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Nuclear Physics A 944 (2015) 190–203

NUCLEAR PHYSICS A

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Mass spectrometric searches for superheavy elements in terrestrial matter

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Received 25 March 2015; received in revised form 7 May 2015; accepted 12 June 2015

Abstract

Recent searches for traces of long-lived superheavy elements (SHEs) in terrestrial materials by mass spectrometric means are reviewed. Positive evidence for long-lived neutron-deficient Th isotopes in Th and Rg isotopes in Au, and a possible $A = 292$, $Z \sim 122$ nuclide in Th was reported from experiments with Inductively Coupled Plasma Sector Field Mass Spectrometry (ICP-SF-MS). These findings were not confirmed with Accelerator Mass Spectrometry (AMS), with abundance limits lower by several orders of magnitude. In addition, the extensive AMS searches for 42 SHE nuclides ($A = 288$–310) around the much discussed "island of stability" ($Z = 114$, $N = 184$) in natural Pt, Au, Pb, Bi materials are reviewed. Due to the flatness of the mass distribution and the relatively large bandwidth of the mass acceptance in AMS searches, an effectively much larger number of SHE nuclides was scanned in the respective materials. No positive evidence for the existence of long-lived SHEs ($t_{1/2} > 10^8$ yr) with abundance limits of 10^{-12} to 10^{-16} was found.

Keywords: Superheavy elements; Natural abundance limits; Accelerator mass spectrometry

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1. Introduction

One of the earliest speculations about superheavy nuclides was presented by J.A. Wheeler at the International Conference on the Peaceful Uses of Atomic Energy, which took place in

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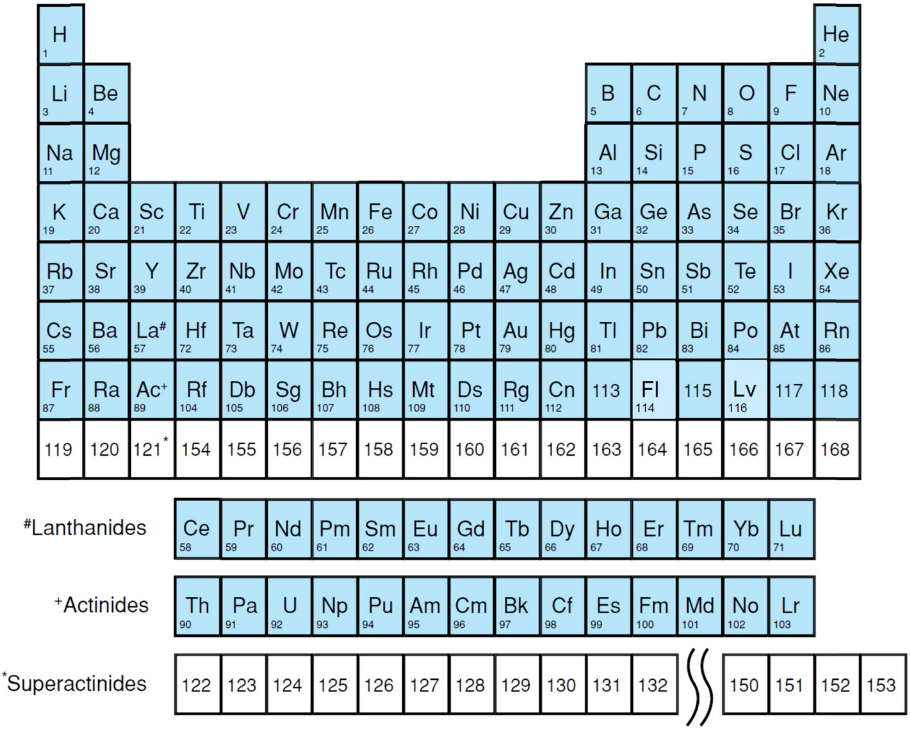
http://dx.doi.org/10.1016/j.nuclphysa.2015.06.003
0375-9474/

Geneva in August 1955 [1]. He extrapolated current knowledge about the stability of heavy nuclei as far as $Z = 147$ and $A = 500$. A more extended calculation on superheavy nuclides was published a few years later [2]. In these estimates shell corrections and nuclear deformations were neglected. Around the same time, G. Scharff-Goldhaber [3] mentioned that a region of relative stability at the doubly magic nucleus ${}_{126}\mathrm{X}^{310}$ ($N = 184$) may exist. When shell effects and deformations were finally explicitly included, a large number of calculations ensued [4–11]. Glenn Seaborg is sometimes credited for introducing the term "island of stability" for nuclides around $Z = 114$, $N = 184$ (Georgi Flerov promoted it as well). Seaborg was discussing the extension of both nuclear and chemical properties of SHEs (Fig. 1), indicating the hope to find traces of the longest-lived ones in nature [12,13].



H 1																	He 2
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10
Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
Cs 55	Ba 56	La# 57	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
Fr 87	Ra 88	Ac+ 89	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109	Ds 110	Rg 111	Cn 112	113	Fl 114	115	Lv 116	117	118
119	120	121*	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168

#Lanthanides	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71	
+Actinides	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103	
*Superactinides	122	123	124	125	126	127	128	129	130	131	132	150	151	152	153

Fig. 1. The extended Periodic Table of Elements, as envisioned by Glenn Seaborg in 1969 [12,13]. The blue area show the elements which are currently known. The white area shows the schematic extension of Seaborg. At the time Lawrencium (${}_{103}$Lr) was the heaviest element known. Fourteen new elements, all the way up the possible noble-gas-like Eka-Rn with $Z = 118$, have since been synthesized by heavy-ion reactions in various laboratories around the world [18–21]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In order to find SHEs in nature, several conditions must be fulfilled: (i) They need to be produced in stellar nucleosynthesis, most likely by the r-process in supernovae [14–16]. (ii) Their half-lives need to be around 10^8 years, in order to detect traces of SHEs in terrestrial materials today. In this respect, an encouraging half-life estimates of 2.5×10^9 years for the SHE nuclide $^{294}110$ was published in 1972 by Fiset and Nix [11]. (iii) Evidence for SHEs with considerably shorter half-lives (~million-year time range) may also be found, if signatures from extinct radioactivity of SHEs in meteorites (e.g. characteristic Xe isotope abundances from spontaneous