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Measurements of Th, U and K Concentrations in a Variety of Materials

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Abstract

Measurements have been made of the thorium, uranium and potassium concentrations in a variety of materials. The methods of direct γ-ray counting and neutron activation analysis have been employed, and cases of secular disequilibrium most notably in aluminum have been identified. Several comprehensive tables of results are provided.

Introduction

In recent years a need has grown up to find and produce materials especially low in the radioactive primordial elements thorium, uranium and potassium. Such materials are required for constructing detectors sensitive to very rare events such as double β decay or interactions of cold dark matter particles. They are also needed in the components of very large underground detectors of solar and supernova neutrinos. And of course they are needed in the construction of low-background facilities which are used to test materials for low levels of Th, U and K.

At the University of Guelph interest in determining low levels of primordial elements Th and U was stimulated by the objective of building a very large, ultra low background high purity Ge detector to search for neutrinoless double β decay of ^{76}Ge$^{1)}$. Initially neutron activation analysis was developed and used to select materials for the first detector. Subsequently this detector, in a low ambient background environment, was used to select materials for a second-generation, double-β decay detector and for substitution of components in the first detector as well[2-5]. In recent years the Sudbury Neutrino Observatory (SNO) project has created the need to determine the concentrations of radioactive elements in a wide variety of materials[6]. The methods of neutron activation analysis and direct γ-ray counting using the low-background facility developed previously have become complementary tools for this purpose.

Over the years a large number of materials have been studied by the two methods mentioned above. This paper presents a quick review of the methods used at Guelph, discusses some representative results, and provides a comprehensive list of materials and results. Most of these results have been generated on behalf of the SNO project. Other groups in the SNO collaboration, primarily at Lawrence Berkeley Laboratory, Berkeley, California and at Birkbeck College, London, England have also been involved in radioactivity measurements of materials, and supplementary reports on these measurements are available.

In addition radioactivity from Th, U and K in different geographical locations in different rock types, and in water are reported in a symposium proceedings[7]. Radioactive contamination of detector materials is also tabulated in a book by Knoll[8]. In the context of double beta decay investigations, similar information is reported in an abridged form by Avignone and Brodzinski[9].

Techniques

Neutron Activation Analysis

Neutron activation analysis (NAA) is used to detect the primordial elements ^{232}Th and ^{238}U by detecting the γ rays of 27-day ^{233}Pa (312 keV) and 54-hour ^{239}Np (106 keV, 228 keV and 278 keV) following β-decay after n-capture. The sensitivity is limited primarily by the n-capture properties of other elements in the sample, and these elements also limit the universality of the technique. In many materials sensitivities down to 1 ng/g are achievable (especially for ^{232}Th) and in the case of acrylics, sensitivities for ^{232}Th down to a few parts in 10^{12} have been achieved at Guelph. The latter will be described in a separate publication.

Neutron activation has been carried out using the McMaster University nuclear reactor. Typically samples of a few cubic centimetres and up to ten grams are irradiated in a flux of 1.5×10^{13} n/cm^2-s. Samples are irradiated for up to 36 hours for ^{232}Th determination and 10 hours for ^{238}U determination; however, some materials such as acrylic can only withstand irradiation for a few hours. The integrated flux is monitored by using 0.05 g of aluminum kitchen foil whose content of ^{232}Th and ^{238}U has been standardized against well characterized thorium and uranium rock standards. These foils contain typically 100 ng/g ^{232}Th and 1000 ng/g ^{238}U. The reproducibility of the calibration foil values has been extensively checked, and variability is less than 10%. Counting of the samples and standards, after a typical cooling time of one week for U and two weeks for Th, is done with large volume (~50%) high purity Ge detectors with good resolution at low energies (down to 900 eV at 122 keV).

Depending on the application for the material being tested, any or all of the α, β or γ radiations emitted by the radioactive elements may be important. One aspect of NAA that must be kept in mind is that it only determines the abundance of the long-lived parent of the ^{232}Th and ^{238}U decay series. Because both of these series contain relatively long-lived radium isotopes, these series might not be in secular equilibrium in a material which has recently undergone chemical modification (either natural or man-made). Consequently the amounts of α, β and γ radiations will not in general be known precisely. For the Sudbury Neutrino Observatory the β and γ rays of ^{208}Tℓ and ^{214}Bi decay are the most serious so that γ-ray counting (which also gives the intensities of the β-rays of importance) is necessary.

