

# From Masurium to Trinacrium: The Troubled Story of Element 43

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The sole chemical element discovered in Italy was identified by Emilio Gino Segrè (a physicist) and Carlo Perrier (a chemist) at the University of Palermo. It happened in 1937, but this story begins long before. To recall all the stages that led to the discovery, it is useful to show how, at the beginning of the 20th century, by only changing its search strategy chemistry could increase the number of elements in its store.

This discovery, in 1937, represented a turning point in the history of chemistry: for the first time, an element that could not be found in minerals was produced by man in a laboratory. Accordingly, chemists had to change their mental habits and their criteria to recognize new elements: not only could elements be created by man, starting from those already known, but the analytical signals they provided with the most advanced instrumental techniques could be accepted as a proof of existence. Previously detectable quantities had to be produced before the discovery could be acknowledged. New elements need not be discovered by lengthy and traditional analytical operations, such as dissolution, precipitation, fractional crystallization, filtration, solvent extraction, and distillation since their existence could be verified with spectroscopic or radiochemical analysis. Because unweighable quantities of new elements gave faint emission lines or identifiable radioactive emissions, successful detection of new elements could be accomplished by collaborations between physicists and chemists.

The story began in Palermo, where Stanislao Cannizzaro (later professor of chemistry and dean of the University of Palermo) was born; he rose to international reputation during the first International Congress of Chemistry, held at Karlsruhe (Germany) in September 1860. During its final session, he provided congressmen with a simple criterion to distinguish between atoms and molecules and to correctly assess the atomic weight of each element. This was a distressing problem that chemists had unsuccessfully been trying to solve since the beginning of the 19th century, when John Dalton (1766–1844) had first proposed his atomic theory. Despite the high quality of analytical data, from which researchers such as Berzelius determined accurate atomic weights, the chemical formulas of compounds were in dispute. Dalton used the simple criterion that a single atom bonded with a single atom in a chemical reaction. This led him to assume, for instance, a formula as “HO” for water; moreover, the difference between atomic and equivalent weight (proposed by Wollaston) was not well understood. As an attempt to clarify the matter, Friedrich August Kekulé von Stradonitz (1829–1896) organized the Congress.

Cannizzaro approached the problem along the same experimental lines he used in teaching chemistry to his class: analyzing many gaseous substances, of known vapor density and percent composition, he had found that the quantities

of a given element, held in equal volumes of the free element or of its compounds, were always a multiple of the same value, which corresponded to the presence of a single atom in a compound. In this way, according to the hypothesis of Avogadro (1811), it was possible to establish the correct number of atoms of each element in a compound and to correctly determine its atomic weight.

According to Julius Lothar Meyer (1830–1895), Cannizzaro's simple and convincing arguments removed “the scales that covered the eyes” of the audience (1a), especially the younger ones. Prominent among these people was the English chemist John Alexander Reina Newlands (1837–1898), who was looking for a pattern to classify chemical elements. He had arranged elements according to their increasing atomic weights, without noticing any regularity. However, when he used weights determined according to Cannizzaro's methods, he found what he called the law of octaves, “the eighth element, starting from a given one, is a kind of repetition of the first, like the eighth note in an octave of music” (1b). Newlands gave each element a serial number, corresponding to its place in the ordered array, which was thereafter called the *ordinal number*. Many chemists were sceptical about this claim, as only a limited number of repetitions were found; others such as Meyer and Dmitri Ivanovich Mendeleev (1834–1907), tried to improve upon it.

Mendeleev used Newlands' ordering criterion, but chose the chemical valence of elements to establish a relationship between them. Following what he called the “natural law of periodicity” (2), he ultimately arranged elements in rows, placing in the same column those elements having the same valence and similar chemical behavior, to obtain an ordered pattern. He was so confident of the correctness of this intuition that he left empty spaces, where he could not fit any known element. He boldly postulated that these places would be filled from elements yet to be discovered, assigning them provisional names and foreseeing their chemical properties. Vindicating his confidence, eka-aluminium, eka-boron, and eka-silicon were identified as gallium (1875, P. M. Lecoq de Boisbaudran), scandium (1879, L. F. Nilson), and germanium (1886, C. A. Winkler) (3) within a few years of Mendeleev's proposal. Two further elements, called eka-manganese and dvi-manganese as, according to Mendeleev, they should be placed beneath manganese (4), showing, like it, a series of colored compounds, were not so easily discovered.

