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Status of the Translawrencium Elements (Z > 103). *

Norman E. Holden

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I. Introduction

As a result of conflicting claims to the discovery of the trans–lawrencium elements (Z > 103), IUPAC's Inorganic Chemistry Nomenclature Commission, (II.2), has been incapable of coming to a decision on rightful discoverer for these elements. In addition, the Atomic Weights Commission, (II.1), has from time to time been interested in the status of the search for the superheavy elements, i.e. those elements which might be found in the vicinity of the 'island of stability'. Theoretical studies by Nilsson[1] and Nix[2] agreed that the next major shell closures beyond Z = 82 and N = 126 would occur at Z = 114 and N = 184. In recent years, many scientists have devoted their time and effort in an attempt to detect these superheavy elements. This paper will review the literature on both of these developments and provide an up to date status report for the use of the Commission. However, this paper will not address the pros and cons of the controversial systematic naming scheme proposed by the Nomenclature Commission, (II.2) and approved by IUPAC.

II. Status of the Elements with 103 < Z < 110.

There have been papers published in the scientific literature over the past twenty years claiming discovery of every chemical element from Z = 104 up to and including Z = 109. In the following report, only those papers published in the refereed literature have been considered. Progress reports, laboratory reports, conference papers and the like have been ignored. The chronological order is followed, dictated by the date of receipt of the manuscript by the journal. In general, heavy ion collisions have been used to produce the new elements. In this region of the Periodic Table, the major competition for decay is between alpha decay and spontaneous fission decay. There is an advantage to discovery of an alpha emitting nuclide over the discovery of a spontaneously fissioning nuclide as far as proof is concerned. Detection of the characteristic radiations and half–lives of the daughter and granddaughter nuclides in time correlations is sufficient proof that the mother must have the charge and mass determined by the daughter (granddaughter) and the alpha particle(s). In the case of spontaneous fission, arguments must be made based on cross bombardment of various targets with various projectiles as well as the shape of heavy ion cross sections estimated from systematics in order to indicate the plausibility of an assignment. There is also a potential problem of producing spontaneous fissioning isomeric states when the heavy ions react with impurities in the target.

III. Experiments Involving Element 104.

The first translawrencium element that was reported to have been discovered was element 104 by Flerov[3] in 1964. Using the reaction $^{242}Pu + {}^{22}Ne \longrightarrow {}^{260}104 + 4n$, they found a spontaneously fissioning activity with a half-life of 300 +_ 100 milli-seconds (ms), which they supposed to be $^{260}104$. This same result was communicated to a second journal[4].

In 1966, based on the expectation that element 104 should be an analogue of hafnium, Zvara[5] developed a rapid continuous separation system to compare the properties of the chlorides of curium, hafnium, californium and this new element. They found that the isotope synthesized had a half-life which did not contradict the 300 +_ 100 ms previously found and it was not similar to the heavy actinides in its chemical properties but in certain (unspecified) properties, it is close to hafnium. In a series of papers[6,7,8,9], they treat the radiochemistry of the various actinides and element 104 by studying the tetrachlorides of Ti, Zr, Hf and the trichlorides of the actinides. Since the tetrachlorides are volatile with a low boiling point and the actinide-chlorides are involatile with a boiling point greater than 1500° C, they devise an experiment to show that the spontaneous fission activity seems to be volatile.

In 1969, Ghiorso[10] reported two alpha emitting nuclides of element 104 using the following reactions: $^{249}Cf + {}^{12}C \longrightarrow {}^{257}104 + 4n$, $^{249}Cf + {}^{13}C \longrightarrow {}^{259}104 + 3n$ and $^{248}Cm + {}^{16}O \longrightarrow {}^{259}104 + 5n$. In both cases, the daughter nuclides, ^{253}No and ^{255}No were milked and their alpha spectra and half-lives measured. In addition, a spontaneously fissioning activity of 11 +_ 2 ms was observed with both $^{249}Cf + {}^{12}C$ and $^{249}Cf + {}^{13}C$ reactions and it was assigned to $^{258}104$.

In 1970, Akap'ev[11] cast doubt on the results of the Ghiorso experiment because of alleged background problems, which were not discussed and an accusation that the half-lives of the new nuclides had been incorrectly determined. Ghiorso[12] answered all the criticisms from Akap'ev in 1971. He mentioned that various background peaks in the spectra presented had been labeled in their earlier article, which indicated that they were aware of background problems but that space limitations imposed by Physical Review Letters precluded giving all the details of their various background studies. They indicated that there was no problem in the half-life determinations.