Direct γ-Ray Counting

A low background facility has been constructed at the University of Guelph based around a 208 cm^3 intrinsic Ge detector custom made from components of low radioactivity. This detector was originally built for a search for double β decay of ^{76}Ge, and its background level has been improved over the years by replacement of some of its cryostat and internal parts with lower background materials and components. The crystal has 4π shielding of 6 mm Hg and 15 cm low background Pb, has a cosmic-ray veto completely surrounding the Pb shield, and is in a basement laboratory below one metre of concrete. Details of this apparatus have been described elsewhere[2-4)]. The important feature of this low background spectrum is that its own internal background has been very well determined by running the system 305 metres underground in a salt mine.

The cavity inside the Hg shield can hold up to one-litre samples in an inverted beaker geometry (Marinelli beaker) surrounding the cryostat end-cap. Generally, samples are crushed or broken into pieces to fill the acrylic Marinelli beaker used, and MnO powder filling a beaker of the same size is used as the standard. This MnO is an in-house standard and has 4.6 μg/g ^{232}Th and 2.9 μg/g U in equilibrium with their daughters, and 0.8% potassium. This standard has also been cross-checked at other laboratories. In special cases a standard will be made to match the geometry of the sample. Because the packed MnO has a density of 2.2 g/ml it is very similar to many of the samples studied and generally self-absorption corrections are not needed. This is especially true because the higher energy γ rays of the decay series are principally used to determine concentrations. In the ^{232}Th series, the γ rays are at 583, 911 and 2614 keV; in ^{238}U series, they are at 609, 1001 and 1764 keV and in ^{40}K, the γ-ray energy is 1461 keV.

An important feature of direct γ-ray counting of thorium and uranium is that it can detect decay series disequilibrium. In the ^{232}Th decay, the 911-keV γ-ray follows ^{228}Ra decay and precedes ^{228}Th decay, and in the ^{238}U series the 1001-keV γ-ray comes from ^{234m}Pa; the intensities of these

γ rays relative to the others in their series is an indication of radium disequilibrium. Probably because of the long radium half-life in the ^{238}U chain compared to the 5.76 y half-life of ^{228}Ra in the ^{232}Th chain, ^{238}U-chain disequilibrium is much more prevalent.

Materials

A large number of materials have been tested by direct γ-counting and by NAA, and a few have been tested by both. The materials include metals, glasses and glass-making raw materials, various inorganic chemical compounds and ceramics, some photomultiplier tube components, cement and concrete components and a variety of plastics and synthetic fibres. Acrylic was part of a special project and will be described in a separate publication; it was found that acrylics can have less than 3×10^{-12} g/g of ^{232}Th and ^{238}U. In the tables the results are presented as grams of Thorium, Uranium or Potassium per gram of material. For results obtained with γ-ray counting, values for ^{228}Th equivalent thorium (employing $^{208}T\ell$ γ-rays) and ^{226}Ra equivalent uranium (employing ^{214}Bi γ-rays) are reported assuming radioactive equilibrium in the respective decay chains. The condition of radioactive equilibrium is tested by determining ^{228}Ra equivalent thorium (via ^{228}Ac 911 keV γ-ray) and ^{238}U equivalent uranium (via ^{234m}Pa 1001 keV γ-ray and ^{235}U 186 keV γ-ray). Significant differences between corresponding values of thorium and uranium indicate radium disequilibrium. Brief discussions follow of some of the general radioactivity levels of materials found in the tables follow. Table 1, with the associated list of materials in table 2, presents concentrations determined by direct γ-counting. Table 3 gives results from NAA, while tables 4 and 5 present disequilibrium results in aluminum.

Glasses Most glasses tested are found to have thorium content in the range 200-700 ng/g and uranium (^{226}Ra) in the range 100-500 ng/g, with the exception of specially prepared low activity glasses. There is no evidence of radium disequilibrium. Potassium levels are much more variable, ranging from 20 μg/g to 6×10^4 μg/g.

Some of the radioactivity in glass comes from erosion of the furnace containing the melt, and one standard furnace liner measured contained 120 μg/g Th and 150 μg/g U. To produce low activity glass, therefore, requires that attention be paid to the furnace liner besides careful selection of raw materials.