## Atomic Number

Mendeleev ordered the elements following an empirical criterion, which needed a sounder basis; for instance, it had to be determined how many empty spaces existed and where they should be placed in the periodic table. In January 1913,

5Antonius Johannes van den Broek (1870–1926), a Dutch lawyer fond of science, suggested a relationship between the atomic number of each element and the number of positive charges in the nucleus of its atoms (5): the charges of two adjacent elements must differ by exactly one unit. van den Broek used these charges to fix their position in the periodic table (6).

It was the young Henry Gwyn-Jeffreys Moseley (1887–1915) who gave experimental support to van der Broek's hypothesis. Working at laboratories at Oxford, he set up a method to record, on a photographic plate, X-ray spectra of different elements to measure the frequencies of their K and L lines. Moseley calculated  $Q$  for the K and L lines as,

$$Q_K = \sqrt{\frac{4 \cdot v}{3 \cdot v_0}} \quad Q_L = \sqrt{\frac{36 \cdot v}{5 \cdot v_0}}$$

where  $v_0$  is the fundamental Rydberg constant ( $1.097373 \times 10^7 \text{ m}^{-1}$ ) (7), and plotted them against  $N$ , the atomic number, as in Figure 1.

He found that, in both series, if elements were placed in the same order as in Mendeleev's periodic table,  $Q$  increased by a constant quantity upon passing from an element to the next one (6). Moseley inferred that, in each atom, there was a fundamental quantity, which increased by regular steps, passing from one element to the next, and that this quantity could only be the positive charge on the nucleus of their atoms (8). Accordingly, "if either the elements were not characterized by these integers, or any mistake had been made in the order chosen or in the number of places left for unknown elements, these regularities would at once disappear" (8).

Although Moseley had thus showed that the ordering criterion of elements was their atomic number, representing the positive charge of their atomic nucleus, instead of their atomic weight, most of Mendeleev's forecasts were proved: the order of the elements, including inversions of places, and empty spaces for missing elements, which Moseley definitively stated to correspond to atomic numbers 43, 61, and 75 (9), to which were later added 72, 85, 87, and 91.

These hints opened a clear road to researchers, which, instead of proceeding by blind attempts, could plan their hunting strategy, focusing their attention on those minerals that contained elements chemically similar to those being sought. This research strategy proved to be successful: in 1917 Lise Meitner (1878–1968) and Otto Hahn (1879–1968) in Germany and Fredrick Soddy (1877–1956) and John Arnold Cranston (1925–1980) in England independently discovered protactinium ( $Z = 91$ ) in pitchblende (10); in 1923 Georg Charles von Hevesy (1885–1966) and Dirk Coster (1889–1950), after repeated crystallizations, obtained hafnium ( $Z = 72$ ) from zirconium ores (10); and in 1925 Ida Eva Tacke (1896–1978), Walter Noddack (1893–1960), and Otto Carl von Berg isolated rhenium ( $Z = 75$ ) from columbite.

The search for new elements would have ended at this stage, because despite a great deal of intensive research, elements 43 and 61 could never be found in nature. Instead, further elements could be created only through radioactive decay or nuclear fission, thus realizing the old alchemists' dream of changing one element into another.

