Pure & Appl. Chem., Vol. 63, No. 6, pp. 879–886, 1991.
Printed in Great Britain.

ADONIS 206922209100097I

INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

in conjunction with

INTERNATIONAL UNION OF PURE AND APPLIED PHYSICS

Criteria that must be satisfied for the

DISCOVERY OF A NEW CHEMICAL ELEMENT TO BE RECOGNIZED

being the report on phase (i) of operations of the
TRANSFERMIUM WORKING GROUP OF IUPAC AND IUPAP

Prepared for publication by

A. H. WAPSTRA

Nationaal Instituut voor Kernfysica en Hoge-Energiefysica, POB 41882, 1009 DB Amsterdam, The Netherlands

Membership of the Transfermium Working Group was as follows:

Chairman: D. H. Wilkinson (IUPAP; UK); *Secretaries*: A. H. Wapstra (IUPAP; Netherlands); I. Ulehla (IUPAP; Czechoslovakia); *Members*: R. C. Barber (IUPAP; Canada); N. N. Greenwood (IUPAC; UK); A. Hrynkiewicz (IUPAP; Poland); Y. Jeannin (IUPAC; France); M. Lefort (IUPAP; France); M. Sakai (IUPAP; Japan).

Criteria that must be satisfied for the discovery of a new chemical element to be recognized

PREFACE (by Y. P. Jeannin, President of IUPAC)

The discovery (synthesis) of a new element has become a very complicated matter because it now requires the intricate equipment of nuclear physics and because the number of atoms prepared is often extremely small. The very short half-life of many of the isotopes poses still further problems of experimentation. There has been considerable discussion and some disagreement concerning the discovery of the transfermium elements. Moreover the discoverers are often interested in proposing names for the new elements they have synthesised. In some cases, it turned out that the first claim was later proved to be wrong. In other cases, the claim was well established and carried conviction. There are also examples where the first claim, though later shown to be correct was based on experiments which were themselves not entirely conclusive so that further experiments were needed; clearly in such cases the discovery has to be shared. To clarify this situation a working group called Transfermium Working Group (TWG) was set up. Its members were nominated both by the International Union of Pure and Applied Physics and by the International Union of Pure and Applied Chemistry since both physics and chemistry were involved in establishing the claims to discovery.

The present document is the Report of Phase (i) of the work of the Transfermium Working Group. It refers to the establishment of criteria that must be satisfied for the discovery of a new element to be recognised. The document has been reviewed and discussed by the three main laboratories involved in this difficult work, namely the Berkeley group, the Darmstadt Group and the Dubna Group, and has been accepted and cleared for publication by the two International Unions.

A second document named Report of Phase (ii) is under preparation. It will apply these criteria to the discovery of the transfermium elements and will report the considered conclusions of the Transfermium Working Group concerning the discovery of each of these elements.

I. ORGANIZATIONAL AND GENERAL INTRODUCTION

I.1. The idea that a few elementary substances could, combined in various ways, build up the whole of matter goes back to the Greek philosophers of the sixth century B.C. The earliest form of the atomic "hypothesis", more or less as we know it today, goes back almost as far, to Leucippus in the fifth century B.C. later elaborated by Democritus. The dead hand of Aristotle relaxed its grip only in the 17th century: atomic science began to emerge from the atomic philosophy of Democritus with Robert Boyle's (1661) recognition of chemical elements as "certain primitive and simple bodies ... not being made of any other bodies or of one another". In the late 18th century Antoine-Laurent Lavoisier, defining a chemical element as something that could not be decomposed by chemical means into simpler substances, recognized about thirty of what we now know to be elements in the modern sense but also included a few particularly stable chemical compounds that resisted attempts to break down. John Dalton, in 1808, introduced the idea of atomic weight as a useful characterization of a chemical element, and chemists began to seek relationships between elements on the basis of such weights. The great step was taken by Dmitri Mendeleev in 1869 who recognized that the chemical properties of the elements (of which he knew about 65) were periodic in their atomic weights; this permitted him to construct his periodic table and to make the dramatic prediction of the existence of then-undiscovered elements, notably eka-boron (scandium), eka-aluminium (gallium), and eka-silicon (germanium). With the discovery of isotopes by J.J.Thomson in 1912 following their inference by Frederik Soddy in 1910, and with the discovery of characteristic X-rays by H.G.J.Moseley in 1913, atomic charge or atomic number replaced atomic weight as the chief determining character of an element.

