

1           **New forensic insight into Carl Auer von Welsbach's 1910 observation of**  
2           **induced radioactivity: theoretical, experimental and historical approaches**

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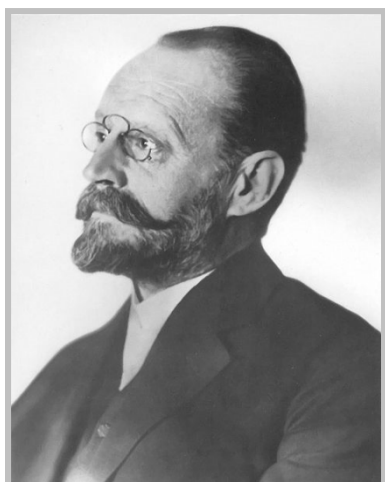
16 **Abstract**

17 In 1910, Carl Auer von Welsbach noted that he had made an observation of a radioactive substance  
18 inducing radioactivity to an inactive substance. From today's point of view, this could have been the  
19 first observation of neutron activation. Herein, we present new insights into our investigation of this  
20 "mysterious observation" as Auer von Welsbach termed it. We believe that one of the activated  
21 objects was a platinum-iridium crucible. The dominating activation product of the crucible could have  
22 been iridium-194. We have discovered several platinum crucibles from Auer's heritage and  
23 investigated them by gamma-spectrometry and, one of them, by SEM/EDX. In the EDX investigations,  
24 however, no iridium was found in the most promising crucible. Hence this particular crucible was  
25 probably not the activated object. In any case, gamma-ray spectrometry revealed very low but  
26 detectable amounts of natural radionuclides. This indicated that these crucibles were used by Auer  
27 von Welsbach for his radioactive work and that these crucibles were bought prior to World War I.  
28 Hence Auer von Welsbach somehow managed to save these crucibles from the noble metal  
29 collections during the war. Auer's 1910 publication carried the suffix "Part I", however, Part II was  
30 thought to be lost. In our recent work, however, we rediscovered a hand-written manuscript of Part  
31 II, in which the peculiar observation is mentioned vaguely. Lastly, we converted Auer's uranium  
32 standard into becquerels. Based on this conversion, we estimated that Auer von Welsbach observed  
33 an  $^{194}\text{Ir}$  activity of the crucible of 500 kBq. It is further estimated that a (thermal) neutron flux density  
34 of approximately  $8\text{E}+4 \text{ cm}^{-2}\text{s}^{-1}$  was needed to activate the crucible in a way to meet Auer's  
35 description.

36 **Introduction**

37 Carl Auer von Welsbach (1858-1929) was one of Austria's most renowned and prolific scientists in  
38 the late 19<sup>th</sup> and early 20<sup>th</sup> century (Fig. 1). He discovered four elements (praseodymium,  
39 neodymium, ytterbium, and lutetium) and revolutionized illumination technology by several  
40 outstanding inventions making him a successful entrepreneur of his time. Auer von Welsbach was  
41 well-known as a hard worker who would spend days and nights in his laboratory. Nonetheless, he  
42 rarely focused on the active development of a specific, practical solution to a specific technical  
43 problem; he did not regard himself as an engineer but as a scientist. Rather, he would continue his  
44 research efforts on fundamental science and develop solutions to existing problems through sole  
45 observation of chemical or physical phenomena during this fundamental research. For example, he  
46 became acquainted with the problems of poor light sources during his military service in the artillery,  
47 when strategic maps and written orders were difficult to read with the poor light sources of his time,  
48 especially at night in the field. Many years later, he recalled the need for better and more intense  
49 lighting when he observed the bright incandescence of rare earth salts when sprayed into the flame  
50 of a gas Bunsen burner. This scientific observation led him to the development of the incandescent  
51 gas mantle which was one of Auer's key inventions.

52 Auer's main specialty was the separation of rare earth elements (REE) which are known to exhibit  
53 much related chemical properties. In the course of these studies he developed chemical separation  
54 skills that were often unmatched by other researchers of his time. It was this specific chemical  
55 knowledge that introduced him to a different field where people with Auer's specific skills were  
56 needed: radioactivity research. In the early days of radioactivity research and the hunt for new,  
57 radioactive elements, chemical separation techniques were the key to success. It is no surprise,  
58 therefore, that Auer von Welsbach dedicated some of his time to the isolation of radioactive  
59 elements from radioactive raw materials that were derived from uranium ores. Since, at least by  
60 comparison to his work in REE chemistry, he was not overly successful in this area, Auer's  
61 involvement in radioactivity research in the beginning of the 20<sup>th</sup> century is somewhat less known.



62  
63 **Fig. 1** Carl Auer von Welsbach (1858-1929). Bildarchiv der Österreichischen Nationalbibliothek.

64 Physical and chemical sciences in the early 1900s were dominated by the discovery of radioactivity,  
65 especially the discovery of radium by Marie and Pierre Curie. In the light of the French dominance of  
66 this new field, scientific leaders in the Austrian-Hungarian Empire (in particular the newly founded  
67 Radium-Commission of the Austrian Imperial Academy of Sciences) realized the need for a large-  
68 scale, industrial production of radium. Marie and Pierre Curie only used manual or semi-technical  
69 separation methods (at best) for the work-up of the uranium ore residues. Thus it was thought that

70 the production on an industrial scale would yield higher amounts of the precious new element  
71 radium, which would fuel the scientific progress in this field in the Danube Monarchy. Auer von  
72 Welsbach offered his gas mantle factory in Atzgersdorf (near Vienna) for this industrial endeavor. He  
73 expected to receive a fraction of the produced radium for his own research, however, as described  
74 previously (Steinhauser, Löffler, and Adunka 2013), his requests for some of the radium were turned  
75 down. Instead, Auer von Welsbach was offered the residues of the radium production: water-rich  
76 filter cakes (water content 77.5%) that were termed “hydrates” and contained both radioactive and  
77 not radioactive substances. Despite his major disappointment, Auer von Welsbach agreed to further  
78 work up these hydrates, hoping he might isolate known or new radioactive substances from them.

79 In the course of his work, Auer von Welsbach made a very strange but fascinating observation that is  
80 the basis of our study. In a 1910 publication (Auer von Welsbach 1910a, b), he described how a  
81 radioactive substance, namely thorium/ionium (Th/Jo) (today known as thorium-230), was capable  
82 of activating non-radioactive substances (Fig. 2). The ionium was a major constituent of the hydrates.

Kurz erwähnen will ich ferner, daß viele Beobachtungen dafür sprechen, daß das Jonium andere ihm chemisch nahestehende Körper bei längerem Kontakt zu radioaktiven Emissionen anzuregen vermag. Es ist wahrscheinlich, daß hierdurch eine Erschütterung des elementaren Bestandes der erregten Körper und damit auch eine Veränderung ihrer chemischen Eigenschaften eintritt.

Im Laufe dieser Untersuchungen habe ich auch Erscheinungen radioaktiver Art beobachtet, die mir mit den heute herrschenden Theorien nicht recht im Einklange zu stehen scheinen.

Ich habe sie in der folgenden Schilderung einfach registriert. Vielleicht bilden manche von ihnen wichtige Fingerzeige für die weitere Erforschung des so geheimnisvollen Gebietes der Radioaktivität.

I would further like to note that many observations indicate that, after long-lasting contact, ionium can induce radioactive emissions from other bodies, which are chemically related to the ionium. In this process, probably a concussion of the elementary inventory of the irradiated samples takes place as well as changes in their chemical properties.

In the course of these investigations, I have observed phenomena of radioactive kind that are not quite in agreement with current theories.

I have simply registered these phenomena. Perhaps some of them will be of importance for the further investigation of the mysterious field of radioactivity.

83

84 Fig. 2. A document of a peculiar observation: Activation processes (Auer von Welsbach 1910b, a)

85 Under normal circumstances, ionizing radiation, in particular  $\alpha$ -particles emitted from thorium-230,  
86 cannot make their targets radioactive (there are, however, some exceptions to this general rule,  
87 which do not seem to apply here). Therefore, only one reasonable explanation for this phenomenon  
88 appeared obvious at Auer’s time: one might only conclude that the “long-lasting contact” of ionium  
89 had caused a contamination of the surface of the seemingly activated objects. Auer von Welsbach  
90 was well aware of this simple explanation for his “mysterious” observation. Later he describes, how  
91 he attempted to decontaminate the activated object: a platinum crucible (Fig. 3). In his (unpublished)  
92 lab journal he even notes that “glowing to red heat does not help”.