## Masurium

Element 43 was a particularly troublesome element. Despite decades of search, it could not be positively identified until it was artificially created by a joint effort of the University of California–Berkeley and the University of Palermo. Its deliberate and systematic search was started in 1924, when C. Bosanquet and C. Keeley, following Mendeleev's hypothesis, analyzed, by X-ray spectroscopy, residuals from several manganese ores. Although unsuccessful, they judged their strategy so promising that they proposed the name of moselium for this previously undiscovered element (4, 9). Further observations suggested that, in many instances, chemical similarity was shown by elements in a row, rather than in a column (Figure 2). Thus, Gerber thought that elements 43 and 75 should resemble molybdenum and tungsten better than manganese, the lighter element of their group. Accordingly, he proposed the names of neo-molybdenum and neotungsten for the elements (11).

Similar lines of thought motivated two German researchers working at the Imperial Physico-Technical Research Office in Berlin: Ida Tacke and Walter Noddack (chief of the chemistry laboratory) who would eventually marry. They looked for these elements in ores containing their horizontal neighbors, such as molybdenum, tungsten, ruthenium, and osmium, rather than elements of the same group. They observed that niobium (called columbium outside of Europe) and tantalum were found in the same ores, as were molybdenum and tungsten; moreover, platinum ores usually con-

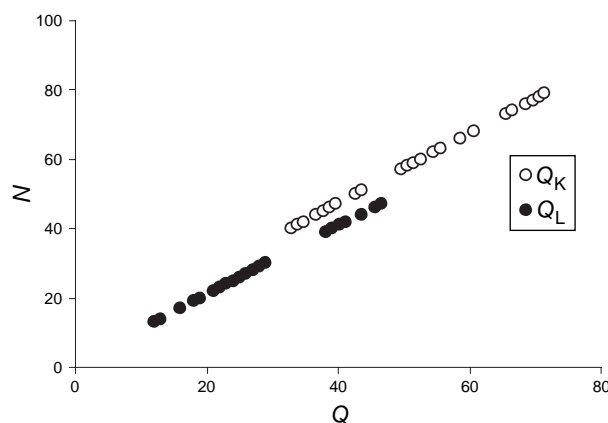


Figure 1. Moseley diagram.

22 Ti	23 V	24 Cr	25 Mn	26 Fe
40 Zr	41 Nb	42 Mo	43	44 Ru
72 Hf	73 Ta	74 W	75	76 Os

Figure 2. Neighbors of element 43 in the periodic table.

tained elements from 44 to 47 and from 76 to 79, while columbite, a black ore consisting of iron, manganese, niobium, and tantalum, also contained elements from 39 to 42 and from 71 to 74 (9). Attempts to isolate new elements from platinum ores were unsuccessful, but a columbite sample from Norway proved to be more promising. After a series of chemical treatments, in 1925 Tacke and Noddack separated a residue, analyzed with the help of Berg at Werner-Siemens A. G. Laboratories. In its X-ray spectrum, they believed they identified weak K and L lines, from which they argued the presence of both elements 43 and 75. Their estimated concentrations in the residue were 0.5 and 5%, respectively, corresponding to initial concentrations of  $10^{-8}$  and  $10^{-7}$  (12).

Tacke and Noddack proposed to call element 43 masurium (Ma), from the Masurian marshes district in eastern Prussia where Noddack was born. They proposed rhenium (Re) as the name of element 75, from Rhenany-Reinland, Tacke's birthplace (10, 13). The Rhine River and Masurian lakes were on the western and eastern Germany borders; unfortunately, during World War I, P. L. von Hindenburg's German troops had defeated the Russian army in a series of bloody battles at Masurian marshes. So, scientists from other countries severely criticized this choice, as "a stupid psychological blunder, which no civilized scientist should make" (14).

On June 19, 1925, the Noddacks patented a method to extract and concentrate rhenium and masurium from their ores: after the ore dissolution, they were precipitated as sulfides, reduced by gaseous hydrogen, and then gently heated in an oxygen stream. The first portion of the sublimate was rich in rhenium, which could be concentrated by further sublimations (15). In 1928, they were successful in increasing their rhenium stock up to 1 g, by treating about 660 kg of Norwegian molybdenite ( $\text{MoS}_2$ ) (16). With this quantity, they were able to investigate its chemical and physical properties (17), so that their discovery of rhenium was accepted by the scientific community.