The centuries-old history of the definition and discovery of chemical elements has a deep scientific and general fascination. This is because the problem is of an essentially finite scope: there can only be a limited number of species of atomic nuclei containing different numbers of protons that can be imagined to have an existence, though perhaps only fleeting, in the chemical sense. But although the problem is of finite scope, we do not know what the scope is: we do not as yet know how many elements await discovery before the disruptive Coulomb force finally overcomes the nuclear attraction. In this sense, the problem is open although of finite scope, unlike the number of continents upon the surface of the earth where we know with certainty that none still awaits discovery. These considerations give to the discovery of new elements an importance, an allure and a romance that does not attach to the discovery of, say, a new comet or a new beetle where many more such discoveries are to be anticipated in the future. This, together with, of course, the insight that they give into the details of the construction of Nature's most complex nuclear edifices and the laws that govern their construction, explains the great investment of material and, most particularly, human resources into the discovery of new elements. Lives are committed over decades to this enterprise, and this is not surprising. Nor is it then surprising that, although from the point of view of science itself (except that of the "science of history") and the associated advance of human understanding it does not matter who makes the discovery, immense importance is attached, personally, institutionally and nationally, by those engaged in the enterprise, to the public recognition of their discoveries. Not less surprising is that differences of opinion have arisen, in certain cases, as to the relative importance of the various contributions, by various research groups, at various times, that might have been made to the recognition of such new elements.

Specifically, such differences of opinion have arisen concerning priority in the discovery of elements beyond $Z=101$. In part, these difficulties have been caused by a change in the experimental methods needed to produce these elements. The reported discoveries have been made using complete-fusion/neutron-evaporation reactions. In them, overwhelming competition with prompt fission causes low yields which, combined with the often quite short half-lives, made experimental investigation difficult. Also, backgrounds with properties similar to those expected for transfermium elements but in reality due to lower-Z products of other type (transfer-) reactions, or to reactions on impurities (especially in actinide targets), have sometimes caused confusion.

I.2. It has long been felt that the scientific community should be able to resolve differences of opinion such as those to which reference has just been made by appropriate objective study of the evidence. In 1974 IUPAC in collaboration with IUPAP appointed a group of experts not themselves directly involved in the controversies, 3 from the USA, 3 from the USSR and 3 (including the chairman) from other countries, specifically ".. to consider the claims of priority of discovery of elements 104 and 105 and to urge the laboratories at Berkeley (USA) and Dubna (USSR) to exchange representatives and in their presence to repeat the experiments regarding these elements." This committee never completed its work, nor issued a report nor, indeed, met as a group, though there was some correspondence between members.

At its meeting in September 1985 the Executive Council of IUPAP, faced with renewed calls for the resolution of the continuing problem and in view of the evident lapsing of the earlier initiative, decided to suggest to IUPAC the establishment of a new joint group, the Transfermium Working Group (TWG), to examine the issues ab initio. It was decided that the members should not be drawn from the countries of the major laboratories concerned with research into the heaviest elements which in addition to the USA and the USSR now included West Germany through GSI in Darmstadt.

I.3. The Terms of Reference of the TWG as suggested by its Chairman were approved by the Executive Council of IUPAP in September 1986 and by the IUPAC Bureau in October 1986; they include that the work be divided into two phases:

Phase (i)	The establishment of criteria that must be satisfied for the discovery of a new chemical element to be recognized;
Phase (ii)	The application of these criteria in practice.

It was also agreed by IUPAP and by IUPAC that: "(TWG in Phase (i)) should to some degree work interactively with the major experimental laboratories concerned so as to move to criteria that will command general assent."