In 1970, Oganesyan[13] indicated that a problem with a long-lived background due to the intense neutron beam inside the accelerating chamber had to be corrected for in their 1964 experiment on $^{260}104$. They revised their original half-life estimate from 300 +_ 100 ms to 100 ms. Also in 1970, Ghiorso[14] reported another nuclide of element 104 formed by reaction $^{248}Cm + {}^{18}O \longrightarrow {}^{261}104 + 5n$. Here again, the daughter nuclide, ^{257}No, was milked for identification.

In a pair of papers in 1971, Zvara[15,16] gave details of the chemical separation of element 104 that they claimed had chemical properties which compared favorably with those expected from eka-hafnium. Zvara noted that the original work on element 104 had been refined and that two spontaneously fissioning nuclides had been produced. One was $^{259}104$ (discovered previously by Ghiorso) with a half-life about 4.5 seconds and $^{260}104$ with a revised half-life of 100 ms (revised from 300 +_ 100 ms originally reported). Their earlier chemical experiments in 1966 had involved half-life measurements from 200 ms to 1 second. When Oganesyan revised the

$^{260}104$ half-life to 100 ms, they realized that they had not been following the chemistry of $^{260}104$ as reported. They think that the alpha emitting nuclide, $^{259}104$, has a spontaneous fission branch and they actually followed its chemistry. They claimed that certain possible gas-solid chromatography 'retention' effects could have caused them to obtain the lower half-life value. In any case, since whatever they followed seemed to have the chemical properties of eka-hafnium and they had done their experiment in 1966, while Ghiorso did not characterize and discover $^{259}104$ until 1969, they felt that they deserved to be considered the discoverers.

Ghiorso[17] commented on Zvara's paper that the systematics of spontaneous fission would require a very large half-life for spontaneous fission of $^{259}104$ since the value for $^{261}104$ was 500 seconds. If this is so, then they could not account for what they saw. Ghiorso argued that ^{256}Md-^{256}Fm might account for the 16 events that they measured. He closed questioning whether element 104 was chemically isolated and identified.

In 1973, Druin[18] used the reaction ^{246}Cm + ^{18}O --> $^{259}104$ + 5n and obtained a spontaneously fissioning activity with a half-life of 3.2 +_ 0.8 seconds, which they noted agreed with Ghiorso's value for $^{259}104$. From theory and calculations of the estimated total cross section and the measured spontaneous fission cross section, they obtained SF/alpha about 7 %.

Also in 1973, Bemis[19] observed the characteristic K-series x-ray from the Nobelium daughter in coincidence with the alpha particle of the 4.5 second $^{257}104$ to prove the parent atomic number, Z = 104.

In 1976, Druin[20] reported a new measurement on $^{260}104$ formed using the reaction ^{246}Cm + ^{18}O --> $^{260}104$ + 4n. They obtained a half-life of 80 +_ 20 ms.

In 1977, Druin[21] reported the synthesis of $^{260}104$ using a reaction with a larger cross section, ^{249}Bk + ^{15}N --> $^{260}104$ + 4n. A half-life of 76 +_ 8.1 ms was obtained with a cross section of 8 +_ 2 nanobarns (10^{-33} cm^2).

In 1981, Nitschke[22] measured the reaction ^{249}Bk + ^{15}N --> $^{260}104$ + 4n at a variety of energies from 78 MeV to 100 MeV, since it had been reported that this reaction had the largest cross section for production of $^{260}104$. They found a 23 +_ 2 ms activity for spontaneous fission with a peak cross section of 19 +_ 4 nanobarns. They searched for the 80 ms activity reported by Druin and were unable to observe this activity at the level of 0.5 nb or larger.

Also in 1981, Bemis[23] used the reaction, ^{249}Cf + ^{13}C --> $^{259}104$ + 3n, to measure both alpha decay and spontaneous fission decay in the same experiment. A half-life of 3.0 +_ 1.3 sec. was obtained with a branching ratio, SF/alpha = 0.063 +_ 0.037, in agreement with the 0.07 value that Druin had obtained.