93

Die erste Mutterlauge der zweiten Fraktion der Thorreihe lieferte eine sehr geringe Menge eines schwarzen Rückstandes, e. r., der mit Salpetersäure aufgenommen wurde. Die Platinschale war selbst nach kräftigem Scheuern noch r. Unlöslicher Teil (Platin) r. Lösung st. r. Auf Ammoniakzusatz fielen etliche eben sichtbare Flöckchen. Filterchen e. r. Das Elektroskop konnte nicht mehr geladen werden. Das Präparat entlud den stark geriebenen Glasstab auf etwa 5 cm Entfernung in etwa einer Sekunde vollständig.

The first mother liquor of the second fraction of the thorium chain yielded a very small amount of a black residue (enormously radioactive), which was dissolved in nitric acid. The platinum crucible remained radioactive even after intense scrubbing and cleaning. (Insoluble part (platinum) “radioactive”, solution “strongly radioactive”). Several yet visible flakes precipitated upon the addition of ammonia. Filters: “enormously radioactive”. The electroscope could not be recharged again. The sample uncharged the heavily rubbed glass stick already at a distance of approx. 5 cm within ca. 1 second.

94

95 Fig. 3 Facsimile of Auer’s publication: Failed elimination of a possible contamination (Auer von Welsbach 1910b, a)

97 In our previous report (Steinhauser, Löffler, and Adunka 2013) we already outlined that there are  
98 several reasons to believe that Auer von Welsbach incidentally observed neutron activation. Neutron  
99 radiation is the only type of ionizing radiation that can activate stable nuclei under the “normal”  
100 circumstances that prevailed in Auer’s laboratory and experimental setup. The neutrons are believed  
101 to originate from a nuclear reaction of beryllium with  $\alpha$ -particles:  ${}^9\text{Be}(\alpha, n){}^{12}\text{C}$ . In this nuclear reaction,  
102 a beryllium-9 nucleus captures an alpha particle and yields both a carbon-12 nucleus and a neutron  
103 that is emitted as radiation. We speculate that beryllium was incorporated into the hydrates as a  
104 contamination in the course of the radium production in Auer’s incandescent gas mantle factory in  
105 Atzgersdorf. In that factory, large amounts of beryllium salts were used for the production of the gas  
106 mantles (Steinhauser, Löffler, and Adunka 2013).

107 Neutron activation would follow the physical laws of the activation equation (1):

$$108 \quad A = N_0 \Phi \sigma (1 - e^{-\lambda t_{irr}}) \quad (1)$$

109 where  $A$  is the resulting activity after neutron irradiation,  $N_0$  is the number of target atoms of the  
110 activatable isotope,  $\Phi$  is the neutron flux density under which the target is exposed to neutrons,  $\sigma$  is  
111 the cross section for neutron capture in the target nucleus,  $\lambda$  is the decay constant (defined as  
112  $\lambda = \ln(2)/T_{1/2}$ ), and  $t_{irr}$  is the irradiation duration. One reason, why we believe that neutron activation  
113 is the key to the mystery is that Auer von Welsbach explicitly mentions the “duration” of the contact  
114 between the radioactive sample and the activated object (“long-lasting contact”). This is one major  
115 indication that the platinum crucible experienced more than a sole contamination.

116 The neutron was finally discovered by James Chadwick only in 1932 (Chadwick 1932b, a), also taking  
117 advantage of the nuclear reaction  ${}^9\text{Be}(\alpha, n){}^{12}\text{C}$ . Not only did Auer von Welsbach have no idea of the  
118 existence of the neutron. At the time of his peculiar observation, he had a very different view of the  
119 constitution of matter in general since Bohr published his model of the atom only three years later  
120 in July 1913 (Bohr 1913). Auer von Welsbach likely still had Thomson’s model of the atom in mind  
121 (“plum pudding model”).

122 Even after our previous report (Steinhauser, Löffler, and Adunka 2013), many questions remained  
123 open. For example, why was not there any “Part II” of the mysterious publication (Auer von Welsbach  
124 1910b, a)? What happened to the platinum crucible as it seemed to have disappeared? How  
125 radioactive was the “activated” object and what neutron source strength would be needed to  
126 produce this activity? In the current paper, we report on new insight into these questions, and we  
127 conducted further historical research as well as forensic investigations to gain more knowledge on  
128 what happened more than 100 years ago.

129

## 130 **Methods**

131 This project is a continuation of our continuing interest in forensic history of science (Steinhauser,  
132 Löffler, and Adunka 2013, 2014, Steinhauser et al. 2008). For the historic investigations we rely on  
133 original objects and documents collected at the Auer von Welsbach-Museum in Althofen, Austria, or  
134 provided by the heirs of Carl Auer von Welsbach.

135 Several objects were investigated by  $\gamma$ -spectrometry at the low-level HPGe Canberra<sup>TM</sup>  $\gamma$ -counting  
136 facility of the Atominstitut. Specifics of the detector can be found elsewhere (Steinhauser et al. 2013).  
137 The objects included a total of 11 platinum crucibles and 6 platinum spatulas from the heritage of  
138 Carl Auer von Welsbach. The six spatulas were counted together with nine crucibles in one batch

139 measurement (duration more than 15 days) for an overview on possible radionuclide contaminations  
140 (a picture of these objects is available from the authors upon request).

141 The most interesting object, however, was an original platinum crucible which was also provided for  
142 the purpose of investigation in this study by inheritors of Carl Auer von Welsbach. It was counted  
143 separately on the  $\gamma$ -detector for more than 11 days. The crucible has a mass of approx. 330 g and a  
144 diameter of 17 cm. It is special because, on the interior, it shows characteristic scratches (see Fig. 4)  
145 – scratches that may have occurred in decontamination attempts. We were also allowed to apply  
146 scanning electron microscopy-energy dispersive X-ray spectroscopy (SEM/EDX) at Treibacher  
147 Industrie-AG for information on the bulk elemental composition of this particular crucible.



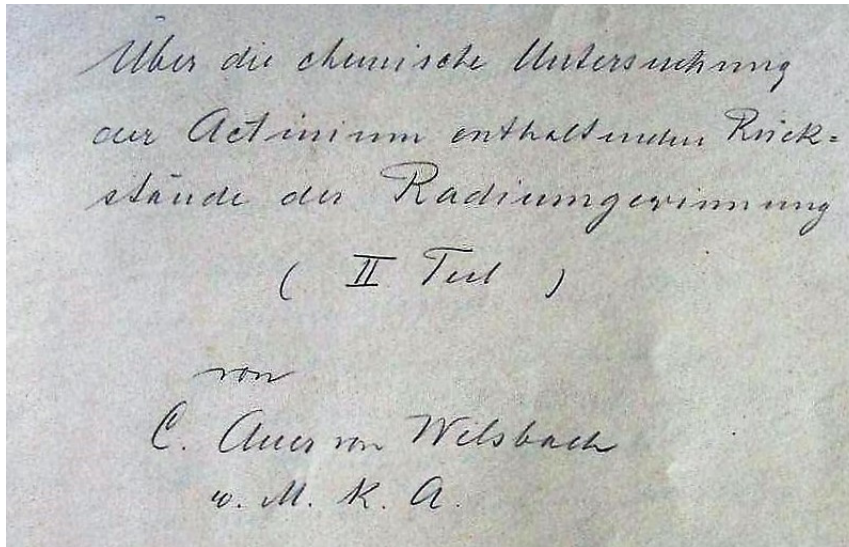
148  
149 **Fig. 4** A platinum crucible for Auer's heritage. It shows very distinct scratches under right illumination (picture on the right).  
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### 152 **Rediscovery of the Seemingly Lost Part II of Auer's Publication**

153 Auer's 1910 publication was published twice; once in Sitzungsberichte der mathematisch-  
154 naturwissenschaftlichen Klasse (Auer von Welsbach 1910a) and once in Mitteilungen der Radium-  
155 Kommission der Kaiserlichen Akademie der Wissenschaften, Chemie-Heft (Auer von Welsbach  
156 1910b). It carries the name "Über die chemische Untersuchung der Actinium enthaltenden  
157 Rückstände der Radiumgewinnung (I. Teil)" [On the chemical investigation of the actinium-  
158 containing residues of the production of radium (Part I)]. The second part was never published. Until  
159 recently, there was no indication of the existence of a draft of this second part. Finally, we can report  
160 that a hand-written and rather rough draft of the second part was rediscovered in the archive of the  
161 Auer von Welsbach-Museum in Althofen (Fig. 5).  
162



163

164 **Fig. 5** Title page of the hand-written draft of the manuscript entitled “Über die chemische Untersuchung der Actinium  
165 enthaltenden Rückstände der Radiumgewinnung (II. Teil)” von C. Auer von Welsbach w.M.K.A. [On the chemical  
166 investigation of the actinium-containing residues of the production of radium (Part II) by C. Auer von Welsbach w.M.K.A.  
167 (full member of the Imperial Academy)]. Apparently Auer von Welsbach had intended submission of the manuscript to the  
168 Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften.

