A GLIMPSE OF TRANSURANIC RADIOACTIVE ELEMENTS

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The discovery of the phenomenon of radioactivity provided an important means in detecting the existence of a specific kind of materials, namely, the radioactive elements, some of which sometimes can occur naturally or can be artificially synthesized. Originally, the total number of naturally occurring elements in Mendeleev's periodic table was 92 ending with uranium, but by 2016, with the syntheses of the new transuranic radioactive elements, the total number of elements has been increased to 118. All these 118 elements, thirty-seven of which are radioactive, have been appropriately accommodated in the modern periodic table, as extended by Glean Seaborg. Occurrences and syntheses of all the natural and artificial radioactive elements in the periodic table, have been briefly discussed.

Introduction

In nuclear science, search for new chemical elements is an area of active research to-day. At the beginning of the creation of the Universe billions of years ago, the formation of the chemical elements started shortly after the big bang through nucleosynthesis of the primordial nucleons such as neutrons and protons, formed from quark-gluon plasma. Nucleosynthesis of elements occurred primarily in two phases, the primordial or 'big bang' nucleosynthesis and stellar nucleosynthesis. In the first phase, only the light elements from hydrogen to lithium were formed. In the second phase, formation of the heavier element up to iron took place and is still taking place in the interior of the stars and galaxies. Supernova explosions are probably responsible for nucleosynthesis of the naturally occurring elements heavier than iron such as uranium and thorium. Elements that could possibly be present on the Earth during its formation are known as the primordial elements. The arenas of cosmochemistry and astrophysics describe the chemical make-up and the evaluation of the universe.

Around 300 B. C., it was proposed that all materials were made up of four essential elements, namely, earth, air, fire and water. The Greek philosopher, Aristotle (383 – 322 B.C.) considered these elements as being combinations of four properties, hot, cold, dry and moist. During the passage of scientific history, the very idea of the four 'elements' has undergone extensive changes and Robert Boyle in his "Sceptical Chymist" in 1661 was the first to define the element as a form of matter that could not be split into simpler forms. Historically, Dr. Brand of Hamburg was the first to discover a naturally occurring true element, namely, phosphorous, in 1669 and other elements have subsequently been discovered.

The discovery of radioactivity by Antoine Henri Becquerel in 1896 provided the scientists with an important pathway in achieving a highly sensitive method for detecting the existence of certain kinds of matter as radioactive materials. In 1998, Marie and Pierre Curie used this phenomenon of radioactivity to identify the first two new natural radioactive elements, namely, polonium and radium. Frederick Soddy in 1910 predicted the existence of isotopes. In 1919, Ernest Rutherford demonstrated nuclear transmutation of one element into another. The concept of nuclear transmutation hinted the existence of a specific class of elements, namely, radioactive elements, in nature that are continually being changing from one

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species to another accompanied by the release of a large amount of nuclear energy. An element is generally termed as radioactive element, all isotopes of which spontaneously transform into one or more different nuclides, giving off various types of nuclear radiations. The radioactive elements primarily do not have any stable isotopes and the unstable isotopes may degenerate spontaneously.

Several outstanding scientific achievements by nuclear scientists and technologists, such as, the discovery of artificial radioactivity, development of different nuclear devices and facilities, particularly, the atom smasher - cyclotron, nuclear fission and many others, have enhanced the possibility of synthesis of different artificial radioactive elements, beyond the existing naturally occurring radioactive elements. Focussed scientific attempts to explore the possibility of creating an element beyond uranium were first made by Enrico Fermi and co-workers in 1934. It is highly interesting that the efforts of changing an element to another date back to the period of Medieval Alchemy or even earlier.

Since 1930s, several advanced nuclear laboratories in USA, Russia, France, Germany and Japan, have been engaged in synthesizing new heavier elements with higher atomic numbers beyond uranium (92) and these newly synthesized transuranic elements have gradually been added to the existing periodic table. In 1945, G. T. Seaborg made an extension of Mendeleev's periodic table for proper placement of the newly synthesized heavier elements. By 2016, the total number of elements has been increased from 92 to 118 and all of them have been properly included in this extended/modern periodic table. The elements that follow uranium in the periodic table are all unstable and radioactive and are known as transuranium or transuranic elements. The 14 elements with atomic numbers 90–103 are found to be very similar to one another and they make up a group as actinide series similar to that of the lanthanide series in the table.

Radioactive Elements

The discovery of natural radioactivity in uranium by Becquerel, and discovery of X-rays by W. C. Roentgen in 1895, initiated a new era of nuclear science. Becquerel observed that the radiation, emitted by the uranium compound, could penetrate heavy paper and also affect photographic film and concluded that an element that gives off radiation is a radioactive element. Scientists soon realized that the phenomenon of radioactivity is a unique property of some kind of matter. It also became evident that an unstable radioactive nuclide eventually returns to its stable state by releasing some energy by a process called radioactive decay. The decay of a radioactive element occurs mainly by the emission of alpha(α), beta (β) and gamma (γ) - rays. In addition to these radioactive decay modes, many heavier elements may also undergo spontaneous fission decay. Depending on nuclear properties, the characteristic value of the length of time for a particular radioactive species to decay to one-half of its initial value of activity is termed as half-life. The half-life varies from element to element and provides a good probability of the life of a radioactive element.

The discovery of artificial radioactivity by Frederic Joliot and Irene Curie in 1934 was a momentous event in nuclear science. They produced the artificial radionuclide, ^{13}N, by the interaction of alpha particles with boron by the nuclear reaction, ^{10}B (α, n) ^{13}N, and it was for the first time that a radioactive nuclide was synthesized and chemically identified on the scale of a few atoms. In 1929, E. Walton and J. Cockcroft developed the voltage multiplier to accelerate protons to fairly high energies as useful bombarding projectiles. The Van de Graaff electrostatic generator produced a beam of hydrogen and other positively charged ionsat higher energies. Lawrence built the first nuclear device, cyclotron, capable of accelerating positive ions to very high energies. The heavy-ion linear accelerator (HILAC), developed later, can accelerate the higher energy projectiles of heavier ions. James Chadwick in 1932 discovered the neutral particle, neutron, which provided a new means to researchers to initiate varieties of nuclear reactions on a large scale.

In 1934, a group of scientists led by Enrico Fermi realized that simple addition of neutrons to the nucleus of an atom like uranium would make not only a heavier isotope of the already known heaviest elements, it would possibly make new heavier elements of atomic numbers higher than 92, if the incoming neutron could cause some rearrangement within the nucleus accompanied by addition of proton. In course of their study, they hinted the creation of the new heavier elements with atomic numbers 93 and 94.

E. McMillan and P. H. Abelson were the first to produce a synthetic transuranic element, neptunium, as ^{239}Np (half-life 2.3 d), with 93 protons in its nucleus. The four missing radioactive elements of Mendeleev's table, technetium, promethium, astatine and francium, some of which have been found to exist in traces usually as short-lived members of natural radioactive decay-series, were also synthesized later artificially in the laboratory.

The radionuclides, ^{232}Th, ^{235}U and ^{238}U, form the basis for the natural radioactive series whose intermediate members with atomic numbers 84-89 and 91, are secondary natural radioactive elements.The elements with atomic number higher than 83 are all radioactive. Since the synthesis of the first transuranium element, neptunium (93), a steady stream of new radioactive elements has been added to the periodic table. So far, 24 synthetic radioactive elements with atomic numbers 95–118 have been synthesized and all are unstable, decaying with half-lives ranging from million years to a few microseconds. In 1945, Seaborg, a co-discoverer of about 10 new elements, proposed an extension of the existing periodic table of Mendeleev for proper accommodation of the newly synthesized radioactive elements. He incorporated the concept of Actinide series comprising the elements 89 to 103 homologous to the lanthanide series from elements 57 to 71. He also moved these elements out of the main body of the Mendeleev's periodic table to their current location as the Actinide series below the Lanthanide series in his extended periodic table, as presented in Figure 1. Currently, there are about thirty-seven radioactive elements which either have no stable naturally occurring isotope or else are entirely artificial having no stable isotope.

In chemistry, a synthetic element is a chemical element that does not occur naturally on earth and can only be created artificially. The radioelements with comparatively shorter half-lives, even if it had once existed on earth, would have decayed completely long ago. These short-lived elements cannot occur naturally and are produced synthetically. In authentication of a new synthetic radioactive element, the proof of its atomic number (Z), chemical properties, characterization of nuclear radiations and the decay profile of the relevant nuclide to its radioactive daughters, are essentially needed and characterization of its mass (A) is not always necessary.

So far, most of the work on production and identification of the transuranium elements have essentially been performed at the four advanced nuclear research laboratories, namely, Lawrence Berkeley National Laboratory, the United States (elements 93–101, 106, and joint credit for 102–105), the Joint Institute for Nuclear Research, Russia (elements 114–118, and joint credit for 102–105), the GSI Helmholtz Centre for Ion Research, Germany (elements 107–112), and RIKEN NishinaCenter for Accelerator-Based Science, Japan (element 113).

Presently, the authenticity of discovery of a new synthetic element has to be recognized first by an International body, the Joint Working Party (JWP), of the International Union of Pure and Applied Chemistry (IUPAC) and the International Union of Pure and Applied Physics (IUPAP). Similarly, the final naming of the newly discovered element with its symbol has to be officially accepted by the IUPAC. According to the accepted conventions, the naming of a new element can be made after a mythological concept or character (including an astronomical object), a mineral or similar substance, a place or geographical region, a property of the element; or a scientist. For example, the IUPAC, following the regular conventions, has recommended the names for the three elements, 113, 115, 117, respectively as nihonium, moscovium and tennessine, after the places of their respective discoveries and the element 118, was named after the renowned scientist, oganesson, the four new superheavy elements discovered in recent years.

