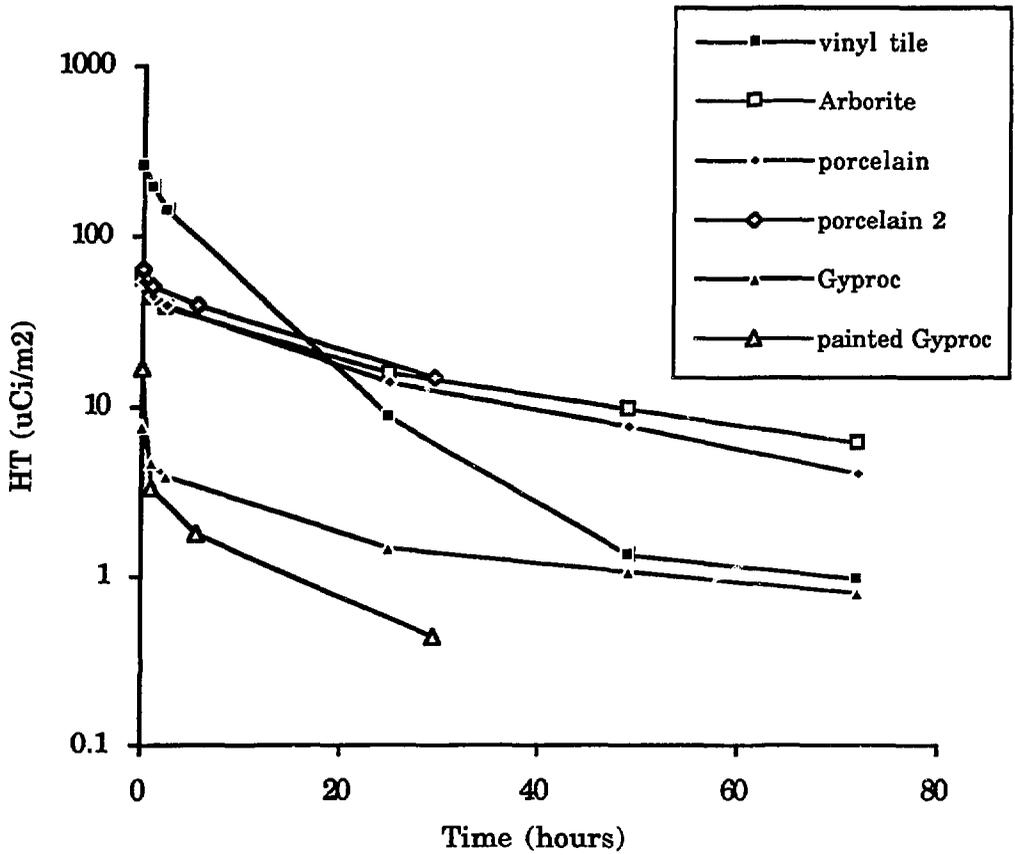Exposure Atmosphere - 8.7 Ci/m^3 HT, 0.0005 Ci/m^3 HTO

Figure 2 - HT Sorbed Versus Time for Non-metallic Samples.
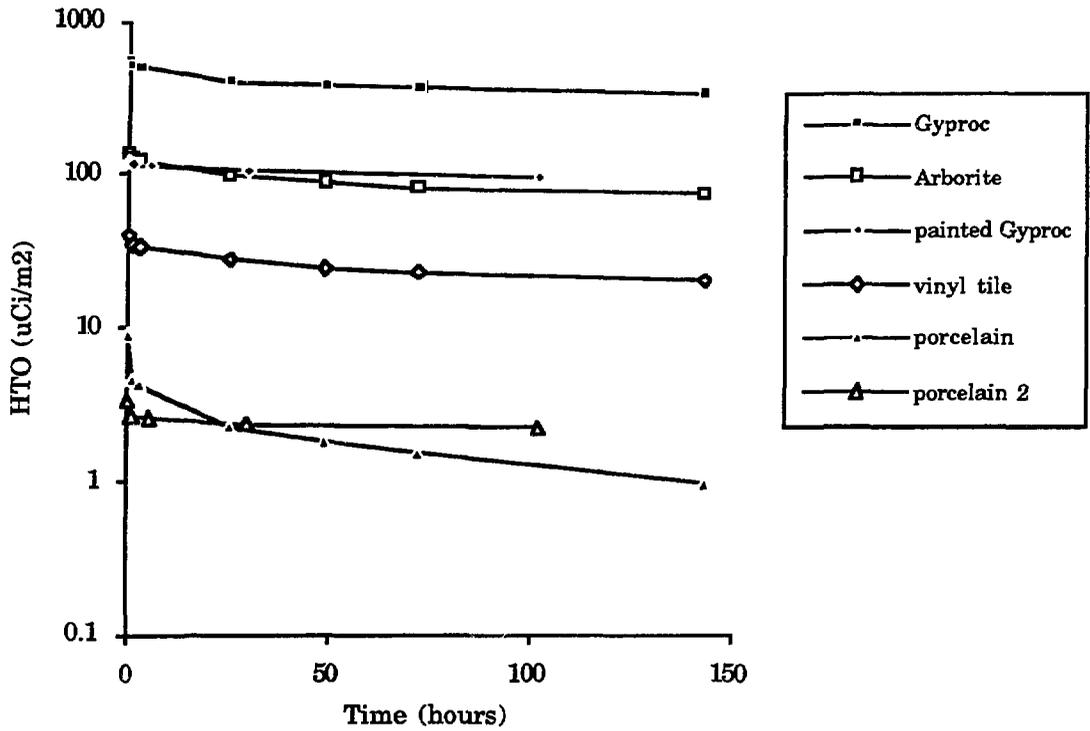Exposure Atmosphere - 13.8 Ci/m^3 HT, 0.02 Ci/m^3 HTO

