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HEAVY MASS ELEMENTS TOTAL HALF-LIVES FOR SELECTED LONG-LIVED NUCLIDES

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Heavy Mass Elements Total Half-lives for Selected Long-lived Nuclides

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I. Introduction

In the past, many compilations and evaluations of half-lives have been made which have uncritically accepted authors' values and uncertainties. They have merely recommended weight-averaged reported results. This evaluation attempts to reanalyse each experiment in the literature including an estimate of the standard deviation utilizing, where possible, an estimate of the systematic error. This paper constitutes a preliminary step in the process of recommending values.

The long-lived nuclides of heavy mass elements are of interest in determining geological ages using the Re-Os or the Lu-Hf dating methods, in supplying information on the p-process (proton capture) of nucleo-synthesis, in providing information on lepton number conservation and the rest mass for the electron neutrino from double β decay processes and in the case of tantalum because it represents the first long-lived state which is actually an isomer.

Experimental data on the half-lives of selected nuclides have been evaluated and recommended values and uncertainties are presented for the following nuclides: ^{128}Te, ^{130}Te, ^{129}I, ^{138}La, $^{144,145}Nd$, $^{146,147,148}Sm$, ^{152}Gd, ^{154}Dy, ^{176}Lu, ^{174}Hf, ^{180}Ta, ^{187}Re, ^{186}Os, ^{190}Pt, $^{204,205}Pb$ and $^{230,232}Th$.

It is shown that ^{204}Pb, which was previously thought to be radioactive, is stable. For ^{205}Pb, the L electron capture x-rays have been revised for the M and higher x-ray yields. The resulting half-life for ^{205}Pb is $1.9 \pm 0.3 \times 10^7$ years. ^{146}Sm with a half-life of $1.03 \pm 0.05 \times 10^8$ years is the longest-lived extinct natural nuclide.

II. Recommended Data

Table 1 $T_{1/2}$ (^{128}Te)

Author	Reference	Value 10^{-24} (years)	Comment
Alexander	1	$>$.12	
Srinivasan	2	$>$2.7	
Hennecke	3	1.54	
Hennecke	3	3.0±0.5	using $\frac{^{128}Te}{^{130}Te}$ half-life ratios
Kirsten	4,5	5.5	using $^{128}Te/^{130}Te$ half-life ratio

The recommended value is based on Kirsten's $^{128}Te/^{130}Te$ half-life ratio and the recommended ^{130}Te half-life. It should be noted that the Kirsten ratio gives 23.6×10^{24} (mean value)

$>10.7 \times 10^{24}$ years (mean + standard deviation)

$> 7.4 \times 10^{24}$ years (mean + 2 standard deviations)

The recommended value has greater than 99% confidence.

Table 2 $T_{1/2}$(^{130}Te)

Author	Reference	Value (10^{-21} years)	Comment
Inghram	6	1.4	
Alexander	1	2.03	
Srinivasen	2	2.51	
Hennecke	3	0.97	
Fdesenko	7	1.2	
Kirsten	8	$22^{+0.7}_{-0.5}$	
Kirsten	4,5	260±0.28	

The half life for double beta decay of ^{130}Te is based on the measurement by Srinivasan of four different samples of Swedish tellurobismuthith, and the measurements by Kirsten[191], and Kirsten [192,193] of native tellurium from the Goodhope Mine, Colorado, $T_{1/2}(^{130}Te) = 2.4 \pm 0.2 \times 10^{21}$ years.

Table 3 $T_{1/2}(^{129}I)$

Author	Reference	Value x (10^{-7}years)	Comment
Katcoff	9	1.72±0.09	
Russel	10	1.56±0.06	
Emery	11	1.57±0.04	
Kuhry	12	1.97±0.14	

A weighted average of the four measurements is the recommended half life, $t_{1/2} = 1.6 \pm 0.1 \times 10^{7}$ year.

Table 4 $T_{1/2}$ (^{138}La)

Author	Reference	Value x (10^{-11}years)	Comment
Turchinetz	13	1.15±0.1	revised
Glover	14	1.13±0.04	revised
DeRuytter	15	1.04±0.02	
Ellis	16	1.53±0.3	revised
Marsol	17	1.23±0.18	revised
Cesana	18	1.25±0.12	revised
Taylor	19	1.25±0.12	revised
Sato	20	1.03±0.04	
Norman	21	1.05±0.05	revised

The recommended value is based on a weighted average of the measurements by Marsol, Taylor, Sato and Norman.

Table 5 $T_{1/2}(^{144}Nd)$

Author	Reference	Value(10^{-15} year)	Comment
Waldron	22	1.5	Natural Sample
Porschen	23	5.	Nuclear Emulsion Natural Sample
Porschen	24	2.2	84.2% enriched
Brodley	25	2.1	93.45% enriched
Mac Farlane	26	2.4±0.3	62.62% enriched
Isola	27	2.1±0.4	93.7% enriched

The enriched sample measurements are all in agreement. The recommended value is that of Isola which is the highest enrichment measurement.