I.4. The IUPAP membership of the TWG was determined by IUPAP in September 1987 and the IUPAC membership by IUPAC at that same time:

IUPAP	D.H.Wilkinson (UK) Chairman
"	R.C.Barber (Canada)
"	A.Hrynkiewicz (Poland)
"	M.Lefort (France)
"	M.Sakai (Japan)
"	I.Ulehla (Czechoslovakia)
"	A.H.Wapstra (Netherlands)
IUPAC	N.N.Greenwood (UK)
"	Y.P.Jeannin (France)

The TWG appointed Messrs Wapstra and Ulehla as its joint secretaries.

I.5. The TWG has held the following meetings, of which the first and last were "private", with the remainder in the laboratories of chief concern:

3-5 February 1988	Nonant(France)
12-17 December 1988	Darmstadt(FRG)
19-23 June 1989	Berkeley(USA)
12-16 February 1990	Dubna(USSR)
16-20 April 1990	Prague(Czechoslovakia)

At the meetings in the laboratories, the TWG divided its time roughly equally between "private" meetings and sessions with the scientists of the laboratories. The TWG is most grateful for the warm and open discussions that it has enjoyed in all three laboratories.

I.6. Early in its work, the TWG realized that it was not practicable to effect a clean separation between the establishment of criteria and their application in the sense that the validity of criteria, and the pitfalls that might be encountered in their application, can be assessed only through discussion of their potential impact in real examples. The TWG has, as far as possible, restricted its examination in Phase (i) of such examples to cases that are not contentious in respect of priority claims but only by such "shadow" application of the evolving criteria has it been possible to establish a set of criteria that is indeed applicable in practice. These shadow exercises, not infrequently in respect of cases in which reported assignments to certain nuclides were later found to be incorrect, have proved to be most informative.

A benefit of this practical evolutionary approach to the definition of criteria is that the TWG is now fully ready to proceed to Phase (ii) of operations, the adjudicatory phase, should the present report on Phase (i) be accepted by IUPAP and IUPAC, who have agreed that the TWG as presently constituted should remain unchanged for Phase (ii).

I.7. The TWG has also come to the conclusion that it is not feasible to specify criteria, or combinations of criteria, that, in the words of its Terms of Reference "must be satisfied ..." in order to achieve recognition of the existence of a new chemical element and that would cover all cases. Very few properties indeed, of which perhaps the only uncontentious example is the characteristic X-ray spectrum, unambiguously determined, are sufficient of themselves to establish the existence of a new element. For the rest, identification must rely upon combinations of properties that will vary from case to case and that cannot usefully be exhaustively codified as a set of criteria *).

To adopt any such codification would be to force research into a strait jacket inimical to the spirit of free enquiry. The TWG has therefore discussed, and here presents, those criteria (section II) and properties (sections III and IV) that have been used in the past and that are seen as being of relevance for the future, and gives some indication of the store that it sets by them, but recognizes that their relative importance will vary from case to case depending upon the circumstances in which they are displayed and the manner in which they are combined.

To this degree, therefore, the TWG departed from the letter of its Terms of Reference and would draw attention to the resultant disjunction between the title of this Report, taken from those Terms, and its contents; it holds strongly, however, that the position it presents in this Report is the correct one.

I.8. The TWG has had to adopt an historical perspective in establishing its criteria and testing them through the shadow exercises but, of course, the application of the criteria lies largely in the future. However, it is evident that, historically, new elements were proposed, and accepted, on the basis of evidence that would not meet the criteria of today, even prior to the codification upon which the TWG has been engaged. In terms of published scientific evidence and also in terms of the public presentation of that evidence, there often appear what we can only describe as significant inadequacies. The standards of the times have markedly tightened, not least because of the development of new experimental technologies and, particularly, of the computer. However, this presents us with a problem which must be recognized at this stage although its impact will be felt only in Phase (ii), namely that some of the contentious cases, still to be resolved, now lie in the fairly remote past at a time when standards were different from those of today. We must be constructively sensitive to this when we move to Phase (ii): it would not be fair, or indeed possible, to apply to yesterday the criteria of today without regard for the circumstances of the times.