Figure 3 - HTO Sorbed Versus Time for Non-metallic Samples.
Exposure Atmosphere - 13.8 Ci/m^3 HT, 0.02 Ci/m^3 HTO

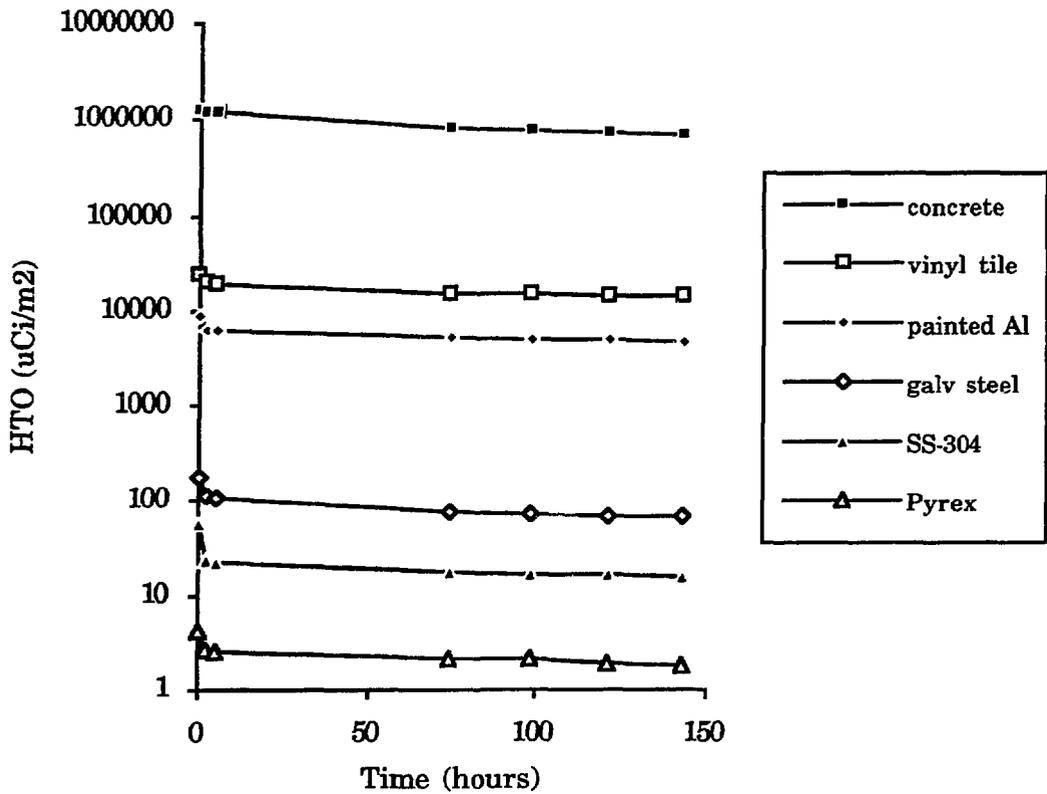**Figure 4 - HTO Sorbed Versus Time. Exposure Atmosphere - 0.02 Ci/m^3 HT, 1.02 Ci/m^3 HTO**