Table 6 $T_{1/2}$ (^{145}Nd)

Author	Reference	Value (years)	Comment
Isola	27	$>6x10^{16}$	70.46%enriched

The lower limit of the ^{145}Nd half life is given by Isola for a 70.46% enriched sample.

Table 7 $T_{1/2}$ (^{146}Sm)

Author	Reference	Value (10^{-8} years)	Comment
Dunlavey	28	0.5	Emulsion work
Mac Farlane	26	<3*	Natural sample
Nurivia	29	0.74±.15	
Friedman	30	1.026±0.048	Surface barrier detector
Gupta	31	<2**	

* half-life assumes continuous nucleosynthesis from $12x10^9$ years to $4.7x10^9$ years.

** half-life limit assumes primordial samarium has an abundance for ^{146}Sm of 3 percent and the age of the elements is $4.5x10^9$ years.

The recommended value is the surface barrier detector measurement by Friedman.

Table 8 $T_{1/2}$ (^{147}Sm)

Author	Reference	Value x (10^{-11}years)	Comment
Hevesy	32	1.8	
Herzfinkiel	33	2.0	
Mader	34	1.5	
Libby	35	0.91	
Hosemann	36	1.5±0.1	
Cuer	37	1.3±0.1	
Picciotto	38	0.99±0.05	
Beard	39	1.25±0.06	
Leslie	40	1.15±0.03	
Beard	41	1.06±0.04	corrected for wrong Sm content.
Karras	42	1.13±0.05	
Mac Farlane	26	1.15±0.05	
Wright	43	1.05±0.02	liquid scintillator
Donhoffer	44	1.04±0.03	Liquid scintillator
Gupta	31	1.06±0.02	97% enriched

The half life is based on the 97.8% enriched ^{146}Sm measurement by Gupta supported by the results of Wright, Donhoffer and Beard (as corrected for samarium content by Wright). It was noted by Gupta that the earlier measurements by ionization chamber have a problem with the sample size deterioration and they have been ignored here.

Table 9 $T_{1/2}$ (^{148}Sm)

Author	Reference	Value (10^{-15} Years)	Comment
Karras	45	.0120±0.003	
Mac Farlane	26	>0.20	83.1% enriched
Korolev	46	8±2	90.8% enriched
Gupta	31	7±3	99.941% enriched

The recommended half life is based on Gupta's measurement of highly enriched ^{148}Sm. The result of Korolev is in agreement with Gupta's value.

Table 10 $T_{1/2}$ (^{152}Gd)

Author	Reference	Value (10^{-14} years)	Comment
Porschen	24	7.8	natural sample
Riezler	47	9.5	14.96% enriched
Mac Farlane	26	1.08±0.08	14.96% enriched

The recommended value is based on ther multi channel analyzed-low background ionization chamber measurement by Mac Farlane rather than the nuclear emulsion measurement by Riezler.

Table 11 $T_{1/2}$ (^{154}Dy)

Author	Reference	Value x(10^{-6} years)	Comment
Mac Farlane	48	1.5±0.9	revised
Mahunka	49	2.9±1.5	
Golovkov	50	10±4	no details
Gono	51	4	revised

Mac Farlane's measurement assumed that the ^{154}Gd (α, 4n) cross section was about 1 barn. A subsequent measurement by Chmielewska[68] of this cross section gave a value of ~ 650±90 millibarns.

Gono's measurement used the ^{153}Dy alpha particle intensity as a monitor. However their 6.8±1 hour estimate was in error and should have been 6.3 hours. In addition, Gono assumed a cross section ratio of ^{154}Gd (α, 4n)/^{154}Gd (α, 5n) ~10. From Chmielewska's cross section measurement a better estimate would be ~7.

The recommended value is $3 \pm 1.5 \times 10^6$ years based on Mac Farlane's and Gono's revised measurements.

Table 12 $T_{1/2}$ (^{176}Lu)

Author	Reference	Value x (10^{-10} years)	Comment
Mc Nair	67	3.1±0.1	
Brinkman	68	3.59±0.05	
Donhoffer	69	2.19±0.06	
Sakamsto	70	5.0±0.3	
Prodi	71	3.27±0.05	
Boudin	72	3.3±0.5	
Komura	73	3.79±0.03	71% enriched
Norman	74	4.08±0.24	
Sguigna	75	3.59±0.05	54.4% enriched
Patchett	76	3.57±0.13	

The recommended value, based on the three most recent Ge (Li) detector measurements by Komura, Norman, and Sguigna and Patchett is $3.73 \pm 0.06 \times 10^{10}$ years.