I.9. The TWG has not been charged with, and will not express opinions about, any matter to do with the naming of the new elements, either in Phase (i) or in Phase (ii). The following information may be useful:

The body primarily concerned with recommending names for the new elements is the IUPAC Commission II.2 on the Nomenclature of Inorganic Chemistry. This Commission does not "decide" on the adoption of names, but only publishes recommendations for international use. The 1990 version of its *"Red Book"* ("Nomenclature of Inorganic Chemistry", Blackwell Scientific Publications, Oxford) states in chapter I.3:

"The names approved by IUPAC are based on considerations of practicality and prevailing usage. It is emphasized that the IUPAC selection carries no implication regarding priority of discovery."

Systematic names have been proposed by IUPAC for all elements with Z=100-999. These names were only intended for use in the period when no "official" names were yet available. However, they have not met with favour among nuclear chemists nor among physicists. They will not be discussed in either phase of the present work.

Although the TWG is not concerned with names it feels that, in due course, following its Phase (ii) report, it would be felicitous if the laboratories concerned in the work leading to the establishment of a new element were to present to IUPAC an agreed joint suggestion as to the name.

I.10. Another matter involving IUPAC custom and practice is of concern here: the TWG will follow the IUPAC *Red Book* definitions for elements and isotopes and their atomic number Z, atomic mass number A and atomic mass M (in atomic mass units). In cases where the difference is important or instructive, the term "isotope" (which strictly speaking refers to two or more atomic species having the same atomic number Z but different atomic masses) will be replaced by "nuclide" (for which no such restriction applies.) We also refer to the *Red Book* for the notation for nuclear reactions and for the definition of their cross sections.

I.11. It has become very clear to the TWG, particularly in its review of historical cases referred to in I.6 above, that the situation in respect of the discovery of a new element is by no means always black-and-white in the sense that it may be unequivocally asserted that a new element was discovered, with the required certainty, by a certain group, using a certain method on a certain date. Sometimes this is the case, and this is what is popularly thought of as a "discovery". Perhaps more often, however, the situation is one in which data accumulated over a period of time, perhaps of years, perhaps in two or more laboratories, gradually bring the scientific community to the conviction that indeed the existence of a new element has been established. However, different individuals or different groups may take different views as to the stage in the accumulation of evidence at which conviction is reached and may take different views as to the existence or otherwise of crucial steps leading to that conviction and as to which those crucial steps were. Such differences can be perfectly legitimate scientifically, in that they may depend upon, for example, differing views as to the reliability of the inference that might be drawn from certain types of evidence, while not disputing the reliability of the evidence itself. So, although the scientific community may reach consensus as to the existence of a new element, the reaching of that consensus is not necessarily a unique event and different views may, in all scientific honesty, be taken as to the steps by which it was reached.

****

*) We distinguish between *properties* and *criteria*. Properties are the objective chemical or physical attributes of atoms and of nuclei or of processes through which they and their behaviour are categorized. Criteria are the conditions that must be met for those properties to be admitted as diagnostic in respect of the character (e.g. the Z-value) of the bodies concerned.

It will be the business of the TWG, in Phase (ii), to analyze these cases in detail and to attempt, where the situation is indeed not black-and-white, to trace, with the aid of criteria now to be discussed, a kind of discovery profile and to delineate the steps by which certainty in "discovery" was reached and, if possible, to indicate the relative importance of those steps. In other words, it is the TWG's conviction that there may be cases in which it would be unjust to assign an absolute priority in the "discovery" of a new element but where the credit should be appropriately apportioned.

The TWG is sensitive to the fact that it may be thought by some that such an apportionment of credit would be shirking the issue. This, however, is not the case and such an opinion could be held only by those disregarding the high complexity of the researches involved and the frequent lack of total specificity in their application. Demand for absolute priority assignments in all cases related to the new elements would imply an attachment to outmoded concepts of the nature of discovery.

I.12. The TWG realizes, consonant with its views expressed in I.11, that certain things relating to discovery will have to be made matters of individual definition in that they stand outside scientific criteria as such. An example of this might be Paper I that presents evidence relating to a possible new element but which is not adequate of itself to establish the existence of the new element without the evidence published later in Paper II, perhaps from a different laboratory, that, together with Paper I, carries certainty but which is also not sufficient of itself. It is now certain that Paper I "saw" the new element but could not prove it at the time. Where does the priority lie? Is it with Paper I or is it shared between Paper I and Paper II? And if, between Paper I and Paper II, there was published a Paper III that was complete in itself and carried conviction, does the credit lie wholly with Paper III even though, after the publication of Paper II, it is evident that Paper I saw the new element first?