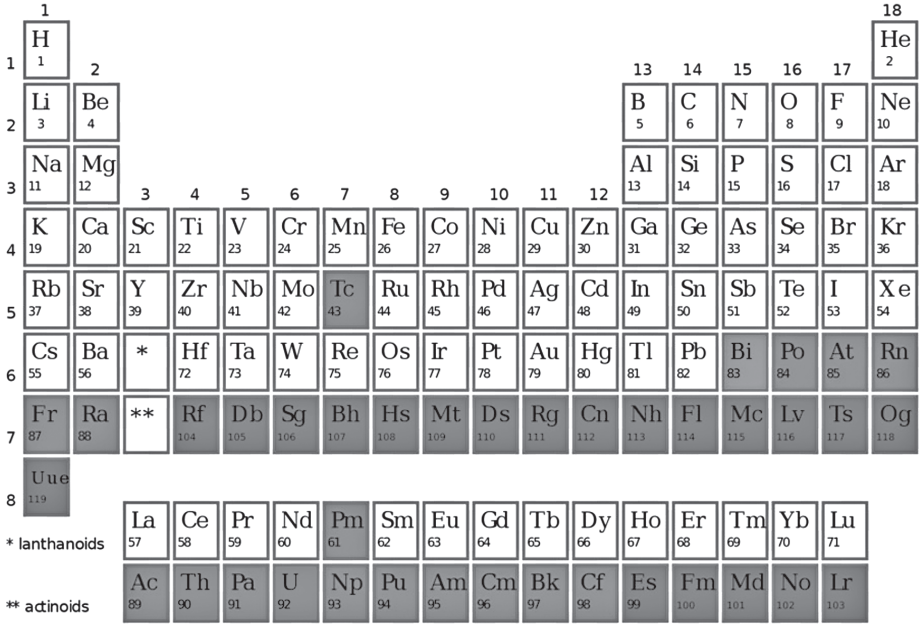

Figure 1. Modern or Extended Periodic Table of Elements

Element 93, Neptunium (Np)

Neptunium is a radioactive chemical element with symbol 'Np' and atomic number 93. It is the first transuranic element. Traces of neptunium, ^{237}Np and ^{239}Np, occurred in nature, are the decay

products of uranium. The neptunium-237 decay chain, commonly known as the "neptunium series", eventually decays to ^{209}Bi and ^{205}Tl.

In 1934, a group of scientists led by Fermi on bombardment of uranium with neutrons, first observed the indication of formation of isotopes of a new element with an atomic number of 93, but they could not isolate it chemically and the claim for synthesizing a new element remained unresolved for several years.

E. McMillan and P. H. Abelson in 1939, synthesized a radioactive species chemically different from all known sources by the bombardment of a sample of uranium with neutron in the 60-inch cyclotron at the Lawrence Radiation Laboratory,University of California. They identified the new radioactive species as element 93 in 1940 and called it 'neptunium' as it lies beyond the element uranium just as the planet Neptune lies beyond Uranus in the solar system. Seaborg and A. Wahl, produced a significant amounts of long-lived ^{237}Np, as a part of the Manhattan Project in 1942. It is generally formed as a by-product of plutonium production in nuclear reactors.

About 20 radioisotopes of neptunium with atomic masses of 225 to 244 have been characterized. The most stable isotope, ^{237}Np, has a half-life of 2.14 million years. Two other long lived isotopes are ^{236}Np (154,000 yrs) and ^{235}Np (396.1 d). The isotope, ^{237}Np, an α-particle emitter, has been separated in pure form from spent nuclear fuels and ^{235}Np and ^{236}Np are respectively produced through irradiation of uranium-235 with protons and deuterons in a cyclotron. The short-lived heavier isotopes, ^{238}Np and ^{239}Np, are produced through neutron irradiation of neptunium-237 and uranium-238 respectively. The isotopes, ^{235}Np, ^{236}Np and ^{237}Np, are predicted to be fissile.

Neptunium, the fifth actinide, is located in between uranium and plutonium and below the lanthanide promethium. In terms of physical workability, it is similar to uranium. It exists in oxidation states ranging from +3 to +7 in forming chemical compounds in solutions.

Neptunium is radiotoxic and can be accumulated in bones.The short-lived isotopes, ^{238}Np and ^{239}Np, are used as radiotracers.The long-lived isotopes, ^{236}Np and ^{237}Np, produced through atmospheric nuclear weapon tests and explosions, can be encountered in the environment. It is used in high-energy neutron detectors, spacecraft and military applications.^{237}Np is the most mobile actinide in the deep geological repository environment.

Element 94, Plutonium (Pu)

Plutonium is a radioactive chemical element with symbol 'Pu' and atomic number 94. It is the second transuranic metal. It is the element with highest atomic number to occur in nature as traces of plutonium results from neutron capture of natural uranium-238. Traces of ^{239}Pu with its decay products are found in some concentrated ores of uranium, such as in the natural nuclear fission reactor in Oklo, Gabon.

In 1934, Fermi and his co-workers claimed the discovery of the element 94 and named it as 'hesperium'. G. T. Seaborg, J. W. Kennedy, E. McMillan and A. C. Wahl in 1940 first produced ^{238}Pu by the bombardment of uranium-238 with 16-MeV deuteron in the 60-inch cyclotron at the University of California. The fissionable isotope, ^{239}Pu, was created by J. W. Kennedy, G. T. Seaborg, E. Segrè and A. C. Wahl by slow-neutron bombardment of ^{238}U in the cyclotron in 1941. Seaborg et al. in 1942 isolated trace quantities of plutonium from uranium irradiated in the experimental X-10 Graphite Reactor and first chemically analyzed at the Metallurgical Laboratory, now Argonne National Laboratory (ANL), University of Chicago, OakRidge. The element 94 was finally named as 'plutonium' after Pluto, the next planet beyond Neptune. The fissile ^{239}Pu undergoes fission in the same way as ^{235}U when bombarded with slow neutrons and because of its ease of fission and availability, it is used as a key fissile component in nuclear weapons and other purposes. ^{241}Pu, a parent isotope of the neptunium decay series, is also highly fissile. Production of plutonium constituted a major part of the Manhattan Project during World War II.

About 20 radioactive isotopes of plutonium with atomic masses of 228 to 247 have been characterized. The longest-lived ^{244}Pu has a half-life of 80.8 million years. Some other long-lived isotopes are ^{242}Pu (373,300 yrs) and ^{239}Pu (24,110 yrs). The isotopes with mass numbers lower than ^{244}Pu, mostly as decay products of uranium and neptunium isotopes, are α – active. The isotopes with mass numbers higher than ^{244}Pu are mostly β – active and are produced as decay products of the isotopes of the element 95, americium.

The chemical process, PUREX, is effectively utilized in reprocessing the spent nuclear fuels to extract plutonium and uranium. Plutonium alloying with metals like Zr, Ce, Ti, Mo, Th and U is efficiently used as nuclear fuels in fast breeder reactors. The percentage of ^{240}Pu in a sample determines its grade, whether it is weapon-grade (< 7%), fuel-grade (7% to <19%) or reactor-grade (19% or

more). Fission of a kilogram of ^{239}Pu can produce an explosion equivalent to 21,000 tons of TNT. Disposal of plutonium wastes from nuclear power plants is of nuclear proliferation and environmental concern.

Plutonium is the sixth actinide metal and its chemistry, more or less, resembles uranium. It normally displays four oxidation states in aqueous solution.

Plutonium is highly radiotoxic and can cause radiation sickness, genetic damage, cancer and even death.

Plutonium is well-suited for electrical power generation in devices like radio-isotopic thermoelectric generators and heaters generally used in space probes and spacecraft. ^{238}Pu has been used in pacemakers and also to provide supplemental heat to scuba diving. The IAEA classifies plutonium as 'direct-use' material in the manufacture of nuclear explosive components without transmutation or further enrichment. Production of plutonium and its nuclear use have tremendously affected the human life in different ways.

Element 95, Americium (Am)

Americium is a radioactive chemical element with symbol 'Am' and atomic number 95. The synthetic americiumis the third transuranic element.

In 1944, G. T. Seaborg, L. O. Morgan, R. A. James and A. Ghiorso, first produced the element 95 as ^{241}Am by intense neutron bombardment of plutonium or uranium in the 60-inch cyclotron and chemically identified at the Metallurgical Laboratory as a part of the Manhattan Project. The production of americium and its compounds were, however, patented listing only Seaborg as the inventor. The discovery of the element was announced in 1945 and was named as 'Americium' in analogy with America.

About 19 isotopes of americium have been characterized. The two most common long-lived isotopes, ^{241}Am and ^{243}Am, with respective half-lives of 432.2 yrs and 7,370 yrs, are α – particle emitters.

Plutonium produced in spent nuclear fuels contains about 12% of ^{241}Pu which is spontaneously converted to ^{241}Am and the amount of ^{241}Am reaches a maximum after about 70 years. A ton of spent nuclear fuel has been found to contain about 100 grams of ^{241}Am and ^{243}Am isotopes.^{241}Am undergoes α – particle decay to form ^{237}Np and ^{242}Amtransforms into ^{242}Cm (82.7%) by β-decay. In the reactor, ^{242}Am, by neutron capture, is also up-converted to ^{243}Am and ^{244}Am, which by β-decay transform to ^{244}Cm. Americium is used as a starting material for production of several transuranic elements. For example, the element, berkelium, as ^{243}Bk, was first produced and identified by bombarding ^{241}Am with alpha particles in the 60-inch cyclotron at Berkeley in 1949. Similarly, the element, nobelium, was produced by irradiation of ^{243}Am with ^{15}N ions at the JINR, Dubna, in 1965. The synthesis of the element lawrencium was performed by bombardment of ^{243}Am with ^{18}O, both at Berkeley and Dubna. Bombardment of ^{241}Am by ^{12}C and ^{22}Ne ions yields the isotopes, ^{247}Es and ^{260}Db, respectively. Americium is selectively extracted from spent reactor fuels through multi-step chromatographic and centrifugation techniques, following separation of plutonium by PUREX process.