Ceramics Ceramics are the second major contributor to radioactivity in most photomultiplier tubes. They are often found to contain μg/g levels of thorium and uranium, and potassium at the level of 0.1 to 1 mg/g. Occasionally low activity ceramics are found, but to our knowledge no major research effort has gone into adapting low activity ceramics for photomultiplier tubes.

Cements and Concretes A few Portland type cements were measured and they have levels of thorium and uranium in the μg/g range. Since cement makes up about 20% of typical concrete, lower activity concrete can be produced with low-activity aggregate. Dolomite from Haley, Ontario, quartz from Timmins, some serpentinized Mg pyroxide from Quebec and an ultra basic rock from the Soviet Union which were tested would provide low background aggregates for concrete.

Very low background shielding blocks were made for the Sudbury Neutrino Observatory project out of Haley dolomite with a sulfur and special polymer (SRX) binder (called Sulfurcrete™).

Aluminum Aluminum is an important metal structurally, for detector housings and for reflectors or concentrators on photomultiplier tubes. Thorium and uranium levels in aluminum have been determined by NAA and γ-counting, and some have been analyzed by both methods. Except for specially-refined aluminum, parent ^{232}Th and ^{238}U tend to be in the 100 ng/g and the 1000 ng/g range respectively. The γ-counting measurements indicate that radium is strongly depleted in aluminum, unless the aluminum is old in which case ^{228}Ra in the thorium chain grows back in. In three cases where both NAA and γ-counting were carried out on the same sample, ^{228}Th was found to be strongly enhanced, in one case more than a factor of six higher than the equilibrium level of the ^{232}Th parent. It is not known if this property is associated with most aluminums or not, although we note that it appears to be the case even with household foil.

Other Metals Most other metals that we have tested have no detectable thorium or uranium above our sensitivity level, either in NAA or γ-counting, which is at the few ng/g level generally. In addition, an upper limit on the thorium and uranium (^{226}Ra) levels of OFHC Cu (Cu alloy 101) of 30 pg/g has been obtained from a double β-decay experiment in which the cryostat and the shielding blocks were made of this copper5).

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9) F.T. Avignone III and R.L. Brodzinski, Progress in Particle and Nuclear Physics 21 (1988) 99-191, refer to table II.