169 On pages 3 and 4 of this manuscript, Auer von Welsbach once again mentions the peculiar  
170 observation:

171

172 “Da ich bei der ersten Reindarstellung der Th(Jo)salze aus Roh-Th(Jo)oxalat nach dem Ammoniumoxalat u.  
173 Ammoniumnitratverfahren auf sehr merkwürdige Erscheinungen gestoßen bin, deren quantitative Erforschung nicht in  
174 mein Arbeitsgebiet fällt, so unterließ ich diesmal die Durchführung des im übrigen ganz einfachen und [unreadable]  
175 Trennungsprozesses und übergab das Präparat im ungereinigten Zustande [dem] Institut für Radiumforschung – Wien.

176 Es wurde später, wie ich nicht unerwähnt lassen will, von F. Exner u. E. Haschek spektrographisch geprüft, jedoch, insoweit  
177 das Jo-Spektrum in Betracht kommt, mit völlig negativem Resultat.“

178 [I encountered very peculiar phenomena during the first preparation of pure Th(Jo)-salts from the raw Th(Jo) oxalate using  
179 the ammonium oxalate and ammonium nitrate process. Since quantitative investigation of these phenomena did not fall  
180 into an area of my own expertise, I skipped this separation process now which is, by the way, very simple and [unreadable],  
181 and transferred the substance in its unpurified state to [the] Institut für Radiumforschung – Vienna.

182 I shall mention that the substance was investigated spectroscopically by F. Exner and E. Haschek, but, as far as the Jo-spectrum  
183 is concerned, with an entirely negative result.]

184

185 It is interesting to learn that Auer von Welsbach realized that the analytical methods in his lab did  
186 not suffice to answer the question raised by the mysterious observations he had made. However,  
187 being a chemist at heart, Auer von Welsbach apparently only asked his collaborators at the Institut  
188 für Radiumforschung to check the material for impurities by means of spectroscopic investigations.  
189 He did not suspect a new type of radiation that may be responsible for his observations. It is unlikely  
190 that Exner and Haschek observed anything unusual in the spectroscopic investigations of this raw  
191 material. Their measurements probably revealed the presence of many (stable and unstable)  
192 elements so that even impurities with beryllium would not have raised a “red flag”.

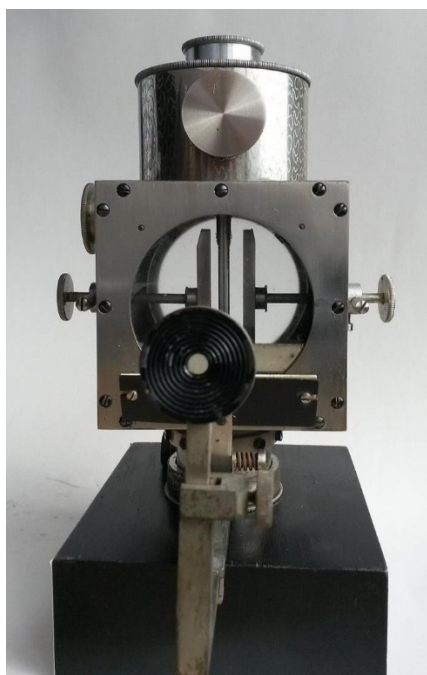
193 As far as we can tell at the very moment, Auer von Welsbach did not further specify the nature of the  
194 peculiar observations in this manuscript of Part II beyond the above statement.

195

196

197 **Auer's Radioanalytical Equipment and Radioactivity Standard**

198 Auer von Welsbach used an electroscope (Fig. 6) as an activity detector. He quantified activity by  
199 comparison to a uranium standard that had a defined activity of "1 Uran-Einheit (Ur.E.)" (uranium-  
200 unit). It is obvious that this standard was frequently used at the beginning of the 20<sup>th</sup> century, because  
201 Auer von Welsbach does not specify the composition and the specifics of this standard. Today this  
202 unit is no longer used. Stefan Meyer and Egon Schweidler (Meyer and Schweidler 1927), however,  
203 describe this uranium standard in great detail. According to them, the uranium-unit goes back to  
204 Henri Becquerel who had defined the activity of 1 g metallic uranium as 1 uranium-unit. However,  
205 since pure uranium metal is difficult to produce, to characterize and to maintain (as it oxidizes fairly  
206 quickly), later modifications of the uranium-unit replaced the metallic uranium by uranium oxides  
207 ( $\text{UO}_3$ ,  $\text{UO}_2$  or  $\text{U}_3\text{O}_8$ ), after thorough removal of the radioactive progeny of the  $^{235}\text{U}$  and  $^{238}\text{U}$  decay  
208 chains. This was a reasonable modification, especially because in the early days of radioactivity  
209 research, mainly  $\alpha$ -radiation was used for many experiments and a solid block or cylinder of metallic  
210 uranium would shield most of its own  $\alpha$ -rays. Instead, 15-20 mg of fine  $\text{U}_3\text{O}_8$  powder were suspended  
211 in ethanol or chloroform and applied to a metal plate to cover an area of  $1\text{ cm}^2$  (or more) upon drying  
212 of the organic solvent. Auer's uranium standard (as shown in the right top of Figure 7), encompassed  
213 an area of  $3\text{ cm}^2$  (note: " $3\text{ cm}^2$ ").



214  
215 **Fig. 6** The electroscope Auer von Welsbach used for activity measurements.

216 Auer von Welsbach used a uranium-unit based on  $\text{U}_3\text{O}_8$ . He defined activities via the discharge time  
217 of the plates of his electroscope. The definition of his activity units are shown in Figure 7 and  
218 summarized in English in Table 1. Natural uranium is constituted by three uranium isotopes:  $^{238}\text{U}$ ,  
219  $^{235}\text{U}$  (both mothers of their decay chain), and  $^{234}\text{U}$  (daughter nuclide of the  $^{238}\text{U}$  decay chain) with a  
220 natural abundance of 99.2742%, 0.7204%, and 0.0054%, respectively. All three uranium isotopes are  
221 virtually pure  $\alpha$ -emitters, however three  $\beta^-$  daughter nuclides will grow quickly into secular  
222 radioactive equilibrium:  $^{234}\text{Th}$  ( $T_{1/2} = 24.1\text{ d}$ ),  $^{234}\text{Pa}$  ( $T_{1/2} = 6.7\text{ h}$ ), and  $^{231}\text{Th}$  ( $T_{1/2} = 25.5\text{ h}$ ). Even a  
223 thoroughly purified uranium sample will therefore also emit  $\beta^-$  particles of various energies within a  
224 time range of a couple of months. The ingrowth of further progeny will be hampered by longer-lived  
225 daughter nuclides down the decay chain, which will prevent a purified uranium sample to reach  
226 anything close to equilibrium of the entire chains within a human life-span and beyond. Based on the  
227 information provided by Meyer and Schweidler [1927], we can assume that Auer's  $3\text{ cm}^2$  uranium



228 standard consisted of 60 mg U<sub>3</sub>O<sub>3</sub> with all non-uranium progeny fully removed (see our estimate of  
 229 the activities of Auer’s reports converted to SI-allowed units in Table 1).