In 1985, Sommerville[24] measured spontaneous fission activity using a variety of heavy ion reactions. Using cross bombardments and comparing measured and calculated cross sections, they made the following tentative assignments: $^{256}104$ - 9 +_ 2 ms; $^{257}104$ - 3.8 +_ 0.8 s; $^{258}104$ - 13 +_ 3 ms; $^{259}104$ - 3.4 +_ 1.7 s; $^{260}104$ - about 20 ms; $^{262}104$ - about 50 ms. The 80 ms activity assigned by Druin to $^{260}104$ was not seen in reactions in which they expected to produce that isotope. Also in 1985, Hessberger[25] produced $^{255}104$ and $^{256}104$ from reactions on ^{50}Ti on ^{207}Pb, and ^{208}Pb.

IV. Experiments Involving Element 105.

In the case of element 105, Flerov[26] reported in 1968 alpha activity at 9.7 +_ 0.1 MeV and at 9.4 +_ 0.1 MeV from the reaction $^{243}Am + ^{22}Ne$, which were assigned to $^{260}105$ with a half-life greater than 10 ms and to $^{261}105$ with a half-life between 0.1 and 3 seconds, respectively.

In 1970, Ghiorso[27] used the reaction, $^{249}Cf + ^{15}N \longrightarrow ^{260}105 + 4n$, to produce alpha activity at 9.0 and 9.1 MeV with a half-life of 1.6 +_ 0.3 seconds. The nuclide was identified by recoil milking the ^{256}Lr daughter. Also in 1970, Flerov[28] again used the reaction $^{243}Am + ^{22}Ne$ to produce spontaneously fissioning activity of 1.8 +_ 0.6 seconds. He argued that if $^{260}105$ had been formed with a compound nucleus and the evaporation of 4 neutrons, the angular distribution of recoil nuclei should have a sharp maximum at small angles. On the other hand, for multinucleon exchange the maximum of the angular distribution would shift to larger angles. Their spontaneously fissioning activity lies closer to the neutron evaporation curve than to the heavy ion emission curve, so the activity could not belong to the region of spontaneous fissioning isomers. From excitation function measurements, they argue for element 105 and the most probable mass is 261. This information was repeated in another publication[29].

In 1971, Druin[30] repeated the measurement of bombarding ^{243}Am with ^{22}Ne ions to look for alpha decay of element 105. Due to lead impurities in their americium target, they were not able to detect alphas in the energy region 8.8 to 9.1 MeV in their 1968 paper[26]. In 1970, new targets were developed with a much smaller lead impurity. With new measurements, an alpha activity at 9.1 MeV was detected with a half-life of 1.4 (+ 0.6 − 0.3) seconds. From time correlations with pulses from element 103 in the energy range 8.3 to 8.6, 7 pulses in the energy range from 8.8 to 9.2 MeV are in coincidence. Alpha particles at 8.9 MeV have a complex time distribution. If a 25 second component assumed to be ^{211m}Po is subtracted, then a short-lived component of about 1.5 seconds is left. It is assumed that this 8.9 MeV activity has the same origin as the 9.1 MeV activity. Since they cannot distinguish between the properties of ^{256}Lr and ^{257}Lr, they cannot determine which isotope of element 105 it is. However, since the half-life is similar to that determined by spontaneous fission earlier, it appears likely that they are the same isotope.

Later in 1971, Ghiorso[31] reported further work on the alpha measurements of element 105. In addition to the 1.6 second activity associated with $^{260}105$, they reported a 1.8 second activity assigned to $^{261}105$ and a 40 second activity assigned to $^{262}105$, where they used both alpha recoil milking and mother-daughter time correlation. They used the reactions $^{250}Cf + ^{15}N \longrightarrow ^{261}105 + 4n$ and $^{249}Bk + ^{16}O \longrightarrow ^{261}105 + 4n$ and also $^{249}Bk + ^{18}O \longrightarrow ^{262}105 + 5n$. They noted that Druin's[25] results are not compatible with the decay of $^{261}105$ to ^{257}Lr since the alpha energy is 8.87 MeV. However, it could be compatible with the decay of $^{260}105$ to ^{256}Lr with alpha energies 8.3 to 8.6 MeV. Their upper limit for the spontaneous fission branch is 50 %. Flerov's[27,28] 1.8 second spontaneous fission activity could be compatible with either $^{260}105$ or $^{261}105$.

In 1975 and 1976, Belov[32] and Zvara[33] developed methods for studying the bromide of element 105 and showing that the spontaneous fission activity is non-volatile, as would be expected for eka-tantalum.

In 1976, Oganesyan[34] reported a spontaneous fissioning activity of 5 seconds from the reactions, $^{209}Bi + {}^{50}Ti \longrightarrow {}^{257}105 + 2n$, $^{208}Pb + {}^{51}V \longrightarrow {}^{257}105 + 2n$ and the reaction, $^{205}Tl + {}^{54}Cr \longrightarrow {}^{257}105 + 2n$.