TABLE 1

Radioactivity Levels in Materials via direct γ-ray counting

SAMPLE TITLE	Th (ng/g)	U non Ra-226 (ng/g)	U via Ra-226 (ng/g)	K (µg/g)
Alumina 1	65 ± 8	37 ± 19	14 ± 2	30 ± 4
Alumina 2	22 ± 6	680 ± 80	12 ± 2	10 ± 4
Alumina 3	17 ± 10	41 ± 50	12 ± 3	< 1
Bakelite Base(Black)1	4070 ± 60		670 ± 100	780 ± 30
Borax 1	55 ± 10	3 ± 18	7 ± 2	60 ± 4
Borax 2	175 ± 40	20 ± 27	46 ± 5	30 ± 10
Borax 3	0 ± 10	< 18	8 ± 3	10 ± 4
Borax 4	123 ± 25	75 ± 75	38 ± 4	40 ± 4
Borax 5	145 ± 9	19 ± 28	36 ± 3	40 ± 4
Boric acid 1	6 ± 6	40 ± 17	8 ± 1	10 ± 4
Boric acid 2	5 ± 5	24 ± 21	2 ± 2	10 ± 4
Boric acid 3	1 ± 7	3 ± 31	2 ± 3	10 ± 4
Cables 1	60 ± 20		4 ± 6	< 5
Cement 1	3120 ± 100	2800 ± 800	2350 ± 75	1580 ± 40
Cement 2	1223 ± 68	4069 ± 541	2362 ± 54	2360 ± 80
Cement 3	4242 ± 104	2012 ± 540	1091 ± 38	7450 ± 130
Ceramic 1	156 ± 70	808 ± 72	61 ± 8	80 ± 20
Ceramic 2	2350 ± 150	436 ± 128	545 ± 15	150 ± 20
Ceramic 3	1340 ± 70	1932 ± 224	2100 ± 50	110 ± 20
Ceramic 4	2160 ± 280		3270 ± 210	610 ± 200
Ceramic 5	200 ± 30		130 ± 10	220 ± 20
Ceramic 6	320 ± 60		190 ± 60	140 ± 20
Ceramic 7	2230 ± 100		1090 ± 40	890 ± 70
Ceramic 8	960 ± 30		1200 ± 200	290 ± 20
Ceramic 9	3870 ± 190		720 ± 180	2460 ± 140
Ceramic 10	130 ± 50		50 ± 20	170 ± 40
Circuit Board 1	690 ± 90		200 ± 43	90 ± 30
Concrete 1	561 ± 15	419 ± 83	76 ± 5	900 ± 20
Concrete 2	290 ± 16	680 ± 110	512 ± 12	470 ± 20
Dolomite 1	5 ± 7	32 ± 17	11 ± 3	40 ± 4
Dolomite 2	15 ± 10	22 ± 21	11 ± 3	40 ± 4
Dolomite 3	325 ± 25	350 ± 100	96 ± 3	160 ± 10
Dolomite 4	2 ± 3	< 10	4 ± 2	30 ± 4
Dolomite 5	6 ± 3	29 ± 14	12 ± 2	50 ± 4
Dolomite 6	2 ± 3	16 ± 14	13 ± 1	10 ± 4
Furnace Liner 1	(1.2±0.3)x10^5		(1.5±0.3)x10^5	3400 ± 1000
Furnace Liner 2	167 ± 9		185 ± 5	190 ± 20
Furance Liner 3	130 ± 10		90 ± 10	110 ± 10
Furnace Liner 4	140 ± 10		150 ± 30	90 ± 10
Glass 1	600 ± 30	406 ± 147	240 ± 20	10210 ± 110
Glass 2	400 ± 50	467 ± 108	402 ± 12	80 ± 10
Glass 3	425 ± 25	530 ± 129	420 ± 15	60 ± 10
Glass 2+3	400 ± 30	500 ± 100	380 ± 15	70 ± 10
Glass 4+5	297 ± 15	186 ± 51	260 ± 10	80 ± 10
Glass 5	290 ± 30	175 ± 50	275 ± 10	90 ± 10
Glass 8	860 ± 30	1338 ± 114	1090 ± 20	1390 ± 20