During the period, Seaborg restructured the periodic table positioning the actinide row below the lanthanide one and the seventh actinide element, americium, was located right below the lanthanide, europium. Chemically, americium usually assumes the oxidation state of +3, especially in solution.

Presence of comparatively a higher concentration of americium in the regions of nuclear weapon testing and nuclear incidents like the Chernobyl disaster has been reported. The bio-sorption and bio-accumulation of americium by bacteria and fungi are harmful to life.^{241}Am is used in neutron radiotherapy, tomography and in passive diagnosis of thyroid function.

Americium is the only synthetic element suitably used in household purposes such as in smoke detectors.^{241}Am is also used in radioisotope thermoelectric generators for spacecraft, space probes and nuclear battery. In industry, ^{241}Am is utilized in radiographic studies and X-ray fluorescence spectroscopy.

Element 96, Curium (Cm)

Curium is a radioactive chemical element with symbol 'Cm' and atomic number 96. The synthetic curium is the fourth transuranic element.

G. T. Seaborg, R. A. James and A. Ghiorso in 1944 were the first to synthesize the element curium by bombarding plutonium-239 with a beam of 32-MeV α – particles in the 60-inch cyclotron at the University of California. The ^{242}Cm was chemically isolated and identified at the ANL, University of Chicago. The production of curium, ^{242}Cm and ^{240}Cm, and their compounds were later patented listing only Seaborg as the inventor. The discovery of the element 96 was announced in 1945 and was named as 'curium' after Marie Curie and her husband Pierre Curie who discovered polonium and radium and have performed pioneering research in

radioactivity. In 1947, L. Werner and I. Perlman produced substantial amounts of ^{242}Cm (~ 30 μg) at the University of California by bombarding ^{241}Am with neutrons.

About 20 radioisotopes of curium with atomic masses of 233 to 252 have been characterized. The longest-lived isotope, ^{247}Cm, has a half-life of 15.6 million years. Some other long-lived isotopes are ^{248}Cm (348,000 yrs), ^{245}Cm (8,500 yrs), ^{250}Cm (8,300 yrs) and ^{246}Cm (4,760 yrs). The most commonly used curium isotopes, ^{242}Cm and ^{244}Cm, have respective half-lives of 162.8 d and 18.1 years. All isotopes between ^{242}Cm and ^{248}Cm, as well as ^{250}Cm, undergo a self-sustaining nuclear chain reaction and thus in principle can act as nuclear fuels in a reactor. The isotope, ^{245}Cm, can be obtained by α - decay of ^{249}Cf, produced by β - decay of ^{249}Bk. Significant amount of ^{248}Cm (35 – 50 mg) produced by α – decay of ^{252}Cf has been used as a common starting material for production of different higher transuranic elements like trans-actinides. For example, bombardment of ^{248}Cm with ^{18}O or ^{26}Mg yielded the isotopes ofseaborgium, ^{265}Sg, and ofhassium, ^{269}Hs and ^{270}Hs.In the discovery of californium, a target of curium-242 was irradiated with 35 MeV α – particles in the 60-inch cyclotron. The radioisotopes, ^{247}Cm and ^{248}Cm, because of their longer half-lives and availability in significant amounts from spent nuclear fuels, are commonly used in scientific research.

Chemically, the eighth actinide element, curium, is similar to americium and many lanthanides and usually exhibits valence +3 and sometimes +4 states in solutions.

In human body, curium accumulates in bones, lungs and liver and can promote cancer.

Curium isotopes predominantly emitα – particles and is used in radioisotope thermoelectric generators in spacecraft. It was also used as alpha particle X-ray spectrometers (APXS) to analyze the rocks of Moon and Mars.Curium is also utilized in producing ^{238}Pu as a power source in artificial cardiac pacemakers.

Element 97, Berkelium (Bk)

Berkelium is a radioactive chemical element with symbol 'Bk' and atomic number 97. The synthetic berkelium element is the fifth member of the transuranium series.

In 1949, G. T. Seaborg, A. Ghiorso, S. G. Thompson and K. Street. Jr first synthesized the element 97 as ^{243}Bk, by irradiating a target of ^{241}Am coated on a platinum foil with 35 MeV α – particles for ~ 6 hours in the 60-inch cyclotron at the Lawrence Radiation Laboratory. The new element 97 was named as 'berkelium' with the symbol 'Bk' after the name of its place of discovery, Berkeley. As a collaborative work between USA and Russia, minute quantities of berkelium, ^{249}Bk, were produced in high-flux nuclear reactors at ORNL and at the Research Institute of Atomic Reactors in Dimitrovgrad. The production of ^{247}Bk was also performed by irradiation of^{244}Cm with high-energy α - particles.

About 20 radioactive isotopes of berkelium with atomic masses of 235 to 254 have been characterized. The long lived isotopes of the element are ^{247}Bk (1,380 yrs), ^{248}Bk (~ 300 yrs) and ^{249}Bk (330 d). The half-lives of other isotopes vary from microseconds to several days. The ^{249}Bk isotope decays to ^{249}Cf (351 yrs).

In the periodic table, berkelium is the ninth actinide element and is located in between curium and californium and below the lanthanide terbium with which it shares many similarities in physical and chemical properties. The oxidation state of +3 is most stable, especially in aqueous solutions, but +4 and possibly +2 berkelium compounds are also known.

In the atmosphere, presence of berkelium is mostly concentrated in the regions of nuclear weapon testing and nuclear accidents such as the Chernobyl disaster and the Three Mile Islands.

Since 1967, significant quantities of berkelium have been produced in the United States. A scientific collaboration between JINR and Lawrence Livermore National Laboratory (LLNL) was initiated in 1989 to utilize berkelium for the synthesis of some heavier transuranic and trans-actinide elements like lawrencium, rutherfordium, bohrium and tennessine. For example, the elementtennessine (6 atoms) was first synthesized by bombarding a target of ^{249}Bk with ^{48}Ca ions in a cyclotron at the JINR, in 2009. Currently, berkelium is mostly used in basic scientific research.

Element 98, Californium (Cf)

Californium is a radioactive chemical element with symbol 'Cf' and atomic number 98. The synthetic californium is the sixth transuranium element.

S. G. Thompson, K. Street, Jr., A. Ghiorso and G. T. Seaborg were the first to synthesize about 5,000 atoms of the element 98 as ^{245}Cf (44 m), by bombarding a microgram target of ^{242}Cm with a beam of 35 MeV α – particles in the 60-inch cyclotron at the Radiation Laboratory, University of California, in 1950. The element

was named as 'californium' with symbol 'Cf' after the name of the university and the state of California where it was discovered. By 1995, about 500 milligrams of californium were produced annually utilizing plutonium as target material in the High Flux Isotope Reactor (HFIR) at ORNL. Prolonged irradiation of americium, curium and plutonium with neutrons produces milligram amounts of ^{252}Cf and microgram amounts of ^{249}Cf. As of 2006, significant amounts of californium-249 to 255 have been produced by irradiation of curium-244 to 248 with neutrons. Bombardment of ^{250}Cf with neutrons also results ^{251}Cf and ^{252}Cf. ^{252}Cf has also been produced at the Research Institute of Atomic Reactors in Dimitrovgrad. Californium has been utilized to produce some heavier transuranium elements. For example, the element 103, lawrencium, was first synthesized by bombarding californium with boron in 1961. Similarly, three atoms of oganesson (element 118), the heaviest element ever synthesized, have been identified as the product of bombardment of ^{249}Cf with ^{48}Ca at the JINR in 2006.

About 20 radioisotopes of californium have been characterized. The most stable isotope, ^{251}Cf, has a half-life of 898 years. ^{252}Cf, with a half-life of about 2.64 yrs, is the most common isotope used. Most of the isotopes of californium decay to isotopes of curium via α – particle decay.Californium isotopes with mass numbers 249, 252, 253, and 254 have been detected as atmospheric fallout in nuclear explosions.

In the periodic table, the chemical properties of the tenth actinide element, californium, are predicted to be similar to those of the other actinide elements and the lanthanide, dysprosium, above californium. It exhibits oxidation states of +4, +3, or +2.

The element is radiotoxic and can cause bone and liver cancer. It can also disrupt the formation of red blood cells by bio-accumulation in some specific tissues. However, neutron therapy using californium is employed to treat certain cervical and brain cancers where other radiation therapy becomes ineffective.

The ^{252}Cf is used in reactor start-up, fuel rod scanning and activation analysis. It is utilized as an online elemental coal analyzer, in oil well logging and neutron spectroscopy and also as a portable neutron source for detection of precious metals.

Element 99, Einsteinium (Es)

Einsteinium is a radioactive chemical element with symbol 'Es' and atomic number 99. The synthetic einsteinium is the seventh transuranic element. The element was observed in Przybylski's Star in 2008.

A. Ghiorso and co-workers at the University of California in collaboration with the Argonne and Los Alamos National Laboratories, first identified and chemically recovered ~ 200 atoms of the element 99, from the debris of the first Hydrogen bomb, 'Ivy Mike', explosion in 1952. The isotope of einsteinium, ^{253}Es, has been characterized by its high-energy α - decay and a half-life of 20.5 days. The isotope could be produced through the capture of 15 neutrons by uranium-238 followed by seven β - decays. The discovery of the new element 99 was announced at the first Geneva Atomic Conference, 1955. The Berkeley group suggested its name as 'einsteinium' after Albert Einstein with the symbol 'E', but the symbol was later changed to "Es" by IUPAC.