Conversely, the identification of masurium could not be confirmed, either by the Noddacks or any other research group. As a consequence, many began to cast doubt on its existence. The Noddacks' evidence rested on X-ray lines, but, at that time, this was not considered a sufficient proof to confirm a claim if not matched with the production of appreciable quantities of the element or its derivatives. The influential analytical chemist Wilhelm Prandtl (1878–1956) denied the Noddacks' discovery supposing that zinc and tungsten spectral lines could have led them to wrong conclusions (4).

In 1934, Josef Mattauch (1895–1976) published a selection rule (18) that stated that stable isobar pairs (having the same atomic mass) could not exist if they differed by only one charge unit. For molybdenum and ruthenium, their closest neighbors in the periodic table have stable isotopes showing all the possible mass values for element 43; therefore, Mattauch's rule definitively ruled out the possibility of masurium's existence in the earth crust. The Noddacks' claim of its recovery from ores was then ridiculed and they were scientifically discredited. This general discredit likely played a role in the general dismissal of Tacke's work on nuclear fission (19). Five years before the classic Meitner paper (20),

she suggested that, in Fermi's experiments on neutron bombardment, uranium nuclei broke down and no heavier element was formed.

## A New Mine: The Cyclotron

The second act of this story took place at the Physics and Mineralogy Institutes of Palermo University (Figure 3). Its chief character was Emilio Gino Segrè (1905–1989), one of Fermi's co-workers, who in 1935 had won the chair of experimental physics in Palermo. During the following summer holidays (1936), Segrè went to Berkeley to visit the radiation laboratory of the University of California. The laboratory chief was Ernest Orlando Lawrence (1901–1958), who in 1930 had developed the cyclotron, a device that generates beams of subatomic particles, such as protons, deuterons, and alpha particles. The beams are accelerated to high energies along a circular path and then are directed to strike targets of different materials, generating radioactive isotopes. Thus, the cyclotron was a useful tool to study nuclear reactions and the stability of atomic nuclei.

Segrè obtained from Lawrence some broken or worn out parts from the cyclotron. He hoped to use them as radioactive sources for his experiments in Palermo, where the funding shortage was chronic (21). So Segrè brought home some small brass and copper plates. To separate and analyze their radioactive components, he looked for the help of Carlo Perrier (1886–1948), who was well-suited for this task: after obtaining a degree in chemistry at Turin University, he had worked at Zurich Polytechnic (Switzerland) with the great analytical chemist, Frederick Pearson Treadwell (1857–1918) (22). From 1935 Perrier held the chair of mineralogy at Palermo University and was the chief of the Mineralogy Institute, in the same building where the Physics Institute was located (23).

The analysis of the brass and copper specimens revealed the presence of many radioactive elements. Most of this ra-



Figure 3. A recent photo of the building on Archirafi Street, seat of physics (ground and first floor) and mineralogy (second floor) departments; the building appeared the same in 1936.



dioactive material was  $^{32}\text{P}$ , which Perrier and Segrè (Figure 4) used to investigate phospholipid metabolism, in collaboration with Camillo Israele Giuseppe Artom (1893–1970), professor of physiology at the same university (24).

On January 6, 1937, Segrè received a Christmas card from Lorenzo E. Capodilista, working at Berkeley, containing a molybdenum plate that had been part of the cyclotron for a long time. The opposite sides of the plate showed different quantities of radioactivity, apparently owing to the beam of charged particles that affected the sides of the molybdenum plate (25). Segrè waited until January 30 to start the analysis to allow short-lived isotopes to completely decay. Segrè and Perrier wanted to ascertain which element caused the long-lasting radioactivity. Segrè and Perrier directed their attention to only a few elements that most probably could have been generated from bombardment with deuterons. Beside molybdenum, these elements were zirconium, niobium, and element 43. They dissolved the specimen in aqua regia and, in order to recover very small quantities of the sought elements, they added, step-by-step, salts of niobium, zirconium, and manganese. None of these three, nor molybdenum, showed any appreciable radioactivity after their recovery (25).