SAMPLE TITLE	Th (ng/g)	U non Ra-226 (ng/g)	U via Ra-226 (ng/g)	K (µg/g)
Glass 9	840 ± 40	850 ± 200	1085 ± 10	70 ± 10
Glass 10	246 ± 20	101 ± 38	129 ± 5	300 ± 10
Glass 11	340 ± 25	335 ± 90	360 ± 7	350 ± 10
Glass 12	1150 ± 20	1500 ± 600	1500 ± 30	1120 ± 20
Glass 13	63 ± 15	158 ± 62	93 ± 4	60 ± 10
Glass 14	115 ± 18	271 ± 44	201 ± 8	140 ± 10
Glass 15	604 ± 67	371 ± 120	351 ± 25	180 ± 10
Glass 16	588 ± 55	644 ± 152	357 ± 32	210 ± 20
Glass 17	615 ± 81	598 ± 149	355 ± 29	180 ± 20
Glass 18	635 ± 79	496 ± 139	330 ± 27	170 ± 10
Glass 19	460 ± 61	457 ± 106	377 ± 24	80 ± 10
Glass 20	454 ± 81	522 ± 159	422 ± 31	110 ± 10
Glass 21	423 ± 71	597 ± 141	315 ± 28	90 ± 10
Glass 22	441 ± 72	440 ± 148	411 ± 31	100 ± 10
Glass 23	400 ± 67	535 ± 124	341 ± 27	100 ± 10
Glass 24	244 ± 29	159 ± 72	147 ± 46	350 ± 30
Glass 25	108 ± 54	352 ± 108	88 ± 15	220 ± 30
Glass 26	382 ± 30	402 ± 107	264 ± 15	3660 ± 60
Glass 27	520 ± 33	692 ± 136	968 ± 22	7160 ± 70
Glass 28	688 ± 72	519 ± 283	775 ± 35	61250 ± 330
Glass 29	66 ± 19		76 ± 10	30 ± 10
Glass 30	314 ± 20	304 ± 91	457 ± 15	80 ± 10
Glass 31	40 ± 5	89 ± 33	81 ± 3	270 ± 10
Glass 32	218 ± 9		265 ± 6	210 ± 10
Glass 33	211 ± 11		725 ± 11	1070 ± 20
Glass 34	18 ± 4		18 ± 4	25 ± 5
Glass 35	20 ± 4		22 ± 5	30 ± 5
Glass 36	20 ± 6		1 ± 1	< 5
Glass 37	72 ± 15		55 ± 7	20 ± 10
Glass Solder 1	39 ± 7		25 ± 3	20 ± 5
Gypsum 1	225 ± 25	750 ± 250	725 ± 25	920 ± 20
Indium 1	6 ± 7	0 ± 30	1 ± 2	10 ± 4
$KMnO_4$ 1	30 ± 22	300 ± 190	12 ± 10	245700 ± 300
Lime 1	40 ± 10	59 ± 36	40 ± 3	100 ± 10
MnO_2 1	52 ± 9	< 14	8 ± 2	10 ± 4
Mn-coated beads 1	30 ± 60		29 ± 14	47000 ± 300
Molecular Sieve 1	2280 ± 110	10280 ± 440	710 ± 40	1830 ± 90
Molecular Sieve 2	2780 ± 80	1020 ± 340	1200 ± 50	3180 ± 100
Nepheline syenite 1a	875 ± 50	308 ± 174	385 ± 15	37600 ± 120
Nepheline syenite 1b	875 ± 50	1041 ± 354	355 ± 25	37800 ± 230
Nepheline syenite 2	150 ± 10	39 ± 96	36 ± 3	76230 ± 90
Nepheline syenite 3	200 ± 30	136 ± 117	36 ± 7	77320 ± 90
Polymer 1	145 ± 25	118 ± 57	55 ± 5	250 ± 10
Polymer 2	160 ± 10	109 ± 34	50 ± 4	90 ± 4
PVC 1	19 ± 4	43 ± 47	42 ± 7	20 ± 3
Quartz 1	< 3	< 9	3 ± 1	1 ± 4
Quartz 2	18 ± 6		38 ± 4	10 ± 5
Quartz 3	29 ± 6		104 ± 20	20 ± 5
Residue 1	885 ± 25	501 ± 82	96 ± 6	10 ± 10
Rock 1	20 ± 8	21 ± 33	0 ± 2	10 ± 4

SAMPLE TITLE	Th (ng/g)	U non Ra-226 (ng/g)	U via Ra-226 (ng/g)	(μg/g)
Rock 2	106 ± 5	79 ± 27	66 ± 5	170 ± 10
Rock 3	78 ± 5	48 ± 30	23 ± 2	140 ± 10
Salt 1	3 ± 2	8 ± 15	1 ± 1	40 ± 4
Salt 2	6 ± 7	4 ± 46	2 ± 4	80 ± 1
Sand 1	2160 ± 50	442 ± 199	300 ± 25	1200 ± 40
Sand 2	5050 ± 50	2400 ± 150	1062 ± 20	90 ± 10
Sand 3	415 ± 25	102 ± 70	158 ± 6	270 ± 10
Sand 4	790 ± 30	800 ± 100	575 ± 20	170 ± 10
Sand 5	20 ± 6	23 ± 16	10 ± 1	30 ± 4
Sand 6	390 ± 10	200 ± 75	140 ± 3	380 ± 10
Sand 7	43 ± 10	20 ± 18	15 ± 2	20 ± 4
Sand 8	320 ± 15	258 ± 60	140 ± 7	50 ± 10
Sand 9	322 ± 14	373 ± 21	263 ± 11	< 10
Sand 10	255 ± 12	107 ± 37	130 ± 5	70 ± 4
Sand 11	249 ± 10	125 ± 31	122 ± 4	90 ± 4
Sand 12	22 ± 3	36 ± 17	6 ± 2	140 ± 10
Scintillator Paint 1	19 ± 60		40 ± 30	80 ± 40
Silica 1	2650 ± 100	753 ± 257	440 ± 20	1430 ± 60
Silica 2	560 ± 25	194 ± 145	200 ± 15	550 ± 30
Silica 3	375 ± 25	785 ± 215	200 ± 15	43800 ± 170
SS Welding Wire 1	3 ± 1		< 1	< 5
SS Welding Rod 1	< 1		< 1	< 5
Stainless Steel 1	< 1		< 1	< 5
Stainless Steel 2	14 ± 6		5 ± 3	10 ± 5
Stainless Steel 3	< 3		4 ± 2	< 5
Sulfurcrete 1	17 ± 2	9 ± 10	14 ± 1	30 ± 4
Sulphur 1	2 ± 5	19 ± 13	2 ± 1	10 ± 4
Sulphur 2	20 ± 4	16 ± 15	9 ± 1	20 ± 4
Tubing 1	< 15		< 8	< 5
Tubing 2	< 15		< 8	< 5
ZnS 1	23 ± 6	753 ± 57	15 ± 3	20 ± 5
ZnS 2	130 ± 80		140 ± 40	130 ± 50