About 19 isotopes of einsteinium with atomic masses of 240 to 258 have been characterized. The most stable isotope, ^{252}Es, has a half-life of 471.7 days. The four heavier isotopes, ^{249}Es, ^{250}Es, ^{251}Es and ^{252}Es, were simultaneously obtained by bombarding ^{249}Bk with α-particles. Neutron irradiation of plutonium results in the formation of different isotopes of einsteinium like ^{253}Es (α-emitter, 20.03 d), ^{254m}Es (β-emitter, 38.5 h), ^{254}Es (α-emitter, ~ 276 d) and ^{255}Es (β-emitter, 24 d). The isotopes, ^{248}Es and ^{257}Es, were respectively produced by irradiating ^{249}Cf with deuterium ions and ^{241}Am with carbon. An alternative route of producing einsteinium involves the bombardment of uranium-238 with high-intensity beam of nitrogen or oxygen ions. Einsteinium, because of its large mass, relatively long half-life and availability in significant amounts, is sometimes favoured for production of higher transuranic elements and trans-actinides. For example, the element 101, mendelevium, was synthesized by irradiating a target of about 10^9 atoms of ^{253}Es with α - particles through ^{253}Es (α, n) ^{256}Md reaction in the 60-inch cyclotron in 1955.Einsteinium is the heaviest transuranic element that has ever been produced in macroscopic quantities (0.48 – 3.2 mg) mostly as ^{253}Es using plutonium as target material.

In the periodic table, the eleventh actinide einsteinium is located in between californium and fermium and below the lanthanide, holmium, with which it shares many similarities in physical and chemical properties. Einsteinium exists primarily in +3 oxidation state; the +2 state is also accessible, especially in solids.

The toxicity of the element towards bone and other organs, is similar to that of plutonium.

The isotope, ^{254}Es, was used as the calibration marker in the chemical analysis spectrometer, 'alpha-scattering surface analyzer' of the Surveyor 5 lunar probe.

Element 100, Fermium (Fm)

Fermium is a radioactive chemical element with symbol 'Fm' and atomic number 100. The synthetic fermium is the eighth transuranic element. It is the heaviest element that can be formed by neutron irradiation of lighter elements and in macroscopic quantities.

A group of scientists led by A. Ghiorso at the Radiation Laboratory, University of California, discovered the element 100, fermium, as ^{255}Fm with a half-life of 20.07 h in the debris of the first hydrogen bomb explosion in 1952, but announced in 1955.They named the element as 'fermium' in honor of Enrico Fermi, one of the pioneers of nuclear physics and the developer of the first artificial self-sustained nuclear reactor, the Chicago Pile-1.The Berkeley team also produced fermium through neutron bombardment of ^{239}Pu in 1954. A Swedish group at the Nobel Institute for Physics, Stockholm, also independently created the element 100 as ^{250}Fm with half-life of 30 m by bombarding a target of uranium-238 with oxygen-16 in 1953 -1954.

About 19 isotopes of fermium with atomic masses of 242 to 260 have been characterized until 2003. The longest-lived isotope, ^{257}Fm, has a half-life of 100.5 days. However, most studies on fermium has been carried out with ^{255}Fm (20.07 h), as it can be easily isolated as a decay product of ^{255}Es (~ 39.8 d).

The nuclide, ^{258}Fm, a neutron-capture product of ^{257}Fm (370 microseconds), undergoes spontaneous fission. Similarly, the isotopes, ^{259}Fm (1.5 s) and ^{260}Fm (4 ms), are also unstable with respect to spontaneous fission indicating that neutron capture cannot be used to create nuclides with a mass number greater than 257, unless carried out in nuclear explosions. Thus, ^{257}Fm is the last and heaviest isotope that can be obtained by a neutron-capture process. Milligram quantities of fermium were believed to be produced in the thermonuclear explosions in the debris.

The twelfth actinide fermium, located below the lanthanide, erbium, under normal conditions, exists in +3 and +2 oxidation states.

The International Commission on Radiological Protection (ICRP) has set annual exposure limits for the two most stable isotopes, ^{253}Fm and ^{257}Fm, at 10^7 Bq and 10^5 Bq respectively. Fermium is mainly used in basic scientific research.

Element 101, Mendelevium (Md)

Mendelevium is a radioactive chemical element with symbol 'Md' and atomic number 101. The synthetic mendelevium is the ninth member of the transuranic series. It is the first of the second hundreds of the chemical elements synthesized. Mendelevium is the first element that currently cannot be created in macroscopic quantities through neutron bombardment of lighter elements and can only be produced in particle accelerators by bombarding lighter elements with charged particles.

In early 1955, A. Ghiorso, G. T. Seaborg, G. R. Choppin and B. G. Harvey led by S. G. Thompson synthesized the element 101, mendelevium, as ^{256}Md with a half-life of 77 m by bombarding a billion atom target of einsteinium, ^{253}Es with α - particles in the 60-inch cyclotron in the Berkeley Radiation Laboratory. The isotope, ^{256}Md, was the first nuclide of any element to be produced one-atom-at-a-time and in total, seventeen mendelevium atoms have been synthesized. The required target material, einsteinium-253, was produced by irradiating plutonium with 41 MeV high beam density α – particles in the Berkeley cyclotron. The ^{256}Md nuclide which decays by electron capture to ^{256}Fm (1.5 h), was chemically identified in the irradiated target material. The element 101 was named as 'mendelevium' with symbol 'Mv' by the discoverers after Dmitri Mendeleev, the father of the periodic table of chemical elements. The name 'mendelevium' with the symbol 'Mv' was first accepted by the IUPAC in 1955 but the symbol was later changed to 'Md' in 1957.

About 16 isotopes of mendelevium have been characterized. The most stable isotope, ^{258}Md, has a half-life of 51.5 days. The isotopes, ^{254}Md to ^{258}Md, have been produced through bombardment of ^{253}Es, ^{254}Es and ^{255}Es with α - particles. The isotope ^{247}Md has been created through bombardment of bismuth target with heavy argon ions, while the slightly heavier ones, ^{248}Md to ^{253}Md, have been respectively produced by bombarding plutonium and americium targets with lighter ions of carbon and nitrogen. ^{259}Md is formed as a daughter product of ^{259}No and a transfer reaction between ^{254}Es and oxygen-18 results ^{260}Md. Femtogram quantities of ^{256}Md have been produced by utilizing microgram quantities of einsteinium.

Mendelevium is the thirteenth actinide element located below the lanthanide, thulium. Chemically, it can exists in +3 and +2 oxidation states. Currently, it is used only in basic scientific research.

Element 102, Nobelium (No)

Nobelium is a radioactive chemical element with symbol 'No' and atomic number 102. The element is synthetic and the tenth member of the transuranic series.

In 1956, A. Ghiorso, T. Sikkeland, A. E. Larsh and R. M. Latimer in the Lawrence Radiation Laboratory, first produced the element 102, nobelium, as ^{254}No, by the bombardment of ^{246}Cm coated on nickel foil with a 68-MeV heavy ion beam of carbon-12 or carbon-13 in the linear accelerator, HILAC. They also claimed the creation of the element by bombarding an electroplated layer of ^{253}Es on a thin gold foil with 41-MeV α – particles in the 60-inch cyclotron at the university of California. In 1966, a group of Soviet scientists in the JINR confirmed the synthesis of the element 102 by bombarding a target of uranium-238 with neon ions. The element 102 with very short half-life (~ 3s) was produced 'one-atom-at-a-time' and was identified through its decay daughter product, ^{250}Fm. The scientists at the Nobel Institute in Sweden proposed the name as 'nobelium' with symbol 'No' for the element 102, in honor of Alfred Nobel, the inventor of dynamite and the creator of the Nobel Prize. The IUPAC credited the Soviet team with the discovery of the element 102 and accepted the Swedish proposal of naming it as 'nobelium' with the symbol 'No' in 1997.

About 12 isotopes of nobelium with atomic masses of 250 to 260 and 262 have been characterized. The longest-lived isotope, ^{259}No, has a half-life of 58 minutes. The isotopes of nobelium, excepting ^{262x}No, are mostly produced by bombarding actinides like uranium, plutonium, curium, californium, or einsteinium, as target materials. ^{262}Nois produced as the daughter product of lawrencium, ^{262}Lr. The shorter-lived ^{255}No with half-life 3.1 m has been produced, comparatively in larger quantities, by irradiation of curium-248 or californium-249 with carbon-12 ions, and is more often used in chemical experimentation.

In the periodic table, nobelium is the fourteenth and the penultimate member of the actinide series. It is located in between mendelevium and lawrencium, and below the lanthanide, ytterbium. Chemically, it behaves as a heavier homologue of ytterbium. The chemistry of nobelium is known only in aqueous solution, in which it can exist in +3 or +2 oxidation states, the latter being more stable.

Element 103, Lawrencium (103)

Lawrencium is a radioactive chemical element with symbol 'Lr' and atomic number 103. The synthetic lawrencium is the eleventh transuranic metal element.

During 1950s - 70s, several claims for the synthesis of the element lawrencium were made by different laboratories in Soviet Union and United States. In 1961, scientists at the Lawrence National Laboratory, attempted to synthesize the element 103 in different pathways, by bombarding a target of curium with nitrogen-14 ions and also a target of californium with boron-10 and boron-11 in the HILAC. The Berkeley group in 1971 successfully detected the nuclear decay properties of the lawrencium isotopes with mass numbers from 255 to 260, and all doubts about the discovery of element 103 were finally dispelled in 1976 - 77 when the X-ray energies due to ^{258}103 were confirmed.Scientists at the JINR, also independently reported the production of ^{256}103 by bombarding ^{243} Am with oxygen-18. In 1992, the TWG officially recognized both Dubna and Berkeley groups as the co-discoverers of the element 103, and accepted the name 'lawrencium' with symbol 'Lw', as suggested by Berkeley group in honor of Ernest Orlando Lawrence, the inventor of the atom smasher cyclotron, a device that was used to discover many artificial radioactive elements. The IUPAC finally accepted the name, lawrencium, for the element but changed the symbol 'Lw' to 'Lr' during a meeting in Geneva, 1997.