Table 13 $T_{1/2}$ (^{174}Hf)

Author	Reference	Value x (10^{-15} years)	Comment
Riezler	77	4.3. n.u.	natural sample
Mac Farlane	26	2.0±0.4	10.14% enriched

The recommended value is based on Mac Farlane's measurement on the 10.14% enriched sample since natural hafnium has a ^{174}Hf abundance of 0.16%.

Table 14 $T_{1/2}$ (^{180}Ta)

Author	Reference	Value (years)	Comment
Eberhardt	78	$>9.9\times10^{11}$	β branch
Bauminger	79	$>2.3\pm0.7\times10^{13}$	electron capture branch
		$>1.7\pm0.6\times10^{13}$	β branch
Eberhardt	80	$>4.6\times10^{9}$	K capture branch
Sakamoto	81	$>1.5\pm0.5\times10^{13}$	electron capture branch
Ardisson	82	$>2.1\times10^{13}$	electron capture branch
Cumming	83	$>1.2\times10^{15}$	

All measurements correspond to lower limits on the two branches of the ^{180}Ta decay. The recommended half life is based on the measurement by Cumming.

Table 15 $T_{1/2}$ (^{186}Os)

Author	Reference	Value x(10^{-15} years)	Comment
Viola	84	2.0±1.1	61.27% enriched

The recommended value is that of the 61.27% enriched 186Os measurement by Viola.

Table 17 $T_{1/2}$ (^{190}Pt)

Author	Reference	Value x (10^{-11} years)	Comment
Hoffmann	85	≈ 5	
Porschen	24	10.	nuclear emulsion
Mac Farlane	26	6.9±0.5	0.76% enriched

The recommended half-life is based on the 0.76% enriched ^{190}Pt measurement by Mac Farlane. Note that natural platinum has a ^{190}Pt abundance of 0.012%.

Table 18 Tl/2 (^{204}Pb)

Author	Reference	Value	Comment
Riezler	86	–	E_α = 2.6 Mev exceeds available energy

Riezler used a nuclear emulsion technique to measure a sample of ^{204}Pb enriched to 27.0%. A peak was found between 8 μ and 9 μ in the emulsion which from Faraggi's range energy curves[190] was attributed to an alpha energy of 2.6 MeV. The latest mass data on ^{204}Pb, ^{200}Hg, and ^{4}He imply an available alpha energy of 1.93 MeV, ie. a peak below 6.5 μ. The peak has to be due to something other than the alpha decay of ^{204}Pb. There is no evidence that ^{204}Pb is radioactive.

Table 19 $T_{1/2}$ (^{205}Pb)

Author	Reference	Value x 10^{-7} years	Comment
Huizenga	87	~5	
Wing	88	1.9±0.3	Revised

Wing's measurement of the L electron capture x-rays from ^{205}Pb decay has been revised for the M and higher x-ray yields. The latest binding energy estimates indicate that the energy difference $^{205}Pb \rightarrow {}^{205}Tl$ is only 53.5 Kev, well below the Tl K-X-ray energy. However, a recent calculation gives L/L+M+N+... = 0.61. The mean L- fluorescence yield from Bambynek[188] agrees with Wing's estimate. The resulting half life of ^{205}Pb is $1.9 \pm 0.3 \times 10^{7}$ years.

Table 20 $T_{1/2}$ (^{230}Th)

Author	Reference	Value (years)	Comment
Soddy	89	74200	Meadows recalculation
Soddy	90	71400±3600	Meadows recalculation
Soddy	91	76900±3000	Meadows recalculation
Curie	92	82300±2500	
Soddy	93	73200±3700	Meadows recalculation
Hyde	94	79900±3400	26.4% enriched
Attree	95	76100±1400	12.11%enriched
Meadows	96	75381±295	99.65% enriched

The results of Hyde and Attree have been revised with the latest parameters as well as with the assumption that all the thorium in their samples, which was not ^{230}Th, was ^{232}Th. Meadows recalculated the earlier values based on ^{226}Ra to the presently accepted half life of 1600 years. The recommended value is based on Meadows 99.65% enriched source measurement.

Table 21 $T_{1/2}$ (^{232}Th)

Author	Reference	Value x (10^{-10} years)	Comment
Kovaric	97	1.39±0.03	
Senftle	98	1.42±0.07	Na(I)
Piciotto	99	1.39±0.03	nuclear emulsion
Macklin	100	1.45±0.05	incidental to cross section measurement
Farley	101	1.41±.014	ion-chamber alpha spectrometry
LeRoux	102	1.40±0.007	liquid scintillator

The recommended value is based on the LeRoux measurement by liquid scintillation. The relative errors on the measurements are considered good so that a weighted average will give 1.40×10^{10} years. The error has been increased from 0.5% to 0.7% to account for systematic errors. Recommended half-life is $1.40 \pm 0.01 \times 10^{10}$ years.