TABLE 2

Code to Materials tested by direct γ-ray counting

Alumina	1	Calcined Alumina (Alcan)
	2	Hamamatsu
	3	CERA Hydrate
Bakelite Base for PMT (Hamamatsu)		
Borax	1	Anhydrous Borax (Miscellaneous)
	2	US Anhydrous Borax
	3	US Borax Gran Sq.
	4	US Anhydrous Borax
	5	Miscellaneous
Boric Acid	1	US Anhydrous Boric Acid HP
	2	Hamamatsu
	3	Miscellaneous
Cables	1	Coaxial cables
Cement	1	White Portland Cement Type 10 (Federal White Cement)
	2	Richmond Cement
	3	Bath Cement
Ceramic	1	Dynode Ceramic Squares (RCA)
	2	Mauve Ceramic Ring (RCA)
	3	White Ceramic Ring (RCA)
	4	PMT Ceramic (Burle)
	5	White PMT Ceramic (Burle)
	6	Green PMT Ceramic (Burle)
	7	Ceramic Posts for PMT (Burle)
	8	PMT Ceramics (Hamamatsu)
	9	Green Ceramics (EMI)
	10	White Ceramics (EMI)
Circuit Board	1	Flexible circuit board
Concrete	1	Bath Concrete
	2	Borated Concrete
Dolomite	1	Whitish-grey Dolomite (Haley, Ont.)
	2	Sandy-stained Dolomite (Haley, Ont.)
	3	Bluish Dolomite (Haley, Ont.)
	4	West Dolomite (Haley, Ont.)
	5	Middle Dolomite (Haley, Ont.)
	6	East Dolomite (Haley, Ont.)
Furnace Liner	1	"ZAC-stone" (Schott)
	2	Special liner (Schott)
	3	Quarzal liner #1 (Schott)
	4	Quarzal liner #2 (Schott)

Glass	1	RCA Glass Slides
	2	ZW3468 dark PMT glass, Hamamatsu
	3	ZW3468 clear PMT glass, Hamamatsu
	4	ZW4693 dark PMT glass, Hamamatsu
	5	ZW4693 clear PMT glass, Hamamatsu
	6	ZW4751 dark PMT glass, Hamamatsu
	7	ZW4751 clear PMT glass, Hamamatsu
	8	Schott Glass 8245
	9	Schott Glass 8020
	10	2 Gencom glass plates, (Thorn EMI Gencom)
	11	Cullet glass, (Kimble)
	12	Philips Glass
	13	Schott Glass 8246-1
	14	Low-Rad Glass Type 1001, EMI
	15	IWAKI 7740
	16	"
	17	"
	18	"
	19	H-32, Hamamatsu
	20	"
	21	"
	22	"
	23	"
	24	Philips Glass 6
	25	Philips Glass 211
	26	Hamamatsu Glass H-50
	27	Hamamatsu Glass HS-50
	28	Burle Schott 8250
	29	Schott 8246-2
	30	ACMI UV1008, CIRCON Corp.
	31	ACMI B472, CIRCON Corp.
	32	K-7003-D (Iwaki), from Hamamatsu
	33	SKS-48 (Akagawa), from Hamamatsu
	34	Schott 8246-3
	35	Schott 8246-4
	36	Glass 300
	37	Russian Glass, Philips
Glass Solder	1	Generic
Gypsum	1	Generic
Indium	1	Indium Scrap
$KMnO_4$	1	University of Guelph
Lime	1	CaOMgO Lime, Haley
Mn-coated beads	1	Acrylic beads, Secam Canada
MnO_2	1	Manganese Oxide
Molecular Sieve	1	Nuclear Diodes
	2	Union Carbide type 5A