In 1977, Bemis[35] used the reaction, $^{249}Cf + {}^{15}N \longrightarrow {}^{260}105 + 4n$ to produce an alpha activity of 1.52 +_ 0.13 seconds with an alpha branching of 90.4 +_ 0.6 % and with a spontaneous fission branching of 9.6 +_ 0.6 %. The characteristic L series x-ray of lawrencium seen in coincidence with the three alpha groups provided the elemental identification. The spontaneous fission was linked to the alpha decay via a similar half-life of 1.89 +_ 0.88 seconds for 184 events. There was no evidence of the 8.9, 9.4, or the 9.7 MeV alphas, previously reported, seen in the decay of $^{260}105$. Only the three alpha groups from 9.0 to 9.1 Mev were observed in this experiment.

In 1979, Druin[36] produced a 35 second spontaneous fission activity using the reaction, $^{249}Bk + {}^{18}O \longrightarrow {}^{262}105 + 5n$. The assignment was made on the basis of the cross section, which was in agreement with the calculated value and a half-life, which was similar to the alpha activity of $^{262}105$.

V. Experiments Involving Element 106.

In the case of element 106, Ghiorso[37] used the reaction, $^{249}Cf + {}^{18}O \longrightarrow {}^{263}106 + 4n$ to produce a 9.06 +_ 0.04 MeV alpha with a half-life of 0.9 +_ 0.2 seconds reported in 1974. Time correlation of the alpha with those of $^{259}104$ and with those of ^{255}No provided the identification. Also in 1974, Oganesyan[38] reported using the reactions, $^{207}Pb + {}^{54}Cr$ and $^{208} + {}^{54}Cr$ to produce spontaneous fission activity of half-life 4 to 10 ms, which they attributed to element 106. This was based on control experiments for producing isotopes with Z less than 106, which found the contribution of these reactions to be very small at the bombarding energies used.

In 1979, Druin[36] used the reaction, $^{249}Cf + {}^{18}O \longrightarrow {}^{263}106 + 4n$, to produce spontaneous fission activity with a half-life of 0.64 (+0.32 − 0.18) seconds. They noted that it agreed with the half-life obtained in the alpha decay experiment of Ghiorso[37] for $^{263}106$. The measured cross section agreed with the calculated value for this reaction. From the peak cross section and that from Ghiorso's measurement, the branching ratio for spontaneous fission was estimated to be 70 %.

In 1984, Demin[39] irradiated enriched lead targets with ^{54}Cr ions to produce spontaneous fission activity of 6 (+2 −1) ms and 1.5 (+0.3 −0.2) seconds, which were assigned to $^{260}106$ and to $^{255}104$, respectively. The half-life and yields agreed with the results of Oganesyan[38].

VI. Experiments Involving Elements 107 to 109.

In 1976, Oganesyan[40] used the reaction, $^{209}Bi + {}^{54}Cr \longrightarrow {}^{261}107 + 2n$, to produce spontaneous fission activities with half-lives of about 5 seconds and about 2 ms. The yield of the 2 ms emitter correlated in all experiments with the yield of the 5 sec. activity, so they

explained the 5 sec. activity as being due to 5 sec. $^{257}105$, produced after (the unobserved) alpha decay of $^{261}107$. They assigned the 2 ms activity to $^{261}107$. From cross bombardments, they concluded that their assumption that they observed element 107 is sufficiently well founded, in their opinion.

In 1981, Muenzenberg[41] used the reaction, $^{209}Bi + {}^{54}Cr \longrightarrow {}^{262}107 + 1n$, to produce a group of 6 distinguished correlated decays through $^{258}105$, ^{254}Lr, ^{250}Fm and ^{250}Md. At their bombarding energies, they did not observe the spontaneously fissioning activity assigned to $^{261}107$ by Oganesyan.