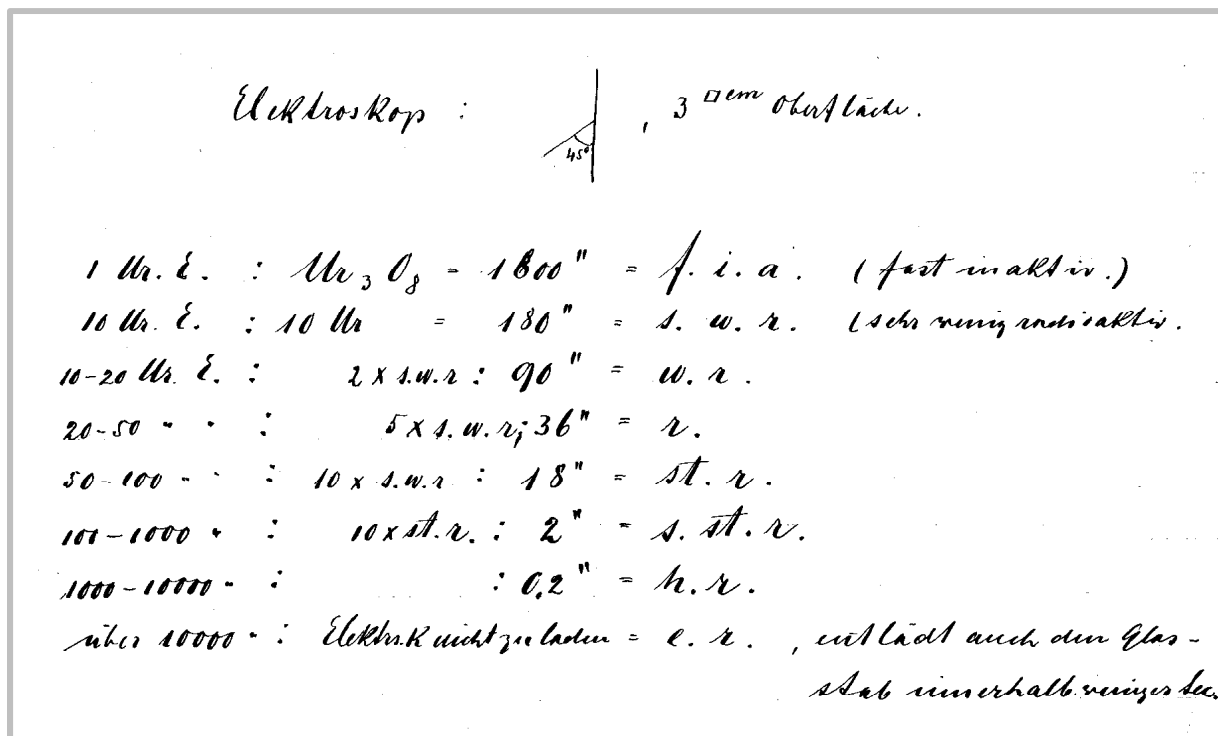
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231 **Table 1:** Auer’s definition of radioactivity units and estimated conversion to SI-allowed units.

| Uranium-Units (Ur.E.) | Time to discharge the electroscope (s)                                     | Symbol  | Characterization                                  | Estimation of the activity in SI-allowed units                                      |
|-----------------------|--|---------|---|---|
| 1 Ur.E.               | 1800   | f.i.a.  | almost inactive (fast inaktiv)                    | ca. 2.6 kBq (1300 α particles per second; 1300 β <sup>-</sup> particles per second) |
| 10 Ur.E.              | 180  | s.w.r.  | very little radioactive (sehr wenig radioaktiv)   | 26 kBq  |
| 10-20 Ur.E.           | 90   | w.r.    | little radioactive (wenig radioaktiv)             | 26 – 52 kBq   |
| 20-50 Ur.E.           | 36   | r.      | radioactive (radioaktiv)                          | 52 – 130 kBq  |
| 50-100 Ur.E.          | 18   | st.r    | strongly radioactive (stark radioaktiv)           | 130 – 260 kBq   |
| 100-1000 Ur.E.        | 2  | s.st.r. | very strongly radioactive (sehr stark radioaktiv) | 260 – 2.6 MBq   |
| 1000-10,000 Ur.E.     | 0.2  | h.r.    | highly radioactive (hochradioaktiv)               | 2.6 MBq – 26 MBq  |
| > 10,000 Ur.E.        | electroscope cannot be charged and discharges the glass rod within seconds | e.r.    | enormously radioactive (enorm radioaktiv)         | > 26 MBq  |

232

233 It is interesting to note how the perception of radioactivity changed throughout the decades since  
 234 Auer’s time based on the improvement of radioanalytical techniques. Naturally, Auer’s electroscope  
 235 was a rather primitive analytical device compared to modern radiation detectors. Nevertheless, Auer  
 236 von Welsbach described an activity of 2600 Bq as “almost inactive”, which is actually a rather  
 237 considerable activity by today’s standards. For a better illustration, this activity is higher by a factor  
 238 of 26 than the regulatory limit for radiocesium in normal food (100 Bq/kg) after the Fukushima  
 239 nuclear accident (Merz, Shozugawa, and Steinhauser 2015).



240

241 Fig. 7 Auer's chart of definitions of activities

242

243 **Theoretical Considerations of the Activation of the Platinum Crucible**

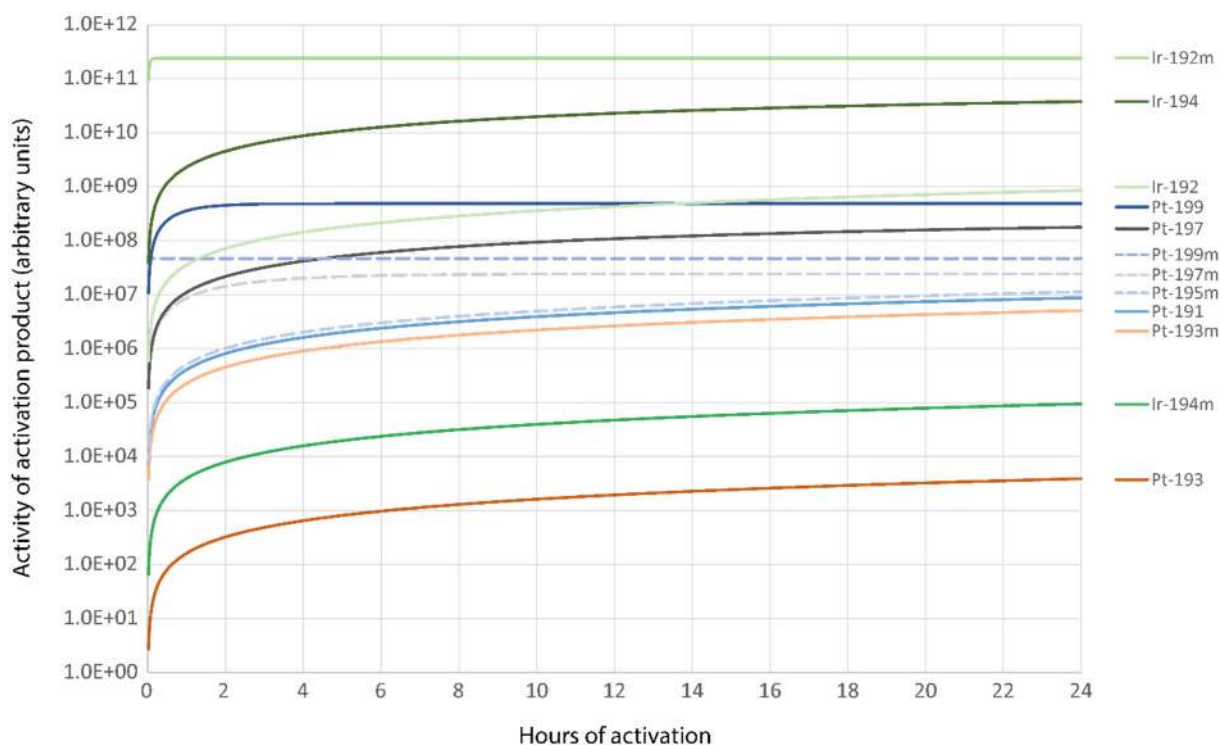
244 Auer's observation was clearly described for a platinum crucible. Therefore, our interest focuses on  
 245 trying to identify the platinum crucible that showed signs of activation. We regard this object as key  
 246 to possibly solving the forensic question whether or not Auer von Welsbach had incidentally  
 247 discovered neutron activation in 1910. For many years, it has been believed that any platinum  
 248 crucibles and other platinum objects from Auer's private property had been donated/confiscated in  
 249 the course of noble metal collections of World War I in order to support the war efforts of the  
 250 Austrian-Hungarian Monarchy. However, recently, we have been in contact with inheritors of several  
 251 platinum objects from Auer's collection which somehow could be saved from the confiscation or  
 252 which were purchased after the war.