About 12 radioactive isotopes of lawrencium with atomic masses of 252 to 262 and 266 have been characterized. The most stable isotope, ^{266}Lr, with a half-life of 11 h, was discovered in the decay chain of tennessine-294 in 2014. The isotopes, ^{256}Lr and ^{260}Lr, with respective half-lives of 27 s and 2.7 m, are usually used in chemical studies of the element. While the heaviest ^{266}Lr and the lighter ^{252}Lr to ^{254}Lr isotopes are produced only as α – decay products of dubnium (Z = 105) isotopes, the middle order isotopes, ^{255}Lr to ^{262}Lr can be produced by bombarding the actinide targets of americium to einsteinium with beams of light ions, boron to neon. For example, ^{256}Lr and ^{260}Lr were respectively produced by bombarding californium-249 with 70 MeV boron-11 and berkelium-249 with oxygen-18. The longest lived isotopes, ^{266}Lr, known to date, suggests that it, perhaps, is on the shore of the island of stability of superheavy nuclei.

In the periodic table, lawrencium, the final member of the actinide series, is located in between nobelium and rutherfordium, and under the lanthanide, lutetium, with which it shares many physical and chemical properties. Both Dubna and Berkeley groups demonstrated an actinide chemistry for the last actinide element, lawrencium.

Element 104, Rutherfordium (Rf)

Rutherfordium is a radioactive chemical element with symbol 'Rf' and atomic number 104. It is the first synthetic trans-actinide element.

The scientists at the JINR, first reported the discovery of the element 104, rutherfordium, by bombarding a target of plutonium-242 with neon-22 ions in 1964. They separated and identified the isotope, ^{259}Rf, in the irradiated matrix and proposed the name 'kurchatovium'for the element in honor of Igor Kurchatov, the former head of Soviet nuclear research. In 1969, scientists at the Lawrence National Laboratory also claimed the production of the element 104 by bombarding a target of californium-249 with carbon-12 ions and conclusively confirmed the formation of the element in 1973 through identification of ^{257}Rf as the parent of its decay product, ^{253}No. The Americans suggested the name 'rutherfordium' for the new element to honor Ernest Rutherford, known as the 'Father of Nuclear Physics'. In 1992, the TWG suggested that the credit for the discovery of the element 104 should be shared by both Dubna and Berkeley groups and the IUPAC accepted the name 'rutherfordium'with symbol 'Rf' for the element in 1997, as suggested by the Americans.

About 16 isotopes of rutherfordium with atomic masses of 253 to 270 with the exceptions of 264 and 269, have been characterized. The most stable isotope, ^{267}Rf, has a half-life of ~ 1.3 hours. The lighter isotopes have shorter half-lives in the order of microseconds (μs). Most of these nuclides predominantly decay through spontaneous fission pathways.The heavy isotopes, ^{266}Rf and ^{268}Rf, have been respectively identified as electron capture daughters of the isotopes of dubnium, ^{266}Db and ^{268}Db.

In the periodic table, the first trance-actinide, rutherfordium, is a member of the 7th period elements. Chemically, it behaves as the heavier homologue of hafnium in group 4 and also compares well with the chemistry of the other elements of the group. It exhibits a stable oxidation state of +4, in addition to a less stable +3 state.

Element 105, Dubnium (Db)

Dubnium is a radioactive chemical element with symbol 'Db' and atomic number 105. It is the second synthetic trans-actinide element.

In 1968, a group of Soviet scientists at JINR, first reported the discovery of element 105, dubnium. They bombarded a target of americium-243 with a beam of neon-22 and identified the element, as ^{260}Db and ^{261}Db, through their respective α-active daughters, ^{256}Lr and ^{257}Lr. Similarly, a team of workers led by A. Ghiorso at the University of California, also claimed the synthesis of the element 105 by bombarding a target of californium-249 with nitogen-15 in 1970.

The Soviet and American teams initially proposed the name for the element 105 respectively as 'nielsbohrium' after the Danish Nuclear physicist Niels Bohr and 'hahnium' after the German Nuclear chemist Otto Hahn, the 'Father of Nuclear Chemistry'. The JWP credited both the Soviet and American teams for the discovery of the element 105. The IUPAC, however, named the element as 'dubnium' with symbol 'Db', after Dubna, the site of the JINR in 1997.

By 2016, only about 23 atoms of dubnium have been created. The most stable isotope of dubnium, ^{268}Db, has a half-life of ~ 28 hours. For the second most stable isotope, ^{270}Db, only three atoms in total, with a half-life of ~ 33.4 h have been produced.

In the periodic table, dubnium is located in period 7. It is a heavier homologue of tantalum in group 5 and exhibits the oxidation states of +5 and +3.

Element 106, Seaborgium (Sg)

Seaborgium is a radioactive chemical element with symbol 'Sg' and atomic number 106. It is the third synthetic trans-actinide element.

A group of Soviet scientists led by Yuri Oganessianat Dubna reported the creation of a few atoms of the element 106 as ^{260}Sg by irradiating the targets of lead-208 and lead-207 with an accelerated ion beam of chromium-54 in 1974. Seaborg and his co-workers at the University of California, also claimed the synthesis of the element 106 by the bombardment of a target of californium-249 with oxygen-18 ions in the same year. They predicted the formation of the isotope, ^{263m}Sg, with a half-life of 0.9 ± 0.2 seconds. The TWG recognized the Berkeley team as the discoverer of the element 106 in 1993 and the IUPAC named the element as 'seaborgium' with symbol 'Sg' in 1997, after Glenn T. Seaborg, a pioneer in the discovery of nearly a dozen of super-heavy synthetic elements. Seaborgium is one of only two elements named after a living person at the time of naming, the other being Yuri Oganessian.

About 12 isotopes of seaborgium with atomic masses of 258 to 267, 269 and 271 have been characterized. All of the isotopes undergo only α - decay and spontaneous fission, with the single exception of ^{261}Sg which undergoes electron capture to form ^{261}Db. The half-lives of these

isotopes vary from 92 microseconds for ^{261}Sg to 3.1m for the most stable known isotope, ^{269}Sg. The longest-lived predicted isotope, ^{272}Sg, has been expected to have a half-life of about an hour.

In the periodic table, seaborgium is a member of the 7th period and belongs to the group 6 elements as the fourth member of the transition metals. Chemically, it behaves as the heavier homologue of tungsten in group 6 and compares well with the chemistry of the other elements of the group.

Element 107, Bohrium (Bh)

Bohrium is a radioactive chemical element with symbol 'Bh' and atomic number 107. It is the fourth synthetic trans-actinide element.

In 1976, a Russian team led by Y. Oganessian at JINR, first reported the evidence of formation of the element 107, bohrium, by irradiating targets of bismuth-209 and lead-208 with accelerated beams of chromium-54 and manganese-58 respectively. In the process, they identified two atoms of ^{261}Bh with a half-life of 1 to 2 ms and its daughter, ^{258}Db, with a half-life of 5 seconds. Similarly, in 1981, a German research team led by P. Armbruster and G. Munzenberg at the GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, claimed the production of 5 atoms of ^{262}Bhby the bombardment of a target of bismuth-209 with an accelerated beam of chromium-54 and confirmed further by the study of the α - decay chain of the produced bohrium atoms to known isotopes offermoim and californium. The German group suggested the name 'nielsbohrium' with symbol 'Ns' for the element 107, after the Danish physicist Niels Bohr who figured out the electron structure of atoms and thus explained the periodic table. In 1992, the TWG recognized the GSI team as the discoverer of the element 107 and the IUPAC in 1997 officially named the element as 'bohrium' with the symbol 'Bh'.

About 11 isotopes of bohrium with atomic masses of 260 to 262, 264 to 267, 270 to 272, and 274, all of which undergo only α - decay have been characterized. The heavier isotopes, ^{270}Bh and ^{274}Bh, have half-lives of about 61 s and 54 s respectively. The other lighter isotopes usually have shorter half-lives of 10s to 100 milliseconds. The unknown isotopes, ^{273}Bh and ^{275}Bh, are predicted to have longer half-lives of around 90 m and 40 m respectively. The proton-rich isotopes with masses of 260 to 262 were directly produced by cold fusion, those with masses of 262 and 264 were reported to be formed in the decay chains of meitnerium and roentgenium, and the neutron-rich isotopes with masses of 265 to 267 were created by irradiations of actinide targets. The four most neutron-rich isotopes with masses of 270 to 272 and 274 appear in the decay chains of ^{282}Nh, ^{287}Mc, ^{288}Mc and ^{294}Ts, respectively.

In the periodic table, trans-actinide bohrium is the heaviest member of group 7 elements below manganese, technetium and rhenium. Chemically, it behaves like its heavier homologue, rhenium and also compares well with the chemistry of the other elements of the group. It is expected to form a stable +7 state.

Element 108, Hassium (Hs)

Hassium is a radioactive chemical element with symbol 'Hs' and atomic number 108. It is the fifth synthetic trans-actinide element.