In 1984, Muenzenberg[42] used the reaction, $^{208}Pb + {}^{58}Fe \longrightarrow {}^{265}108 + 1n$, to produce 3 correlated alpha decays with a half-life of 1.8 (+ 2.2 – 0.7) ms and an alpha energy of 10.36 +_ 0.03 MeV. Correlations to decays of $^{261}106$ and to $^{257}104$ provided the elemental identification. Also in 1984, Oganesyan[43] used the following reactions: $^{209}Bi + {}^{55}Mn \longrightarrow {}^{263}108 + 1n$; $^{207}Pb + {}^{58}Fe \longrightarrow {}^{264}108 + 1n$; $^{208}Pb + {}^{58}Fe \longrightarrow {}^{265}108 + 1n$; and finally $^{208}Pb + {}^{58}Fe \longrightarrow {}^{264}108 + 2n$ to produce spontaneously fissioning activities with the half-lives 1.1 (+ 0.6 – 0.4) sec. (assigned to $^{263}108$), 6 (+ 5 – 2) ms and 8(+ 20 – 4) ms (assigned to $^{264}108$).

In 1982, Muenzenberg[44] used the reaction, $^{209}Bi + {}^{58}Fe \longrightarrow {}^{266}109 + 1n$, to produce 1 correlated alpha decay chain, with a half-life of 5.0 ms and with an alpha energy of 11.10 +_ 0.04 MeV assigned to $^{266}109$. In a followup paper in 1984, Muenzenberg[45] gives various alternative interpretations of their observations on the element 109 experiment and they conclude that the assignment of $^{266}109$ is the statistically most significant assignment.

VII. Status of the Superheavy Elements (SHE).

As the number of protons in the nucleus became very large, it had been expected that the Periodic Table would reach its limit. The repulsion between the protons would become so large that the cohesive nuclear forces would no longer hold the nucleus together and it would undergo rapid spontaneous fission. This conclusion was drawn as the spontaneous fission half-life became shorter and shorter with increasing values of the atomic charge, Z. However, theoretical studies showed that in the region of Z = 114 and N = 184, the ground states of nuclei would stabilize against spontaneous fission decay. The theoretical estimates of the total half-life for some nuclei was comparable to the age of the solar system. A large commitment of time and money was made in an attempt to discover SHE either in natural samples or among the reaction products of heavy ion reactions. As far as the search for the superheavy elements in nature is concerned, the prediction of half-lives as long as the solar system meets one of the criteria for potential discovery. The other is the need for these superheavy elements to be produced in nucleogenesis. If they have never been formed, then they cannot be found.

VIII. Search for Superheavy Elements in Nature.

It has been suggested that the most distinct signal for the presence of a SHE would be

the observation of spontaneous fission with a high total fission fragment energy and a high average neutron multiplicity, $\langle\nu\rangle$, i.e. energies of 200–270 MeV and $\langle\nu\rangle$ of 6 to 10 neutrons. In comparison, for uranium the kinetic energy is about 170 MeV and $\langle\nu\rangle$ is 2 neutrons.

Concerning the search for SHE in nature, many experiments have been performed. Twice in the past, data have been presented, which could be interpreted as representing SHE. In 1976, Gentry[6] reported evidence of discovery of element 126. Using proton induced x-ray emission, (PIXE), protons bombarded monazite crystals [(Ce, La, Th)PO_4]. X-ray peaks ascribed to element 126 were found in five of the six monazite crystals. Within 6 to 18 months, it was shown that previous evidence could be explained[47] on the basis of proton excitation of cerium in the crystals via the $^{140}Ce(p,n\gamma)^{140}Pr$ reaction. It was also shown that[48,49] synchrotron radiation of the same monazite source (with 55 times the sensitivity) did not produce x-rays corresponding to element 126, so there was no evidence for SHE.

The second piece of possible evidence for the existence of SHE in nature comes from two experiments performed by Flerov[50,51] and his group at Dubna. Flerov, who had discovered the process of spontaneous fission some 45 years ago, used the distribution of neutrons following spontaneous fission to argue for the discovery of a superheavy spontaneously fissioning element. Flerov searched[50] meteorites of the carbonaceous and non-equilibrium-chondrite types, which are the least differentiated formations of the solar system and have not been depleted in heavy volatile metals such as mercury, thallium, lead and bismuth. From their location in the Periodic Table, the expected SHE are presumably homologues of these metals. Flerov reported spontaneous fission events with neutron multiplicities, ν, of two, three and four. However, only one event of multiplicity four was observed out of the 42 recorded and this was measured on the meteorite, Allende. The remaining data ($\nu = 2$ or 3) might be expected from ^{238}U, or some higher transuranide, but not necessarily a SHE, e.g. Popeko[52] has measured a neutron multiplicity distribution for ^{238}U, in which 30% of the fissions release 3 or more neutrons. Even allowing for the pileup of lower multiplicity events because of the less than 100% efficiency of the neutron detector, the result is less than overwhelming in favor of a SHE.