As this radioactivity had a different character from that of  $^{32}\text{P}$ , Segrè and Perrier supposed it could be element 43. In any case, this was likely present in such unweighable quantities (they estimated it was less than  $10^{-10}$  g; ref 26) that all the most accurate chemical analysis procedures would be unable to reveal it. To increase the quantity of matter to be recovered, they added, as a carrier, small quantities of non-radioactive rhenium, as it would likely show a chemical behavior similar to that of element 43. A flow diagram of their recovery procedure is shown in Figure 5.

By boiling the molybdenum plate in dilute ammonia, Segrè and Perrier dissolved its surface layer, where most of the radioactivity was confined. By the addition of 8-hydroxyquinoline, molybdenum was precipitated and filtered off. The solution was made acidic with hydrochloric acid, and rhenium and manganese were added, respectively, as  $\text{HReO}_4$  and  $\text{MnSO}_4$ . Addition of  $\text{H}_2\text{S}$  gave a radioactive black precipitate and an almost inactive solution. Manganese was dissolved with diluted  $\text{HCl}$ , while the black sulfide still carried all the radioactivity. The sulfide was then dissolved in hydrogen peroxide, heated to dryness, and then dissolved in 80% sulfuric acid. After heating this solution at  $180^\circ\text{C}$  in a current of moist gaseous hydrochloric acid for half an hour, rhenium was distilled

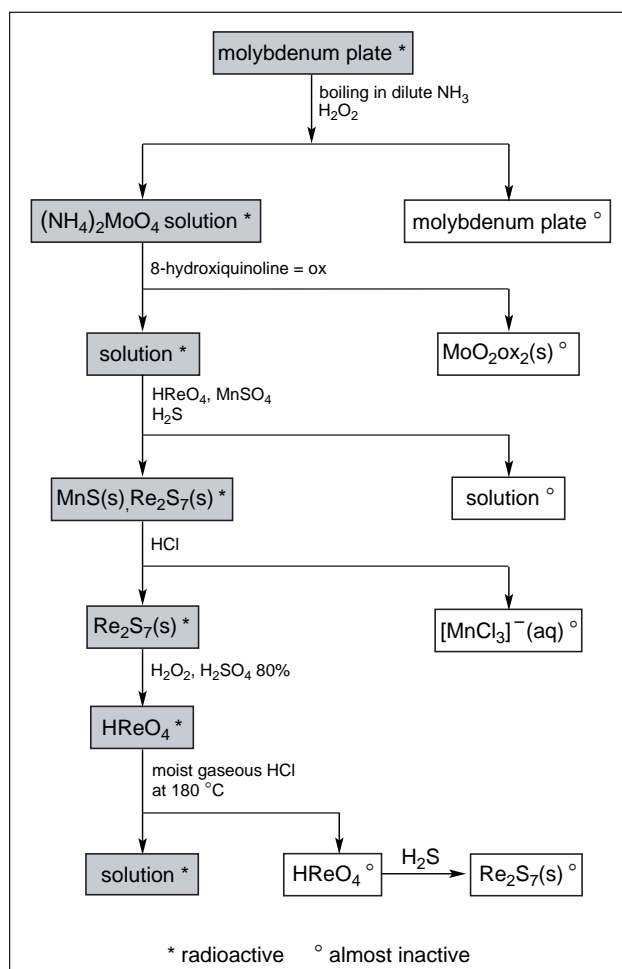


Figure 5. Flow diagram of element 43 separation.

and collected, and showed no activity. The identity of rhenium was confirmed by precipitation with hydrogen sulfide.