A Soviet team led by Y. Oganessian and V. Utyonkov at the JINR, was the first to claim the synthesis of the isotopes, ^{270}Hs and ^{264}Hs, of the element 108, hussium, in 1978. The production of these two radioisotopes along with ^{263}Hs, were later confirmed by them in 1984. Similarly, in 1984, a German group led by P. Armbruster and G. Munzenberg at the GSI Helmholtz Centre for Heavy Ion Research, produced 3 atoms of ^{265}Hs by the bombardment of a target of lead-208 with an accelerated beam of iron-58. They proposed the name 'hassium' for the element 108 in 1992 after the German state of Hessen where the Institute at which the element was discovered, is located.The TWG in 1992 awarded the credit of discovery of the element to the GSI team.The IUPAC also officially adopted the name 'hassium' with symbol 'Hs' for the element 108 in 1997, as suggested by the German group.

About 12 isotopes of hassium with atomic masses of 263 to 277, excepting 272, 274, and 276, have been characterized. More than 100 atoms of hassium have been created to date. The most stable known isotope, ^{269}Hs, has a half-life of about 9.7 seconds. Most of these nuclides decay predominantly through α –particle decay, but some of these also undergo spontaneous fission. The α - active isotope, ^{273}Hs, with a half-life 1.2 s has been found to be produced through α - particle decay of ^{293}Og, an isotope of the element 118 discovered in 1999.

In the periodic table, hassium is the heaviest element of group 8 and the properties should also resemble those of the other elements of the group, iron, ruthenium and osmium. It is expected to form a stable oxidation state of +8 along with the lower oxidation states of +6, +5, +4, +3, and +2 in aqueous solution.

Element 109, Meitnerium (Mt)

Meitnerium is a radioactive chemical element with symbol 'Mt' and atomic number 109. It is the sixth synthetic trans-actinide element.

In 1982, a group of scientists led by P. Armbruster and G. Munzenberg at the GSI Helmholtz Centre for Heavy Ion Research, first claimed the synthesis of a single atom of the element 109, meitnerium, as ^{266}Mt, by irradiating a target of bismuth-209 with an accelerated beam of iron-58.The findings of the German group was confirmed by Soviet scientists three years later at the JINR. The GSI suggested the name of the element 109 as 'meitnerium', with the symbol 'Mt', in honor of the Austrian physicist Lise Meitner, a co-discoverer of the element, protactinium, and also one of the important contributors in the discovery of nuclear fission with Otto Hahn. The IUPAC accepted the German proposal of naming of the element 109 as 'meitnerium' with the synbol 'Mt' in 1994 and adopted officially in 1997.

About 8 isotopes of meitnerium with atomic masses of 266, 268, 270, and 274 to 278 have been reported. The heaviest and most stable isotope, ^{278}Mt, has a half-life of 7.6 seconds. The isotopes, ^{276}Mt and ^{274}Mt, have the respective half-lives of 0.72 s and 0.44 seconds. The remaining isotopes have half-lives between 1 to 20 milliseconds. Most of these isotopes decay predominantly through α - decay, although some of these also undergo spontaneous fission. Some unknown isotopes, such as ^{265}Mt, ^{272}Mt, ^{273}Mt, and ^{279}Mt, are predicted to have half-lives longer than that of the known isotopes.

In the periodic table, meitnerium, as a part of the platinum group metals, is at ransirion element. The basic properties of meitneriumare expected to resemble those of the other group 9 lighter homologues, cobalt, rhodium and iridium. Most stable oxidation states of meitnerium are predicted to be +6, +3, and +1 in aqueous solutions.

Element 110, Darmstadtium (Ds)

Darmstadium is a radioactive chemical element with symbol 'Ds' and atomic number 110. It is the seventh trans-actinide synthetic element.

P. Armbruster and G. Munzenberg under the leadership of S. Hofmann at the GSI Helmholtz Centre for Heavy Ion Research, first detected a single atom of the element 110, darmstadium, as ^{269}Ds, produced by the bombardment of a target of lead-208 with an accelerated beam of nickel-62 in a heavy ion accelerator in 1994. They also carried out the experiment using heavier nickel-64 as an accelerated projectile. During these two runs, production of 9 atoms of ^{271}Ds were convincingly confirmed by correlation with the decay properties of its known daughters. The GSI team suggested the name, 'darmstadium', with symbol 'Ds' for the element 110, after the name of the city of Darmstadt, the base of the nuclear accelerator in Germany where the element was discovered.The Russian and American scientists also proposed the name for the element 110 respectively as 'becquerelium' after Henri Becquerel in 1996 and 'hahnium' after Otto Hahn in 1997. In 2001, the JWP recognized the GSI team as the discoverer for the element 110 and the IUPAC in 2003 officially accepted the name, 'darmstadium' with the symbol 'Ds', as suggested by the German group.

About 9 radioisotopes of darmstadium with atomic masses of 267, 269 to 271, 273, 277 and 279 to 281 have been reported. The heaviest and most stable isotope, ^{281}Ds, has a half-life of 11 seconds.In general, the heavier isotopes are more stable than the lighter ones and most of these nuclei decay predominantly through α - decay, but some of these also undergo spontaneous fission. Some unknown isotopes such as ^{272}Ds and $^{274–276}$Ds, are predicted to have rather long half-lives of a few seconds. The undiscovered isotope ^{284}Ds has been predicted to be most stable towards β - decay.

In the periodic table, darmstadium is a member of the 7th period and is placed in the group 10 elements. It is expected to behave as the heavier homologue of platinum group of transition metals. The basic properties of the element will resemble those of the other group 10 elements, nickel, palladium and platinum.Most stable oxidation states of the element are predicted to be +6, +4, and +2.

Element 111, Roentgenium (Rg)

Roentgenium is a radioactive chemical element with symbol 'Rg' and atomic number 111. It is the eighth synthetic trans-actinide element.

In 1994, an International team of scientists led by S. Hofmann at the GSI Helmholtz Centre for Heavy Ion Research, first synthesized a single atom of the element 111, roentgenium, as ^{272}Rg, by the bombardment of a target of bismuth-209 with an accelerated beam of nickel-64. They repeated the experiment in 2002 and detected three more atoms of the element. The GSI team suggested the name for the element 111, as 'roentgenium' with symbol 'Rg', in honor of the German physicist Wilhelm Conrad Roentgen, the discoverer of X-rays. In 2003, the JWP

acknowledged the GSI team as the discoverer of the element 111 and the name and the symbol for the element, as suggested by the German team, was officially accepted by the IUPAC in 2004.

About 7 radioisotopes of roentgenium with atomic masses of 272, 274, and 278 to 282, all of which decay either through α – decay or spontaneous fission, have been characterized. The heaviest and the most stable isotope, ^{282}Rg, has a half-life of 2.1 minutes.The isotopes, ^{280}Rg and ^{281}Rg, have half-lives of over a second and the remaining isotopes have half-lives in the millisecond range. The undiscovered isotope ^{287}Rg has been predicted to be most stable towards β - decay.

In the periodic table, roentgenium is a transition metal in group 11. It is predicted to be a noble metal and the basic properties of roentgenium will resemble those of the other group 11 elements, copper, silver and gold. It is expected to show stable +5, +3 and – 1 oxidation states.

Element 112, Copernicium (Cn)

Copernicium is a radioactive chemical element with symbol 'Cn' and atomic number 112. It is the ninth trans-actinide synthetic element.

S. Hofmann et al. at the GSI Helmholtz Centre for Heavy Ion Research, first claimed the synthesis of a single atom of the element 112, copernicium, as ^{277}Cn,by bombarding a target of lead-208 with an accelerated beam of zinc-70 in a heavy ion accelerator in 1996. They repeated the experiment in 2000 and synthesized one more atom of ^{277}Cn. In 2004 and 2013, a Japanese group performed the same experiment in the search for a Super-Heavy Element Using a Gas-Filled Recoil Separator set-up at RIKEN and three more atoms of copernicium were produced and confirmed through the decay profile of the synthetic nuclides, as reported earlier by the GSI team. A Soviet team at JINR, also identified two atoms of ^{283}Cn as daughter products of ^{287}Fl formed through the nuclear reaction, ^{242}Pu (^{48}Ca, 3n) ^{287}Fl, in 2006. They repeated the experiment again in 2007 and formation of three more atoms of ^{283}Cn were confirmed. The GSI team proposed the name for the element 112 as 'copernicium' with the symbol 'Cp', in honor of the astronomer Nicolaus Copernicus. The JWP recognized the German team as the discoverer of the element 112 and the IUPAC also officially accepted the name and the symbol for the element in 2009, as proposed by the Germans.

About 6 radioactive isotopes of copernicium with atomic masses of 281 to 285 and 277 have been reported. The most stable isotope, ^{285}Cn, has a half-life of 29 seconds. Other isotopes have half-lives shorter than 0.1 seconds. Most of these radionuclides decay predominantly through α - decay, but some of them also undergo spontaneous fission. It is predicted that the heavier isotopes, ^{291}Cn and ^{293}Cn, with half-lives longer than a few decades, may have been produced in the r-process and be detectable in cosmic rays.

In the periodic table, copernicium is a group 12 element below zinc, cadmium and mercury andhas been predicted to show the oxidation state of +4.

Element 113, Nihonium (Nh)

Nihonium is a radioactive chemical element with symbol 'Nh'and atomic number 113. It is the tenth trans-actinide synthetic element.

The discovery of the element 113, nihonium, as an α – decay product of the element 115, moscovium, has been reported first in 2004 both by a Soviet team at JINR and an American team at the LLNL. A Japanese group led by K. Morita at the RIKEN Nishina Center for Accelerator-Based Science, Japan, also detected a single atom of the element, nihonium, as ^{278}Nh, by irradiating a target of bismuth-209 with an accelerated beam of zinc-70 in 2004. They repeated the experiments in 2005 and 2012 and confirmed the formation of one atom of ^{278}Nh in each case. They named the element 113 as 'nihonium' with the symbol 'Nh', after the common name of Japan, Nihan, in Japanese, the place of its discovery. In 2015, the JWP recognized the RIKEN team as the discoverer of the element 113 and was officially approved by IUPAC in 2016. This is the first time in history that a new element in the periodic table has been discovered by a team of Asian scientists in an Asian country.