Even prior to Flerov's publication, the ores of the heavy volatile metals, Pb, Hg, and Bi were investigated by Cheifetz[53], Stoughton[54] and Fireman[55]. All these experiments ended with negative results. More recent work on the Allende meteorite (which had provided the single event of multiplicity four) by Lund[56] did not support Flerov's results. In fact, zero spontaneous fission decays were reported during 421 days of observation.

In the second experiment, Flerov used water samples rich in heavy volatile metals taken from the hot springs of the Cheleken Penninsula (south-eastern coast of the Caspian Sea) and he measured events with large neutron multiplicities[51]. Unfortunately, the average number of neutrons, $\langle\nu\rangle$, corresponding to these distributions depends very sensitively on the variance, σ^2, of the distribution. Data were recorded for those events with the multiplicities of $n = 2$ up to $n = 6$. If $\sigma^2 = 1.57$ (the measured value for ^{252}Cf, then $\langle\nu\rangle = 4$. If $\sigma^2 = 2.6$, then $\langle\nu\rangle = 2.5$. In general, $\langle\nu\rangle$ varies with mass number. ^{238}U has a value of 2, whereas ^{252}Cf has a value of 3.75. Thus, the evidence is by no means obvious that a SHE has been detected. In addition, there has been speculation that the presence of Pu, Cm and other transuranium elements, which spontaneously fission, could be present in the waters due to nuclear testing in the past and no attempt was made to eliminate this possibility. Basically all other measurements have failed to detect SHE in nature.

IX. Search for SHE in Heavy Ion Collisions

Although some of the lighter transuranium elements were produced using neutron capture process, Heavy ion reactions have been used for the most recently discovered elements as described in sections III to VI. It was natural to attempt to produce a SHE in this same manner. There are a number of approaches that have been used in heavy ion (HI) reactions, complete fusion, deep inelastic collisions and instantaneous fission and fusion approach. We will make some brief comments on each of these approaches

The probability of producing a detectable super heavy nucleus is the product of two factors: 1. the probability to fuse the reacting heavy ions to form a super-heavy compound nucleus in equilibrium, and 2. the cumulative probability of the excited super-heavy compound nucleus to survive the de-excitation process. If a compound nucleus is formed, even with minimum kinetic energy, more kinetic energy is required to overcome the coulomb barrier (i.e. the electrical charge barrier of a target nucleus that an incoming HI might experience because it also carries an electric charge) than is consumed in the fusion process. As a result, excitation energy is available in the compound nucleus and light projectiles and γ-rays are given off to deexcite the final nucleus. Initially, the reaction $^{248}Cm + {}^{40}Ar \rightarrow {}^{288}114$ was used to produce element 114. The N = 174 value for this compound nucleus was so far away from the region of high fission barriers (N = 184), that there was no possibility for this nucleus to survive spontaneous fission decay. A second approach tried was to reach the region of higher fission barriers using the reaction, $^{136}Xe + {}^{170}Er$ with low excitation. Unfortunately the production probability was too small. It is now argued that the fusion probability for reactions of this latter type are effectively zero. A large number of different targets and projectiles have been tried with no success up to the present time.

Another approach which has been used resulted when it was observed that a massive transfer of nucleons occured at low excitation energy. In deep inelastic collisions, interacting nuclei combine for a short time and a number of protons and neutrons can be transferred between the two nuclei before they break up. Calculations predict that the reaction $^{238}U + {}^{238}U \rightarrow {}^{298}114 + {}^{178}Yb$ would have a reasonable formation cross section. Some experiments indicated that more nucleons are transferred per MeV of excitation energy in $^{238}U + {}^{238}U$ reaction than in any other deep inelastic collisions involving heavy targets and lighter projectiles. In these type of reactions, there has been observed a broad mass distribution in the complementary fragments. All experiments have produced negative results to date. Similar experiments with $^{238}U + {}^{248}Cm$ have also been unsuccessful.

One other theoretical suggestion that has been experimentally attempted was to have a heavy nucleus undergo an instantaneous fission fission while in close contact with another heavy nucleus. It was hoped that the second heavy nucleus would fuse with a fission product of the first nucleus. The experiment using $^{208}Pb + {}^{136}Xe$ and also using $^{208}Pb + {}^{238}U$ both proved to be unsuccessful. This approach seems to be the least promising of the above three methods.

Although the early optimism has not been justified, work is still continuing in the hope that a SHE can be produced.

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