On the contrary, the activity was entirely left in the sulfuric acid solution, so it was assigned to element 43. In this way, the element's presence was inferred by the process of elimination without any of the generally accepted proofs. Neither could appreciable quantities of this new element be separated, nor could its X-ray spectrum be observed. Segrè continued in his investigation and, with the help of Bernardo Nestore Cacciapuoti, in November 1937 reported the decay curve of the ac-

Figure 4. Emilio Gino Segrè (left) and Carlo Perrier (right, courtesy of Family Bellanca).



tivity of rhenium sulfide, containing element 43. From the analysis of these curves, they found three radioactive isotopes of element 43, having half-lives of 90, 50, and 80 days (27).

It now had to be determined whether Perrier and Segrè had obtained element 43 for the first time or whether they had simply confirmed the Noddacks' earlier results. Segrè asked to see the Noddacks' X-ray spectra to compare with his own results; the Noddacks refused, saying that photographic plates had been irremediably lost. Segrè started doubting, but was not yet ready to claim his priority based only on tracer analysis (21, 24). In the summer 1938 he went again to Berkeley to investigate the shorter-life isotopes that would have decayed during the journey from the United States to Italy. (Significantly, this research project eventually saved his life because the simultaneous promulgation of racial laws in Italy convinced him never to return. Eventually his German wife Elfriede and his newborn son Claudio moved to the United States).

At Berkeley, together with the young chemist Glenn Theodore Seaborg (1912–1999), Segrè discovered a nuclear isomer of element 43, whose activity had a half-life of 6.6 days. It decayed to the ground state and its  $K\alpha$  line was ascribed to element 43 (28). These last results, especially the X-ray spectrum, convinced Segrè to claim his priority on the assumption that the Noddacks were thoroughly wrong in their approach. The Noddacks would never have succeeded in isolating element 43 from natural ores, as Segrè and collaborators had definitely shown that element 43 could only be obtained by a transmutation, which these new alchemists carried out by means of neutron bombardment. In a 1939 article (26) Segrè wrote that, together with Seaborg, he had first observed an X-ray spectrum containing a line of a new element, artificially obtained in the only mine from which it could be extracted, the cyclotron.

## Looking for a Name

Once it was demonstrated that element 43 could effectively exist and show a well-defined chemical behavior, it had to be named. This too was a troublesome process (4) that had progressed through many different suggestions, following claims that later proved to be incorrect. These concerned

an element showing a chemical character similar to that of manganese and intermediate between those of molybdenum and ruthenium. The first claim was due to Gottfried Wilhelm Osann (1797–1866), who in 1828 believed that he identified it in the insoluble residue of a platinum ore. He proposed the name of polinium, from the Greek word  $\text{πολιος}$  meaning gray (29), but, in a short time, realized that he had actually obtained impure iridium (4).

In 1846 R. Hermann, in some niobium and tantalum ores from the Ilmenian Mountains in the southern Urals, found very small quantities of what he thought to be a new element (4). He called it ilmenium, but the discovery could not be confirmed as Hermann lacked any X-ray technique of identification. Heinrich Rose (1795–1864) contradicted Hermann's claim, suggesting he had obtained impure niobium; Rose in 1847 found something resembling tantalum and niobium, which Hermann showed to be impure niobium (4). Rose had proposed the name of pelopium, after Pelope, son of Tantalus, brother of Niobe.

Thirty years later, Sergei Kern claimed (30) to have spectroscopically identified a new element in platinum ores: he reported some of its reactions and determined an atomic weight of 154 for this element. He proposed to call it davyum, after Sir Humphrey Davy (4). It could be Mendeleev's ekamanganese, but its atomic weight was largely different from the value of 100, calculated by the Russian chemist in 1881. In 1898 J. Mallet accurately repeated Kern's analysis, and showed that he had obtained a mixture of iridium, rhodium, and traces of iron (29).

In 1896 M. Barriere claimed spectroscopic identification of lucium (atomic weight of 104), but William Crookes (1832–1919) showed that the lines were due to yttrium and traces of didymium, erbium, and ytterbium (4). Finally, in 1909 M. Ogawa found in thorionite, reinite, and molybdenite a new element whose chemical properties closely corresponded to those anticipated by Mendeleev: he proposed the provisional name of nipponium and determined an atomic weight of 100, but his identification could not be confirmed (4). In recent years, researchers from Tokyo University have analyzed Ogawa samples and found they actually contained rhenium (31). Names and chemical symbols proposed for element 43 are listed in Table 1.