253 Given the assumption that Auer von Welsbach really had observed neutron activation processes back  
 254 in 1910, what was the dominating radionuclide after the "long-lasting" contact with the hypothetical  
 255 neutron source? Platinum consists of several stable or quasi-stable nuclides (mass numbers 190, 192,  
 256 194, 195, 196, and 198) that all show some significant drawbacks for the "neutron activation"  
 257 hypothesis. Most of these (quasi)stable nuclides have relatively low cross sections (i.e. a low affinity)  
 258 for significant neutron capture of a presumably low-intensity neutron source; or they yield less  
 259 suitable activation products. It can be assumed that the activation product generated by neutron  
 260 capture should have had a half-life of at least a couple of hours to remain detectable throughout  
 261 Auer's cleaning procedures in which it proves to be "difficult" to remove. The half-life of the  
 262 activation product, however, should not be too long either, in order to yield high specific activities.  
 263 Lastly, in order to be detectable for Auer's electroscope, the activation product should be a  $\beta$ -emitter  
 264 (and not just a photon emitter which causes much less ionization events in air). It shows that no  
 265 platinum nuclide or activation product of platinum is a promising candidate under these  
 266 prerequisites.

267 literature, however, teaches us that “platinum crucibles” at the end of the 19<sup>th</sup> century were  
 268 preferably made of alloys of platinum and iridium, with iridium contents up to 30% (Meyers  
 269 *Konversations-Lexikon* 1877, Ullmann 1930a). In contrast to platinum, iridium is easily activated. For  
 270 the following scenario, therefore, we will assume an iridium content of the crucible of 30%.

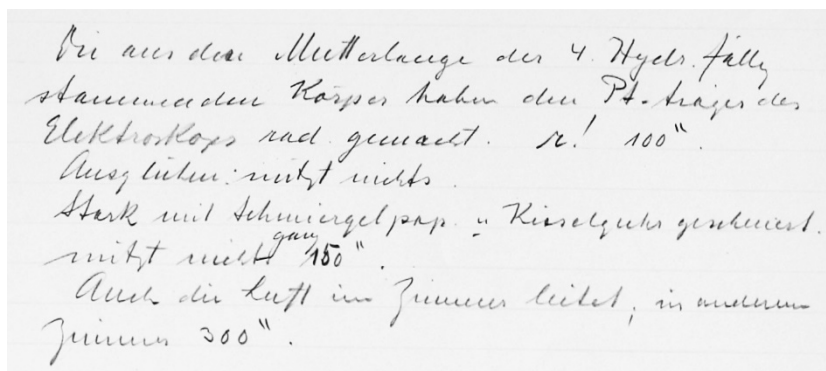
271 A comparison of the activities of every possible neutron activation product (see Fig. 8) of a  
 272 hypothetical platinum crucible with an iridium content of 30 wt.% shows that iridium-194 is the most  
 273 promising candidate for Auer’s observation. It is reasonably long-lived ( $T_{1/2} = 19.15$  hours) and a  
 274 powerful beta emitter. Although it yields even higher activities, iridium-192m is too short-lived to be  
 275 a good candidate ( $T_{1/2} = 1.4$  min). Iridium-194 is activated 100 times more readily than the most  
 276 promising activation product of platinum ( $^{197}\text{Pt}$  with  $T_{1/2} = 18.3$  hours). Generally, the most  
 277 “prominent” activation product of iridium is  $^{192}\text{Ir}$ . The target nuclide  $^{191}\text{Ir}$  has a much higher (by  
 278 approx. a factor of 10) cross section for neutron capture than the respective target nuclide  $^{193}\text{Ir}$  in the  
 279 nuclear reaction  $^{193}\text{Ir}(n,\gamma)^{194}\text{Ir}$ . In this nuclear reaction, stable iridium-193 captures a neutron and yields  
 280 radioactive iridium-194 under emission of a prompt gamma photon. However,  $^{192}\text{Ir}$  has a much longer  
 281 half-life, so it takes much longer to reach saturation upon irradiation with a neutron source.

282 With respect to exposure duration, we do not know what Auer von Welsbach termed as “long-lasting  
 283 contact”. Therefore, we have chosen a duration of activation of 24 hours on an arbitrary basis. It is  
 284 possible, if not likely, that Auer von Welsbach exposed the platinum crucible for more than 24 hours  
 285 to the radiation of his jonium sample, but we wanted to keep our approach rather conservative.  
 286 However, we calculated that it would take a staggering number of 131 days for the constantly  
 287 increasing activity of  $^{192}\text{Ir}$  to finally exceed the activity of  $^{194}\text{Ir}$ . Since Auer von Welsbach was a very  
 288 productive, almost restless character, it seems very unlikely that he “forgot” about the jonium for  
 289 more than four months before he continued with his separation work.



290  
 291 **Fig. 8** Relative neutron activatability of the constituents of a Pt-Ir alloy with the composition of 70% Pt and 30% Ir in a 24 h  
 292 activation cycle. For this model, we used thermal neutron energy cross sections, which is the simplest approach. Pure  
 293 photon emitters are shown in dashed lines.

294 The very high  $\beta^-$  energy of iridium-194 ( $E_{\beta, \text{max}} = 2.2 \text{ MeV}$ ) is another striking argument in favor of the  
295 "iridium hypothesis" since Auer von Welsbach writes a note in his lab journal (see Fig. 9):



[The bodies that originate from the 4th hydr[ate] precipitation have made the Pt carrier of the electroscopes radioactive. r! 100''  
Glowing out does not help.  
Heavily rubbed with sandpaper and diatomite: does not help (unreadable) 150''.  
Also the air in the room becomes conductive; in the other room 300''.]

307  
308 **Fig. 9** Note taken from Auer's lab journal "Notizen über die radioaktiven Arbeiten", dated 26 XI 1913 (three years after the  
309 1910 publication)

310  
311 It is not entirely clear what Auer von Welsbach described as "Pt carrier" in Fig. 9. In any case, only  
312 powerful, highly energetic  $\beta^-$  rays of more than 1 MeV have a range of several meters that would  
313 allow the observation of air becoming conductive in the entire room and also the adjacent room. This  
314 is another powerful argument why  $^{194}\text{Ir}$  is the more likely activation product than the more prominent  
315  $^{192}\text{Ir}$ . The statement of "heavy scrubbing" and the use of sandpaper triggered the hypothesis that the  
316 crucible with the scratches from Fig. 4 may be identical with the platinum carrier Auer von Welsbach  
317 described in this lab note. Therefore we focused our investigation on this object.

318 Auer von Welsbach noted that the platinum crucible remained "r." (radioactive). According to his  
319 uranium standard-based definition (Fig. 7), "r." would correspond to an activity of his uranium  
320 standard of approximately 52-130 kBq (see Table 1). From this value we can roughly estimate the  
321 activity of the crucible and the neutron flux density of the neutron source that would have been  
322 necessary to activate the platinum/iridium crucible to reach a matching iridium-194 activity. The  
323 various types of radiation emitted by the uranium standard are not equally capable of ionizing  
324 surrounding air. Assuming an average energy loss of 34 eV per ion pair formed in air, the  $\alpha$ -radiation  
325 emitted from Auer's purified uranium standard will contribute 10 times more to the ionization of air  
326 than the  $\beta^-$  rays emitted from the standard. A sample with the classification "r." will produce  
327 approximately  $10^{10}$  ion pairs per second in air. In order to reach the same ionization of air, an activity  
328 of  $5 \cdot 10^5 \text{ Bq } ^{194}\text{Ir}$  would be needed.