About 6 radioisotopes of nihonium with atomic masses of 278 and 282 to 286, have been characterized. All these isotopes decay through α - decay, although ^{284}Nh may have an electron capture branch.The heaviest and most stable known nihonium isotope, ^{286}Nh, has a half-life of 20 seconds. The shortest-lived known nihonium isotope has a half-life of just 0.24 milliseconds. It is predicted that even heavier undiscovered nihonium isotopes could be much more stable.

In the periodic table,nihonium is the heaviest element in group 11 below boron, aluminum, gallium, indium and thallium. Chemically, it is predicted to be similar to its lighter homologues and will show stable +3 and possibly +5 oxidation states.

Element 114, Flerovium (Fl)

Flerovium is a radioactive chemical element with symbol 'Fl' and atomic number 114. It is the eleventh trans-actinide synthetic element.

A group of scientists led by Y. Oganessianat the JINR first claimed the synthesis of a single atom of the element 114, flerovium, as ^{288}Fl, by bombarding a target of plutonium-244 with an accelerated beam of calcium-48 in 1998. They repeated the experiment in 1999 and 2007 and confirmed the formation of two atoms of flerovium isotope, ^{289}Fl, which decays through α – particle emission. Similarly, a group of scientists at Berkeley confirmed the production of the isotopes, ^{286}Fl and ^{287}Fl in 2009. In addition, they also claimed the formation of ^{288}Fl and ^{289}Fl as the decay products of ^{268}Db. The Soviet team named the element 114 as 'flerovium' with the symbol 'Fl', after the Soviet physicist Georgy Flyorov. In 2011, the JWP recognized the Soviet group as the discoverer of the element, 114. However, the IUPAC in 2012 officially accepted the name 'flerovium' with the symbol 'Fl', after the Flerov Laboratory of Nuclear Reactions (an older name for the JINR) and not after Flyorov himself as suggested by the JINR team.

About 90 atoms of flerovium with atomic masses varying from 284 to 289 have been created. The most stable known flerovium isotope, ^{289}Fl, has a half-life of around 2.6 seconds. Flerovium is predicted to be near the centre of the theorized island of stability and the heavier flerovium isotopes, especially, ^{298}Fl, may have even longer half-life.

In the periodic table, flerovium is a member of the 7th period and as the heaviest element of the group 14, it is located below carbon, silicon, germanium, tin and lead. It behaves in some way like transition metals and exists inoxidation states of +6 and +4.

Element 115, Moscovium (Mc)

Moscovium is a radioactive chemical element with symbol 'Mc' and atomic number 115. It is the twelfth trans-actinide synthetic element.

In 2003, a joint team of scientists from the JINR and the LLNL,headed by Y. Oganessian attempted first to synthesize the element 115, moscovium, by the bombardment of americium-243 with calcium-48 at Dubna. In the process, production of four atoms of the new element, moscovium, was confirmed through chemical identification of its final decay product, ^{268}Db. In 2009 – 10, two heavier isotopes, ^{289}Mc and ^{290}Mc, were further identified by the joint group as the daughters of the tennessine isotopes, ^{293}Ts and ^{294}Ts. They named the element 115 as 'moscovium' with the symbol 'Mc', referring to Moscow Oblast where Dubna is located. A team of workers from the Lund University and the GSI Helmholtz Centre for Heavy Ion Research, repeated the experiment performed earlier by the Soviet – American joint group and confirmed its findings in 2013. Formation of element 115 was also confirmed by a team of workers at Berkeley in 2015.The JWP in 2015 recognized the Soviet – American collaboration as the discoverer of the element 115 and the IUPAC officially accepted the naming of the element 115 as 'moscovium' with the symbol 'Mc' in 2016.

About 100 atoms of moscovium with atomic masses of 287 to 290 have been characterized to date. The most stable known isotope, ^{290}Mc, has a half-life of only 0.8 seconds.

In the periodic table, moscovium is a member of the 7th period. It is placed in group 15 as the heaviest element below nitrogen, phosphorous, arsenic, antimony and bismuth and predicted to have some properties similar to its lighter homologues. The chemistry of the element in aqueous solution should essentially be of +1 and +3 states.

Element 116, Livermorium (Lv)

Livermorium is a radioactive chemical element with symbol 'Lv' and atomic number 116. It is the thirteenth trans-actinide synthetic element.

A collaboration of scientists from the JINR and the LLNL, first claimed the synthesis of the element 116, livermorium, in 2000. On bombardment of a target of curium-248 with an accelerated beam of calcium-48, they detected the formation of a single atom of a new element, identified later as an isotope of element 116, livermorium, ^{293}Lv, through its α -decay product, an isotope of flerovium. They produced two and eight more atoms of livermorium respectively in their experiments in 2001 and 2005 and confirmed the formation of the isotopes, ^{293}Lv and ^{292}Lv. In 2004 -06, two more isotopes, ^{290}Lv and ^{291}Lv, were produced by replacing the curium-248 target with lighter curium-245. In 2009, workers at Berkeley and the GSI Helmholtz Centre for Heavy Ion Research, confirmed the identity of the flerovium isotopes of atomic masses 286 to 289, as immediate daughters of the four known livermorium isotopes. In 2011, the JWP recognized the Soviet-American collaboration as the discoverer of the element 116 and the IUPAC named of the element as 'livermorium' with the symbol 'Lv' after the Lawrence Livermore National Laboratory, California, in 2012.

About 4 isotopes of livermorium isotopes with atomic mass numbers of 290 to 293 have been characterized. The longest-lived ^{293}Lv has a half-life of about 60 milliseconds.

In the periodic table, livermorium is a member of the 7th period and the heaviest element of group 16 located below oxygen, sulfur, selenium, tellurium and polonium. The element is predicted to have some similar chemical properties to its lighter homologues.

Element 117, Tennessine (Ts)

Tennessine is a radioactive chemical element with symbol 'Ts' and atomic number 117. It is the fourteenth trans-actinide synthetic element and also the second-heaviest known element.

A collaborative team of Russians at JNRI and Americans at ORNL discovered the element 117 in 2004. In producing the element, they bombarded a target of berkelium with an accelerated beam of calcium nuclei and detected two decay chains involving the isotopes of tennessine, ^{294}Ts and ^{293}Ts, with half-lives in the order of milliseconds. In 2012, they repeated the experiment and produced seven atoms of tennessine. The collaboration suggested the name for the element 117 as 'tennessine', with the symbol 'Ts', after 'the region of Tennessee', United States. Similarly, a joint American – German collaboration of the ORNL and the GSI Helmholtz Centre for Heavy Ion Research, claimed the creation of two atoms of tennessine by repeating the Soviet-American experiment in Darmstadt accelerator in 2014.They have predicted the production of the isotope, ^{295}Ts, with a half-life of 18 ± 7 milliseconds through the same berkelium–calcium reaction used to produce ^{293} Ts. In 2015, the JWP recognized the Russian–American team as the discoverer of the element 117 and the IUPAC officially accepted the name 'tennessine', with the symbol 'Ts' for the element in 2016, as suggested by the discoverers.

In the periodic table, tennessine is the penultimate element of the 7th period. It is a member of group 17 elements and is placed below the five halogens, fluorine, chlorine, bromine, iodine and astatine. Chemically, it may exhibit the chemical behavior common to the halogensand besides unstable – 1 state, three more oxidation states are predicted to be +5, +3, and +1.

Element 118, Oganesson (Og)

Oganesson is a radioactive chemical element with symbol 'Og' and atomic number 118. It is the fifteenth trans-actinide synthetic element and has the highest atomic number and atomic mass of all known elements.

In 1922, Niels Bohr suggested the possibility of existence of an element with atomic number as high as 118, as the seventh noble gas below radon in the periodic table. The possibility of formation of the element 118 by fusion of lead with krypton was also theoretically predicted earlier by R. Smolanczukin 1998. A joint team of scientists from the JINR and the LLNL headed by Y. Oganessian first successfully synthesized a total of three to four atoms of the of the element 118, oganesson, as ^{294}Og, through the collisions of californium-249 and calcium-48 in 2006. For the element, anα - decay of three atoms and a direct spontaneous fission for the fourth one, were observed. The nuclide, ^{294}Og, with a half-life of 0.89 ms decayed to^{290}Lv by α - decay. The JWP recognized the discovery of the element 118 by the JINR–LLNL collaboration in 2015 and the IUPAC officially named the element as 'oganesson' with the symbol 'Og' in 2016, in honor of Y. Oganessian, a pioneer in the discovery of the element. It is one of only two elements named after a living person at the time of naming, the other being seaborgium.

For the element, 118, theoretical calculations indicated the possibility of formation of some comparatively more stable isotopes like ^{293}Og, ^{295}Og, ^{296}Og, ^{297}Og, ^{298}Og, ^{300}Og and ^{302}Og, than that of the synthesized isotope, ^{294}Og.

In the periodic table, oganesson is a member of group 18, the zero-valence elements and is expected to have physical and chemical properties similar to other members of its group, most closely resembling the noble gas above it.It is the last element of the 7th period.

Element 119, Ununennium (Uue)

Multiple attempts for the creation of the synthetic elements with atomic numbers greater than 118, have been continued in different nuclear laboratories, but without any success as yet. Presently, the element 119, has been accepted as a hypothetical chemical element and according to 1979 IUPAC recommendations, the name 'Ununennium' with symbol 'Uue' have temporarily been assigned for the element as systematic IUPAC name and symbol respectively. In the modern periodic table, ununennium will be the first element in the eighth period and is predicted to be chemically similar to that of the alkali metals.