**Table 1. Names Proposed for Element 43**

Name	Chemical Symbol	Origin	Proposer	Year	Atomic weight
Polinium	—	$\text{πολιος}$ = gray	G. W. Osann	1828	—
Ilmenium	—	Ilmenian mountains	R. Hermann	1846	—
Pelopium	Pe	Pelope	H. Rose	1847	—
Davyum	Da	Humphry Davy	S. Kern	1877	154
Ekamanganese	Em	—	D. I. Mendeleev	1881	100
Lucium	—	—	M. Barriere	1896	104
Nipponium	Np	Nippon = Japan	M. Ogawa	1909	100
Neomolybdenum	—	—	Gerber	1917	—
Moselium	—	H. G. J. Moseley	C. Bosanquet and C. Keeley	1924	—
Masurium	Ma	Masurian marshes	I. Tacke, W. Noddack, and O. Berg	1925	—
Trinacrium	—	Trinacria = Sicily	—	—	—
Technetium	Tc	$\text{τεχνητος}$ = artificial	C. Perrier and E. Segrè	1947	99

## Technetium

In 1937, Perrier and Segrè's claim of the identification of element 43 gave rise to a widespread enthusiasm in Italy, and many suggested that they connect the discovery to the place where it had been realized (for instance, trinaurium after the ancient name of Sicily) or to the Italian ruling party. These suggestions were not accepted, both because Perrier and Segrè were not sure of the novelty of their discovery and because they did not share these regionalist, political feelings. Coming from northern and central Italy, Perrier and Segrè were not strongly tied to Sicily; concerning politics, they never approved fascist government ruling in Italy, which, moreover, persecuted Segrè for his Jewish origins.

The naming of element 43 was thus delayed until the end of World War II. By then, the international scientific community accepted the possibility of acknowledging the existence of new elements, even if they could not be found in nature, but could only be produced artificially. Austrian chemist Friedrich Adolph Paneth (1887–1958) suggested this change of mental attitude and proposed to give the right to name an element to the first researcher that had given definite proof of the existence of one of its isotopes (32). At the same time, all the previously proposed names, bound to unconfirmed claims, should be deleted. Segrè and Perrier accepted Paneth's suggestion and, being at last confident of the priority and certainty of their discovery, proposed the name of technetium, symbol Tc, from the Greek word *τεχνητος* that means made by art, artificial, to underscore the fact that it was produced in laboratory by men, by molybdenum neutron bombardment (33).

## Nemesis

The story ends with the Noddacks' rehabilitation. Throughout the years, their scientific reliability had been compromised, not only by the lack of agreement on their masurium identification, but also by their stubborn and lasting claim of the discovery. Joined by their strong nationalism and enthusiasm for the Nazi regime, this led to their scientific ostracism. Regarding their firm faith in masurium, Paneth tells an episode told to him by J. Guéron (32). During World War II, Walter Noddack won the chair of inorganic chemistry at University of Strasbourg in occupied France. When in 1945 French chemists returned to Strasbourg, they found that the symbol Ma for masurium had been painted on a large representation of the periodic table hanging in the main chemistry lecture room. In later years these quarrels were overcome by strictly scientific interpretations.

In the 1950s, it was a generally shared opinion that primordial technetium could not have survived on the earth's crust; nevertheless, in 1952 P. Merrill (34) detected fairly strong Tc(I) lines in the spectra of light from various class S stars. This prompted new efforts to find naturally occurring technetium formed, for instance, by nuclear fission of isotopes of elements already found on the earth: in 1940 Segrè had identified technetium among uranium fission products (35).