329 Several assumptions have to be made to estimate the neutron flux density of Auer's neutron source  
330 to reach an activity of  $^{194}\text{Ir}$  of  $5 \cdot 10^5 \text{ Bq}$ . In order to keep this estimate simple, we will assume a thermal  
331 neutron energy, negligible neutron self-absorption, negligible contribution to the ionization of air  
332 through  $\gamma$ -radiation, and negligible geometric effects affecting the activation process. We further  
333 assume that the "long-lasting contact" lasted for 24 hours and that half of the crucible was exposed  
334 to neutrons whereas the other half remained unirradiated. With all these assumptions, the neutron  
335 flux density needed to cause an activity of 500 kBq of  $^{194}\text{Ir}$  would be about  $8 \cdot 10^4 \text{ cm}^{-2}\text{s}^{-1}$ . The question  
336 of neutron energy remains a big challenge. Neutrons produced from the  $^9\text{Be}(n,\alpha)^{12}\text{C}$  reaction are fast  
337 (Q-value 5.7 MeV). Fast neutrons have significantly lower cross sections for neutron capture in most  
338 materials. In order to cause significant irradiation, they need to be thermalized first. We have no idea  
339 what a possible moderator could have been. Auer von Welsbach mentioned that he measured the

340 activities of two bodies, the platinum crucible on the one hand and “solution” on the other. If the  
341 crucible was filled with water or any form of aqueous medium, this would probably have shielded  
342 the  $\alpha$ -rays before they could have reacted with the beryllium nuclei.

### 343 **Alternative Explanations of Auer’s Observation**

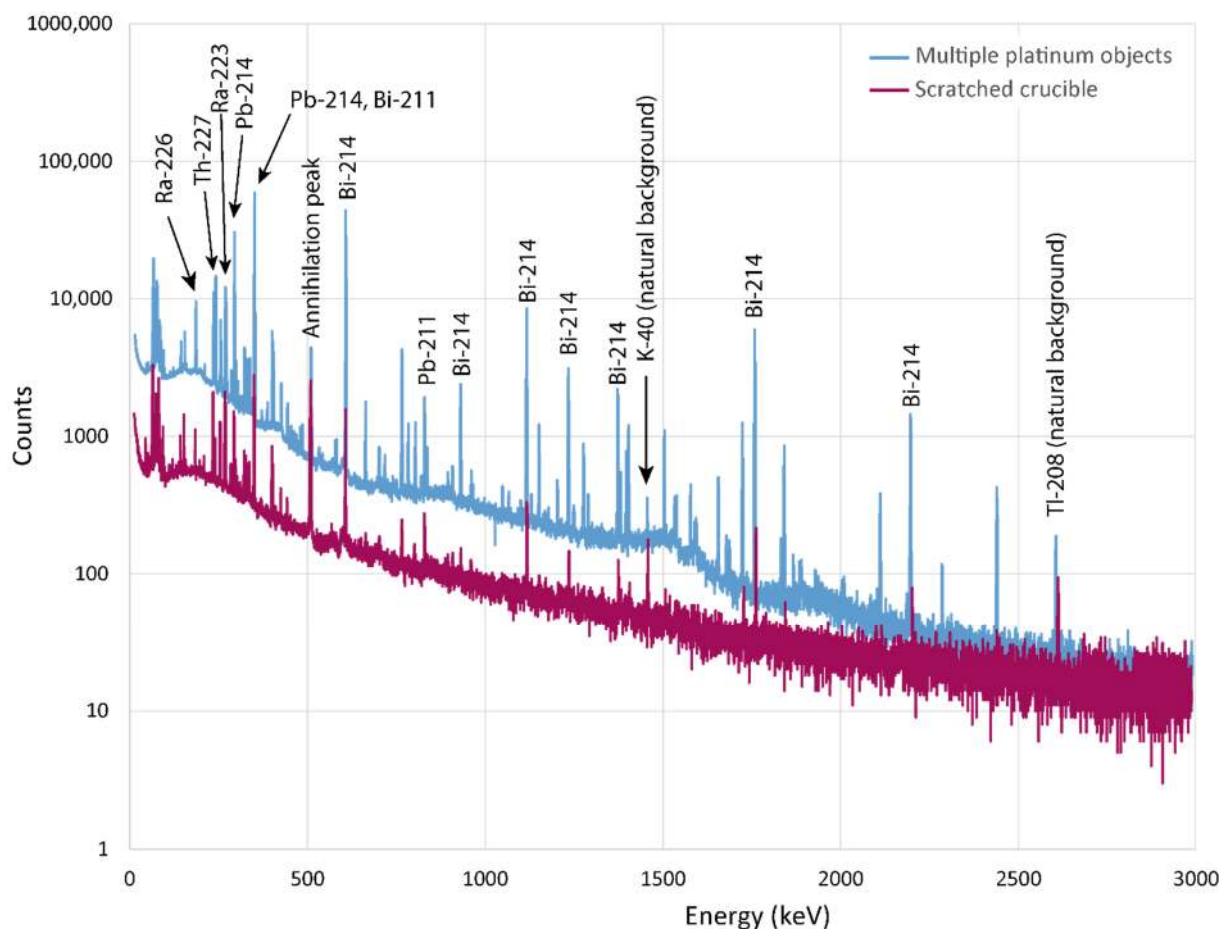
344 Neutron activation is only one of several possible explanations for Auer’s description of the unusual  
345 phenomena. The other, probably more obvious explanation, would have been a contamination of  
346 the crucible with radioactive substances on its surface. Auer von Welsbach was well aware of this  
347 simple explanation to the “mysterious” observation. As shown before, Auer von Welsbach tried  
348 everything to remove contaminations from the surface of the crucible. Generally, platinum surfaces  
349 are easy to clean as they are chemically inert and can be treated with harsh chemicals without being  
350 attacked. We have learned that Auer von Welsbach tried “heavy scrubbing” and “glowing” of the  
351 crucible, but it is likely that he had tried several other methods (probably boiling with acids etc.) to  
352 remove any contaminants from the surface. Being a brilliant and experienced chemist, we can safely  
353 assume that Auer von Welsbach would probably have succeeded in removing the contaminants or  
354 at least reducing their amounts significantly. None of this seemed to be the case.

355 Another theory that needs to be considered, therefore, is the implantation of radioactive recoil nuclei  
356 into the crucible matrix. For example, it may be possible that the  $^{222}\text{Rn}$ -emanation of radium-226 on  
357 the surface of the platinum crucible may have caused the implantation of  $^{218}\text{Po}$  into the  
358 platinum/iridium matrix upon  $\alpha$ -decay, from where it would be difficult or even impossible to  
359 remove. However, this hypothesis is limited primarily by half-lives of polonium-218 and its progeny.  
360 Polonium-218 has a half-life of 3.05 min; lead-214 (26.8 min) and bismuth-214 (19.9 min) are only  
361 marginally longer-lived. If this was the sole cause for the peculiar phenomena, physical decay would  
362 probably have pretended to Auer von Welsbach that his laborious and time-consuming efforts to  
363 remove the alleged contamination (by washing, scrubbing, glowing to red heat etc.) would have been  
364 effective. The next radionuclide in the decay chain, lead-210, is much longer-lived ( $T_{1/2} = 22.3 \text{ a}$ ), but  
365 emits  $\beta^-$  particles with a very low energy. This radionuclide would barely have caused significant  
366 ionization of the air in order to be detectable by Auer’s electroscope, especially not in the “adjacent  
367 room.” This certainly had to be a very powerful beta emitter, which is another strong argument in  
368 favor of the “neutron activation hypothesis.”

369

### 370 **Results of the Experimental Investigation of the Platinum Crucibles**

371 Two gamma-ray measurements were done: (1) a measurement of multiple platinum objects placed  
372 on top of the gamma detector and (2) a separate measurement of the scratched platinum crucible  
373 that was thought to be of particular interest (because the scratches may have resulted from  
374 decontamination attempts as described by Auer von Welsbach). Gamma-ray spectrometry revealed  
375 presence of elevated levels of natural radionuclides in both measurements of platinum objects.  
376 Interestingly, in both cases, the platinum objects showed minute contaminations of daughters of  
377  $^{227}\text{Ac}$  ( $T_{1/2} = 21.8 \text{ years}$ ; member of the  $^{235}\text{U}$  decay chain) and  $^{226}\text{Ra}$  ( $T_{1/2} = 1600 \text{ years}$ ; member of the  
378  $^{238}\text{U}$  decay chain) and its radioactive progeny, but no traces of their mother(s), including the  $\gamma$ -  
379 emitting nuclides  $^{231}\text{Pa}$  and  $^{234\text{m}+\text{g}}\text{Pa}$ , respectively. All  $\gamma$ -emitting daughter nuclides of these nuclides  
380 ( $^{227}\text{Ac}$  and  $^{226}\text{Ra}$ ) could be detected in amounts that suggests the presence of the radioactive progeny  
381 in equilibrium with their mother nuclides (see Fig. 10). This includes  $^{227\text{Th}}$ ,  $^{223}\text{Ra}$ ,  $^{211}\text{Pb}$  and  $^{211}\text{Bi}$  as the  
382 daughters of  $^{227}\text{Ac}$  as well as  $^{214}\text{Pb}$  and  $^{214}\text{Bi}$  as the daughters of  $^{226}\text{Ra}$  (the gamma peak of  $^{226}\text{Ra}$  itself  
383 can also be seen in the spectrum, see Fig. 10).