Nepheline syenite	1	Indusmin
	2	North Cape
	3	North Cape
PVC	1	Generic
Polymer	1	SRX polymer
	2	SRX Polymer used in Sulfurcrete Sample
Quartz	1	Minnor XLA01 Quartz
	2	Powder UHP 20
	3	Powder UHP 50
Residue	1	Air-cooled Residue, Chromasco
Rock	1	Russian black rubble
	2	Russian aggregate
	3	Serpentinised Mg pyroxide
Salt	1	Windsor Iodized Table Salt
	2	Coarse Pickling Salt
Sand	1	Midland Treated Sand, Indusmin
	2	Fine FeSi
	3	Flint, Indusmin
	4	Fluorspar
	5	Corning sand
	6	Russian binder material
	7	Hamamatsu Boric Sand
	8	Silicic Sand Hamamatsu
	9	Acid Washed Quintus Sand
	10	German Sand
	11	Sand (MAM2)
	12	Quartz Sand
Scintillator Paint	1	Generic
Silica	1	Midland-Silica-325M
	2	St. Canut Silica-325M
	3	Minex-4
SS Welding Wire	1	
SS Welding Rod	1	316L
Stainless Steel	1	Alloy 304 plates
	2	Alloy SUS304, PMT parts (Hamamatsu)
	3	Alloy NMBA, PMT parts (Hamamatsu)
Sulfurcrete	1	Sulfurcrete with Haley Dolomite, Sulfurcrete Prod's Inc.
Sulphur	1	Yellow sulphur disks
	2	Sulphur used in Sulfurcrete

Tubing	1	Tygm R3603
	2	Polyclear
ZnS	1	BDH ZnS
	2	Generic

TABLE 3
Generic Materials tested by NAA

	^{232}Th (ng/g)	^{238}U (ng/g)
Aluminum Alloys		
1100	200	
2011	150-322	630-870
2024	100-180	511
3002	<1000	1000
5252	<200	3100
5657	<200	1300
6061	100-170	930
Cominco 6 9's	4	14
MRC UHP	0.5-4	1-3
Kingston Ind., NY	<200	2300
Plastics		
Fiber Glass	5000	N/A
Nylon Rod	0.6	N/D
Polycarbonate	1	<1.5
Teflon Rod	0.6	0.7
Sheet	0.2	0.2
Powder	<1	N/D
Film	<0.010	<0.017
Vespel	2	1
Synthetic		
Epoxy (brown)	2325	350
(white)	61	150
Neoprene	162	N/D
Viton	80	162
Kevlar rope	0.36±0.18	<0.07
Spectra rope	0.25±0.10	0.17±0.13
Vectran rope 1	0.68±0.12	0.14±0.01
2	0.61±0.24	0.17±0.01
Miscellaneous		
Activated Charcoal	<2-18	1-11
Concrete 1	651	320
2	3675	1480
Rock Salt	2.6	<65
Boron Nitride	470	N/D
Metals		
110 Cu	<1	<20
OFHC Cu*	<1	<20
Te-Cu	<24	N/D
Mg	<0.6	N/A
Ti	<14	N/A
Pb	<1	<9

* See also text.

TABLE 4
Determination of U Series Disequilibrium in Aluminum

	NAA	Direct γ-Counting	
Sample No.	^{238}U (ng/g)	(^{238}U + ^{234}Pa) equivalent (ng/g)	^{226}Ra equivalent (ng/g)
Alcan 66250 HO Alloy	350 ± 36	410 ± 80	< 4
Omega Mirror	890 ± 89	940 ± 200	< 20
Alloy 1350		740 ± 40	< 5
Reynolds Kitchen Foil	1110 ± 110	990 ± 60	< 25

TABLE 5
Determination of Th-series Disequilibrium in Aluminum

	NAA	Direct γ-Counting	
Sample No.	^{232}Th (ng/g)	^{228}Th equivalent (ng/g)	^{228}Ra equivalent (ng/g)
Alcan 66250 HO Alloy	67 ± 3	440 ± 10	< 6
Omega Mirror	118 ± 4	400 ± 20	13 ± 20
Alloy 1350		180 ± 10	< 10
Reynolds Kitchen Foil	61 ± 2	180 ± 25	30 ± 20