By improving search strategies and analytical techniques, very small quantities of technetium were finally identified in naturally occurring ores: in 1962 Kuroda and Kenna isolated about  $1 \times 10^{-9}$  g of  $^{99}\text{Tc}$  by chemical treatment of 5.3 kg of pitchblende from the Belgian Congo (36). In 1988, minute quantities were detected in ores from a deep molybdenum mine in Colorado (37). These findings were quite credible assuming that extremely small quantity of technetium could have been naturally created by self-sustained nuclear reactions. From the isotopic  $^{235}\text{U}/^{238}\text{U}$  ratio and the decay rate of the radioactive isotopes, it can be argued that in the past some nuclear fission reactions have been spontaneously occurring in some natural uranium ore deposits, as that of Oklo (Gabon) and a few other locations (38). In these sites, naturally occurring  $^{235}\text{U}$  has had a concentration high enough to self-sustain its fission reaction, as confirmed from the presence of its fission products in the sites. As the ores studied by the Noddacks may have contained as much as 10% uranium, in recent years, John T. Armstrong of the NIST, tried to duplicate their experiments. Using a sophisticated X-ray database and spectral analysis software, Armstrong found that the spectral lines attributed to masurium appear consistent with element 43 (39) and that Noddacks' instruments were sufficiently sensitive to detect less than a billionth of a gram of this element (13).

In conclusion, it took about 75 years to remove the doubt cast on the Noddacks' results and to finally agree on the reliability of their scientific results. It is an irony of fate that nuclear fission, whose existence was firstly suggested by Ida Tacke Noddack, was used to vindicate them.

## Current Technological Uses of Technetium

Known isotopes of technetium, all of them radioactive, range from mass number 90 to 111 (40): the most representative are reported in Table 2. Today technetium is produced by bombarding molybdenum-98 with deuterons, which captures a neutron giving molybdenum-99. This has a half-life of 65.94 hours and undergoes beta decay, giving technetium-99 (41).

**Table 2. Representative Technetium Isotopes**

Isotope	Half-life
$^{95}\text{Tc}$	20.0 hours
$^{95\text{m}}\text{Tc}$	61.0 days
$^{96}\text{Tc}$	4.28 days
$^{96\text{m}}\text{Tc}$	51.5 minutes
$^{97}\text{Tc}$	$2.60 \times 10^6$ years
$^{97\text{m}}\text{Tc}$	90.0 days
$^{98}\text{Tc}$	$4.20 \times 10^6$ years
$^{99}\text{Tc}$	$2.13 \times 10^5$ years
$^{99\text{m}}\text{Tc}$	6.0 hours
$^{100}\text{Tc}$	14.2 minutes

NOTE: Data from ref 40.

Among its isotopes,  $^{99\text{m}}\text{Tc}$ , where m stands for meta-stable, is largely used as radionuclide for diagnostic nuclear medicine. Through an isomeric process, it decays to stable  $^{99}\text{Tc}$ , emitting low-energy gamma rays and electrons. Its physical properties are almost ideal for a medical diagnostic use, as its half-life of 6 hours is long enough to ensure an accurate screening of metabolic processes, but short enough to minimize the radioactive exposure of the patient. Moreover, emitted gamma rays can easily escape human body and be revealed by a scintillation camera that provides maps of its radioactive distribution in the body with great anatomic detail (42). During these diagnostic investigations, the radioactive exposure of the patient is generally lower than for other radiographic procedures, such as, for instance, X-ray imaging;  $^{99\text{m}}\text{Tc}$  that remains in the body soon loses its activity and is quickly excreted through the kidneys (43).

From a chemical point of view, this element forms several compounds that concentrate in different tissues or organs, so that they can be observed by medical scintigraphy (44). For instance, pyrophosphate derivatives are absorbed into the bone structure (43), while the complex with diethylenetriamine pentaacetate ( $^{99\text{m}}\text{TcDTPA}$ ) collects in kidneys (44) and brain (43); other  $^{99\text{m}}\text{Tc}$  derivatives are easily adsorbed into heart, spleen, lungs, and blood.

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