385

386

387 **Fig. 10** Gamma spectra of several platinum objects (combined for the measurement) (blue) and the scratched crucible  
 388 (purple). The most important/relevant peaks were labeled.

389

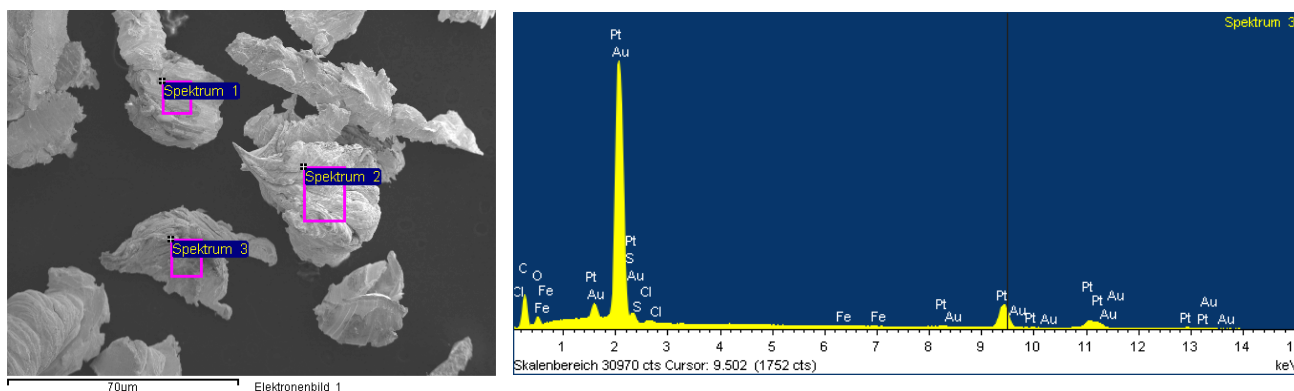
390 Quantification of the contamination could not be performed because the distribution of the  
 391 radionuclides on the surface of the platinum objects could not be determined. Hence the  
 392 measurement took place with unknown geometry. Also, for historical reasons, we decided not to  
 393 remove the contamination as it also has historical value. In any case, the activities were well in the  
 394 sub-becquerel range. This explains why Auer von Welsbach did not spot them using his electroscope  
 395 that naturally lacked the necessary sensitivity.

396 Interesting insight can be derived from the ratio of radionuclides. We observed that the  
 397 measurement with the multiple platinum objects (1) revealed higher activities of radium-226 and its  
 398 progeny compared with actinium-227 and its progeny. The scratched crucible (2), however, had a  
 399 higher activity of the actinium-227-decay-chain compared with radium-226 and its decay products  
 400 (see Fig. 10). At this point it should be noted that more than 5 half-lives of actinium-227 have passed  
 401 since 1910, so this fraction was more than 30 times higher when Auer von Welsbach had worked  
 402 with the objects. However, is not it remarkable that Auer von Welsbach isolated significant activities  
 403 of radium-226 from that residues of the radium-production? The materials were significantly  
 404 depleted in radium, but Auer von Welsbach isolated even visible amounts of radium as discussed in  
 405 (Steinhauser, Löffler, and Adunka 2013).

406 This results clearly shows that Auer von Welsbach used these platinum crucibles in the work-up of  
407 the “hydrates”, and also that they were contaminated in a least two independent steps, because in  
408 the separation actinium and radium performed in different steps. The contamination also is a clear  
409 indication that these crucibles were used at a time when Auer von Welsbach dedicated most of his  
410 time to radioactivity research, which was the time before the First World War (the lab journal “Über  
411 die radioaktiven Arbeiten” [On the radioactive works] does not include any entries dated later than  
412 1913). Therefore it appears likely that these platinum objects were saved from the noble metal  
413 collections of World War I and rather not purchased after 1918.

414 No activities of possible (both  $\gamma$ -emitting and sufficiently long-lived) activation products were found  
415 in any of the measurements.

416 The question whether or not the scratched crucible was the one of Auer’s 1910 observation remained  
417 open. Since we believe that neutron activated iridium was the main culprit of the mysterious  
418 observation, we asked the owner of the scratched crucible for permission to investigate the chemical  
419 composition of this crucible. Hence several flakes from the scratched crucible (shown in Fig. 4) were  
420 investigated with SEM/EDX (Fig. 11).



421  
422 **Fig. 11** SEM images of flakes from the scratched crucible (left) and EDX spectrum of these flakes (right).

423  
424 EDX analysis revealed that the matrix of the crucible does not contain any macroscopic amounts of  
425 iridium. The detection limit in this case is about 0.2 wt.%. In addition to platinum (which is, of course,  
426 is the dominating constituent), traces of gold and carbon (probably stemming from soot of the  
427 burners used and which is known to aggressively corrode platinum (Mylius and Hüttner 1916,  
428 Ullmann 1930b)). In some flakes also cerium was found. Presence of lanthanides such as cerium can  
429 easily be explained by the intensive work of Auer von Welsbach in rare earth element chemistry.  
430 Unfortunately, the lack of iridium makes it rather unlikely this particular crucible was the one that  
431 showed signs of neutron activation. If it really was neutron activation of platinum/iridium, we have  
432 not found yet the right crucible. We will continue our search for platinum crucibles and hope for  
433 permission of the owners to investigate the objects further with respect to their chemical  
434 composition.

435  
436 **Possible Implications of Auer’s Observation**

437 The discovery of the neutron is not “just another milestone” in physics and our view of nature on an  
438 atomic and subatomic level. The discovery of the neutron marks the starting point of nuclear  
439 technology and the nuclear age. After Irène and Frederic Joliot-Curie had discovered artificial  
440 radioactivity by bombarding aluminum with alpha particles in December 1933 (Joliot and Curie 1934),

441 Enrico Fermi realized that neutrons would be even better suited to yield artificial radionuclides as  
442 the neutrons would not have to overcome the Coulomb barrier before being captured by the target  
443 nucleus. Within one year, Fermi had tested numerous elements and their activation products upon  
444 neutron bombardment (Fermi 1934). In total he tested more than 60 elements and characterized  
445 their neutron activation induced radioactivity. In most cases, neutron activation yields an activation  
446 product that exhibits the characteristics of a beta-minus emitter. These nuclides are characterized by  
447 neutron excess in their nuclei. In the course of beta-minus decay, a neutron is transformed into a  
448 proton, hence yielding the element with the next-higher atomic number. This offered a completely  
449 new perspective on the known and unknown elements. The story says that Fermi gave his assistant,  
450 later Nobel laureate Emilio Segrè a 1000 dollars with the order “Get the whole Mendeleev table”  
451 (Kubešová 2016). Thanks to the neutron, science suddenly had a tool to explore unknown regions of  
452 the periodic table. Therefore it was no surprise that scientists also wanted to explore a completely  
453 unknown terrain: the production of elements heavier than uranium which was the heaviest known  
454 element back then. Since irradiation of uranium with neutrons not only induces activation processes  
455 but also fission processes, it was only a matter of only a few years until nuclear fission was (or virtually  
456 rather “had to be”) discovered. In fact, induced fission of uranium was discovered only six years after  
457 the neutron in December 1938 (Hahn and Strassmann 1938, 1939, 2016, Steinhauser 2016).