It has now become evident that the synthesis of the artificial elements through atomic number 100 (fermium) can be performed by bombarding a heavy element, such as uranium or plutonium, with neutrons or alpha particles. The synthesis of trans-fermium elements with atomic

number 101 or greater can be accomplished primarily by the fusion of the nuclei of two elements. For example, elements 101 through 106 were first produced by fusing the nuclei of californium with a light element, carbon. Elements 107 through 112 were first produced by fusing the nuclei of bismuth or lead, with those of other medium-weight elements like iron, nickel or zinc. Elements greater than 112, such as element 114 was produced by the fusion of the nuclei of plutonium and calcium, and that of element 116 using curium and calcium. Thus, the process of complete fusion of heavy ions, the amalgamation of target and projectiles, is primarily being applied to synthesize the superheavy trans-actinide elements. In creating the new even heavier elements 119 and beyond, perhaps a new leap in technological development may be needed.

Generally, the radioactive elements, excepting thorium and uranium, have half-lives much shorter than the age of the earth and hence the atomic species of these elements, if ever were present at the time of formation of earth, have long been decayed. The half-lives of the heavy elements, usually follow a decreasing trend with increasing atomic numbers from the relatively stable uranium (92) to the heaviest known element, oganesson (118). Some of the important characteristic properties of the known radioactive elements are presented in Table - 1

The term superheavy element, abbreviated as **SHE**, is sometimes used to describe a transuranic element. Some scientists consider the element with more than 100 protons in its nucleus (mendelevium) as superheavy, some refer to the trans-actinide elements beginning with rutherfordium (104). All super-heavy nuclei or elements, sometimes, on an atomic scale, have been made artificially and and their half-lives generally vary from minutes to milliseconds order, excepting dubnium(^{268}Db) which has a half-life of over a day

Glenn Seaborg, in his modification of the periodic table, predicted that there may be one or two super-heavy elements with nucleus having double magic numbers of protons and neutrons that would be surprisingly stable and might last much longer in the region, called the 'Island of Stability'. It was also expected that the isotope, ^{298}Fl, of the element 114, flerovium, with a nucleus of double magic numbers of 114 protons and 184 neutrons would be a very stable isotope with half-life in the range of years after lead-208 and would form the center of a so-called 'island of stability'. However, none of the isotopes of elements up to 118, synthesized as yet, has as many as 184 neutrons or the longer half-life as expected. The nuclear scientists are in search for the element that is really quite stable despite being superheavy and still expect to find an island of stability of elements with higher atomic numbers. Physicist Richard Feynman suggested the element 137 to be the limit and some other predicted that this will happen much later around element 170.

The thermonuclear explosion like 10 megaton 'Ivy Mike' in 1952 has been found to be a powerful man-made neutron source, (~ 10^{29} n/cm^2·s), in comparison to that of the HFIR (~ $5x10^{15}$ n/cm^2.s) at ORNL. Since presence of several transuranic elements like plutonium, americium, curium, berkelium, californium, einsteinium and fermium, have been identified in the atmospheric regions and debris of nuclear weapon testing and explosions, it has been expected to discover some new heavier elements with improved yield in the explosion matrices. It is interesting that the French physicist F. Perrin in 1972, discovered several 1.7 billion years old prehistoric and presently inactive naturally occurring nuclear fission reactors in the ore deposits at the Oklo mine in Gabon, West Africa, collectively known as the **Oklo Fossil Reactors**, in which several transuranic elements from americium to fermium, were predicted to occur naturally, but no longer do so.

The radioactive materials are now essentially being utilized to harness the nuclear energy for its potential use in general benefit of human society. For example, thorium, uranium and plutonium, are extensively used in nuclear power plants for generation of much needed electricity. The availability of more than 2500 artificially produced radionuclides of different radioactive elements have enhanced their beneficial applications in a big way almost in every sphere of human welfare, particularly, in medicine, industry, chemistry, geology, archaeology, agriculture and many other fields. Investigations on 'one-atom-at-a-time' of the super-heavy elements will be of special fundamental interest in nuclear science.The super-heavy elements with limited life-times, although have little use in direct human benefit but will continue to provide insight into the basic structure of nature and effective help in advanced scientific research.

Conclusions

The radioactive materials in the environment have been around much longer than humans. The discovery of radioactivity and the radioactive elements towards the end of the nineteenth century have been recognized by the scientific community as a major breakthrough in science. The naturally occurring radioactive nuclei, ^{232}Th, ^{235}U and ^{238}U, have half-lives comparable to the age of the earth and thus, thorium and uranium, as two primordial elements,

TABLE 1. Trans Uranium Elements in the Modern Periodic Table

Name of the Element	Symbol	Atomic Number	Most stable isotope	Half-life	Occurrence	Discovery/ Year	Useful Isotopes & Applications
Neptunium	Np	93	Np-237	2.14 x 10^6 y	From Decay	E. McMillan et al., 1940	^{237}Np (precursor in Pu-238 production for spacecraft and military)
Plutonium	Pu	94	Pu-244	8.08 x 10^7 y	From Decay	G. Seaborg et al., 1940	^{239}Pu (nuclear weapons) ^{238}Pu (electrical power)
Americium	Am	95	Am-243	7370 y	Synthetic	G. Seaborg et al., 1944	^{241}Am (gamma radiography, glass thickness gauge, smoke detectors); ^{242}Am (neutron radiography)
Curium	Cm	96	Cm-247	1.56 x 10^7 y	Synthetic	G. Seaborg et al., 1944	^{242}Cm, ^{244}Cm (possible uses as a thermoelectric power source)
Berkelium	Bk	97	Bk-247	1380 y	Synthetic	G. Seaborg et al., 1949	None
Californium	Cf	98	Cf-251	898 y	Synthetic	S. Thompson et al., 1950	^{252}Cf (gold and silver ores identification, neutron moisture gauges in oil wells, reactor start-up and fuel-rod scanning)
Einsteinium	Es	99	Es-252	471.7 d	Synthetic	A. Ghiorso et al., 1952	^{254}Es (alpha-scattering surface analyser in lunar probe)
Fermium	Fm	100	Fm-257	100.5 d	Synthetic	A. Ghiorso et al., 1952	None
Mendelevium	Md	101	Md-258	51.5 d	Synthetic	A.Ghiorso et al., 1955	None
Nobelium	No	102	No-259	58.m	Synthetic	JINR, 1966	None
Lawrencium	Lr	103	Lr-266	11 h	Synthetic	JINR & Berkeley, 1961	None
Rutherfordium	Rf	104	Rf-267	1.3 h	Synthetic	JINR & Berkeley, 1964	None
Dubnium	Db	105	Db-268	28 h	Synthetic	JINR & Berkeley, 1968-1970	None
Seaborgium	Sg	106	Sg-269	3.1 m	Synthetic	Berkeley, 1974	None
Bohrium	Bh	107	Bh-270	60 s	Synthetic	GSI, Germany, 1981	None
Hassium	Hs	108	Hs-269	9.7 s	Synthetic	GSI, Germany, 1984	None
Meitnerium	Mt	109	Mt-278	7.6 s	Synthetic	GSI, Germany, 1982	None
Damstadtium	Ds	110	Ds-281	11 s	Synthetic	GSI, Germany, 1994	None
Roentgenium	Rg	111	Rg-282	2.1 m	Synthetic	GSI, Germany, 1994	None
Copernicium	Cn	112	Cn-285	29 s	Synthetic	GSI, Germany, 1996,	None
Nihonium	Nh	113	Nh-286	20 s	Synthetic	RIKEN, Japan. 2004	None
Flerovium	Fl	114	Fl-289	2.6 s	Synthetic	JINR, 1998	None
Moscovium	Mc	115	Mv-290	0.8 s	Synthetic	JINR & LLNL, 2003	None
Livermorium	Lv	116	Lv-293	60 ms	Synthetic	JINR & LLNL, 2000	None
Tennessine	Ts	117	Ts-294	~ms order	Synthetic	JINR & ORNL, 2004	None
Oganesson	Og	118	Og-294	0.89 ms	Synthetic	JINR & LLNL, 2004	None
Ununennium	Uue	119	-	-	-	Predicted	-

are assumed to be the primary radioactive elements that have been existing on our planet from the time of its formation. The division of radioactive elements into natural and artificial sometimes becomes arbitrary, because some the radioactive elements are known to occur in nature as decay products in the natural radioactive series and can also be produced artificially in the laboratory. Attempts for the synthesis of transuranic radioactive elements, started in the fourth decade of the nineteenth century, have been continued in several advanced nuclear research laboratories. Presently, there are 118 known elements and possibly more to be discovered. With growing existence of the heavier transuranic elements, Mendeleev's periodic table has been extended by Seaborg, for appropriate placement of the newly discovered superheavy elements. The concept of rearrangement of the periodic table had great predictive value as it led to the discovery of the reminder of the elements of the full actinide series and the trans-actinides elements as well. The question of existence of relatively stable superheavy elements with double-magic numbers, according to the concept of 'island of stability', is still open.

During the period, the general understanding on effective utilization of radioactive elements to harness nuclear power for production of nuclear weapons, has been extensively changed. Studies on the phenomenon of radioactivity helped in revealing the existence of the new super-heavy chemical elements and in opening up the important field of basic research as Nuclear Science. The advanced knowledge involved in the creation of superheavy elements, although have little use in direct human benefit, it will definitely enable the scientists to make the best predictions or propositions about the nuclear forces that hold the atoms together and to learn more about how the universe is held together.As human race's natural curiosity, people wants to know the secrets of nature and the origin where they come from and so on.

The article is mainly based on the Wikipedia, free encyclopedia, of the respective radioactive elements, retrieved on 08. 01. 2017. To have detailed information, further reading of the relevant articles along with referred references are essentially needed.