458 History of science is generally rather reluctant to make “what - if” assumptions. Speculations about  
459 possible implications of an earlier discovery of the neutron are hence difficult to make. Nonetheless,  
460 it is obvious that especially the military application of nuclear power and the nuclear arms race was  
461 only possible because essential discoveries were made only months before World War II or during  
462 the war. All the important milestones towards the atomic bomb happened within a very short time  
463 span. In particular, this includes the discovery of nuclear fission (Hahn and Strassmann 1938), a  
464 deeper understanding of the energy budget involved in a fission cycle (Meitner and Frisch 1939), the  
465 confirmation of the possibility of a nuclear chain reaction (Anderson, Fermi, and Szilard 1939), the  
466 discovery of plutonium by Glenn T. Seaborg, Joseph W. Kennedy, Edwin M. McMillan, and Arthur  
467 Wahl in December 1940, the launch of the Manhattan project in 1942 (triggered by Albert Einstein’s  
468 letter to President Franklin D. Roosevelt on August 2, 1939) and lastly the production of nuclear war  
469 heads that would be tested in New Mexico and deployed over Japan in 1945. This impressive chain  
470 of discoveries was triggered by Chadwick’s discovery of the neutron in 1932. Hence there is reason  
471 to believe that an earlier discovery of the neutron is likely to have triggered some of these discoveries  
472 at an earlier stage that would have allowed other nations and military powers to scrutinize the  
473 applicability of nuclear power for military purposes. We do not know exactly how – but the world  
474 and the warfare of World War II would probably have evolved differently if not only the United States  
475 had been in possession of this extremely powerful new weapon type at the time of World War II.

476 Whether or not Auer’s observation has been the first observation of neutron activation, why did not  
477 anybody uncover the solution to the mystery? Auer von Welsbach certainly felt that there was  
478 something unusual going on with the ionium sample in his experiment. Unfortunately, however, he  
479 apparently did not feel qualified to further scrutinize this mysterious observation by himself. From  
480 Part II of his publication, we have learned that he suspected rather a chemical anomaly than a new  
481 type of radiation. He submitted it to Vienna for further spectroscopic investigations, which did not  
482 reveal any unusual composition. Even if beryllium was found in the sample, it would probably not  
483 have been a sufficiently unusual observation to have rung any alarm bells. So we learn that Auer von  
484 Welsbach did ask colleagues of his time for help, but none of them (including Auer von Welsbach)  
485 put enough effort into this question to finally solve it. It is also probably due to the largely lacking  
486 echo within the scientific community that Auer von Welsbach eventually let this issue rest. We only  
487 know of one comment from the scientific community in response to the short note of Fig. 2. The



488 German chemist Bruno Keetman sent a letter to Auer von Welsbach, congratulating him on this  
489 spectacular result. Unfortunately this letter was lost in the second half of the 20<sup>th</sup> century. Keetman  
490 had earned his doctoral degree in 1909 in Berlin for the retrieval of ionium from uranium ores. Later  
491 he took the lead of the Laboratory of Radioactivity of the Auer-Gesellschaft in Berlin. It seems he was  
492 naturally intrigued by the observation of Auer von Welsbach involving ionium. In any case, Keetman  
493 died on April 13, 1918 at the age of 34, which explains why this trace was lost, too (Wichelbaus 1918).

494 A deeper discussion within the scientific community or a wider dissemination of the reported  
495 observation, however, may not have been the sole key to solving the mystery because the  
496 composition of Auer's crude ionium oxalate would have been difficult to repeat by others; especially  
497 keeping in mind that beryllium impurities would have been the key constituent of such mixture.  
498 Therefore one would have had to investigate the original ionium substance produced by Auer von  
499 Welsbach himself which might have been difficult. Auer von Welsbach was a deeply generous person  
500 and scientist who worked for the advancement of science, who shared his knowledge with everyone  
501 who asked for his advice, and who donated more than 500 samples of precious, purified substances  
502 to other researchers. Nonetheless, he was not what one would regard as a "team player" in modern  
503 scientific terms. For his own research, Auer von Welsbach accepted little assistance by others. He  
504 even preferred to wash his laboratory glassware manually by himself rather than letting anybody  
505 assist him with such back-work. For a deeper understanding of Auer's character, we must understand  
506 that he was deeply traumatized in the course of the discovery of the elements 70 and 71 in the year  
507 1907. Although Auer von Welsbach is generally believed to have been the first who isolated these  
508 elements in pure form (Kragh 1996), a fierce controversy between Auer von Welsbach and Georges  
509 Urbain about the priority of this discovery had erupted, which he finally lost. After such bad  
510 experience, Auer von Welsbach was probably even less likely to share a sample of his substance  
511 (which he truly believed to be of importance for the further investigation of the field of radioactivity)  
512 with others outside the Austrian "radium circle", before having had the possibility of claiming his own  
513 full priority of the discovery. Therefore, it rather appears unlikely that he would have given this  
514 mystery completely out of his own hands and let somebody else than his closest colleagues study the  
515 mysterious ionium sample.

516

## 517 **Conclusions and Summary**

518 Although our recent investigations have not been sufficient to fully answer the question whether or  
519 not Auer von Welsbach really observed neutron activation processes back in 1910, we still believe  
520 that neutron activation is the most likely explanation for the "peculiar observation" Auer von  
521 Welsbach described in his 1910 publications (Auer von Welsbach 1910b, a). Above we have described  
522 some major new steps that can be summarized as follows:

- 523 • We have discovered a hand-written manuscript of Part II of the key publication. It is a rather rough  
524 hand-written draft, on which Auer von Welsbach shortly mentions the "peculiar observations" and  
525 how he did not feel qualified to investigate the phenomenon further. He states that he transferred a  
526 second fraction of raw thorium/ionium oxalate to F. Exner and E. Haschek at the Institut für  
527 Radiumforschung in Vienna. Auer von Welsbach reported that they could not report any insightful  
528 result from their investigation. It seems that they rather analyzed the chemical composition of the  
529 sample with spectroscopical methods, but there is no indication that they investigated it for a  
530 possible new type of radiation (neutron radiation?).
- 531 • Theoretical considerations revealed that neutron activation remains more likely a plausible scenario  
532 for the peculiar phenomenon than surface contaminations or implantation of recoil nuclei from  
533 radon-222 or other  $\alpha$ -emitters into the metallic matrix of the platinum crucible.

- 534 • We attempted the “translation” of Auer’s activity units (Uran-Einheit, Ur.E.) to modern Si-allowed  
535 units (becquerel). It turned out that what Auer defined as “almost inactive” was in fact an activity as  
536 high as 2600 becquerels.
- 537 • We identified iridium as a possibly very important constituent of the crucible material which Auer  
538 von Welsbach terms “platinum crucible”. Presence of iridium in the crucible would increase the  
539 likelihood to observe neutron activation processes by a factor of 100 compared with pure platinum.  
540 It is the much higher cross sections of the stable iridium nuclides, the suitable half-life of the  
541 activation product iridium-194 and its very high  $\beta^-$ -energy which make iridium a much more  
542 promising candidate than platinum.
- 543 • In order to make iridium-194 appear “r.” (“radioactive”, according to Auer’s definition), it would have  
544 had to have an activity of  $\sim 500$  kBq.
- 545 • Based on the assumption that Auer’s crucible contained some 30% iridium, we estimated the neutron  
546 flux density that was necessary to sufficiently activate the object to roughly  $8 \cdot 10^4 \text{ cm}^{-2}\text{s}^{-1}$ . This is a  
547 rather high neutron flux density for a “coincidental”, not designed neutron source.
- 548 • Gamma spectrometry of the platinum crucibles investigated in this study reveals that Auer succeeded  
549 repeatedly in separating actinium-227 and radium-226 from the “hydrates”. This is even more  
550 remarkable as the hydrates were already depleted in radium as they constitute the *residues* of the  
551 radium production. The fact that the platinum crucibles were contaminated with actinium and  
552 radium allows the conclusion that Auer von Welsbach saved these platinum objects from the noble  
553 metal collections of the Austrian-Hungarian Monarchy during World War I because most of his  
554 “radioactive works” were conducted before 1914.
- 555 • SEM/EDX analyses revealed that the most promising crucible (the scratched one) did not contain any  
556 iridium. It is therefore questionable (if not unlikely) that this crucible was the one that Auer von  
557 Welsbach noted his peculiar observations with (provided that Auer von Welsbach indeed incidentally  
558 had observed neutron activation processes).

559

560

## 561 **Acknowledgments**

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563 von Welsbach-Museum in Althofen and for providing their invaluable objects for investigation.  
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