We draw attention to such problems not to propose universal and rigid resolutions such as might lead to the assignment of absolute priorities but rather to support our concept of the discovery profile which we feel will lead to a more equitable appreciation of the range of contributions that might have been made. An absolute priority would often equate to an absolute injustice.

A similar situation in which the discovery profile would offer a fairer assessment would be one in which an early paper could not, at the time, carry conviction but which was later realized to have reported correctly signals from the new element in question, the existence of which was definitely established by subsequent work following up the lead of the early paper. Although it would clearly be wrong to assign absolute priority to that early paper, it would, in our view, be appropriate to recognize its seminal importance.

The discovery profile will also accommodate cases in which two groups correctly report a new element within a brief time interval of each other and in evident independence. In the TWG's view it would be absurd and unjust to accord an absolute priority to the group that, in such circumstances, simply happened to submit first. The discovery profile will enable people who wish to attach importance to such matters to do so.

II. CRITERIA

II.1. Discovery of a chemical element is the experimental demonstration, beyond reasonable doubt, of the existence of a nuclide with an atomic number Z not identified before, existing for at least 10^{-14} s.

Note 1. This lifetime is chosen as a reasonable estimate of the time it takes for a nucleus to acquire its outer electrons. It is not considered self-evident that talking about an "element" makes sense if no outer electrons, bearers of the chemical properties, are present.

Note 2. Discovery of an element can be based on chemical or physical methods or on both.

Note 3. The exact value of Z need not be determined, only that it is different from all Z-values observed before, beyond reasonable doubt.

Note 4. Neither is it required that the exact value of the mass number A be known. Even if a value for A is suggested that is later proved incorrect (but if an isotope with a nearby value of A, which could also have been produced, has the reported properties), this does not necessarily invalidate discovery of the new element (see also II.5.).

II.2. The TWG realizes that the term "reasonable doubt" is necessarily somewhat vague. Cases occur where experts at the time did not feel reasonable doubt about reports that later were found to be incorrect. Conversely, a case is known where expressed doubts could initially not be called unreasonable, but where they later appeared to be based on circumstances proven to be accidental. For these reasons, it is often considered desirable to wait with the assignment of priority until the reported results have been confirmed by later work. Generally speaking, such confirmation should not consist merely in a repetition of the same procedure with the same material, since this would imply too high a probability of repetition of the same unsuspected error (although such a repetition is not without value.)

Confirmation demands reproducibility, which is also related to setting up discovery profiles. All scientific data, other than those relating to unique events such as a supernova, must be susceptible of reproduction. In the case of the new elements the TWG attaches considerable importance to reproducibilty and would indeed like to be able to suggest that no new element should be recognized officially until the data upon which the claim is based have been reproduced, preferably in another laboratory and preferably by a different technique. However, it cannot: given the immense labour and the time necessary to detect perhaps even a single atom of a new element, it would appear unreasonable to apply such a demand of demonstrated reproducibility in all rigidity. We do not believe that recognition of the discovery of a new element should always be held up until the experiment or its equivalent have been repeated, desirable in principle as this may be. However, we would waive this requirement only in cases where the data are of such a nature that no reasonable doubt is possible (for instance for data with a high degree of internal redundancy and of the highest quality), and under circumstances where a repetition of the experiment would imply an unreasonable burden.

II.3. An experiment designed to demonstrate the existence of a new element must have two aspects. The first establishes physical and/or chemical properties of samples suspected of containing (at least one atom of) the new element and that are sufficient to categorize it; these we call *characterization properties*. The second extends to properties that are used to demonstrate that the "characterization properties" are indeed those of an unknown element; these we call *assignment properties*. Some properties can be used for both purposes.

II.4. Most assignment properties do not alone allow sufficient certainty for assigning a unique value to Z. A combination of them may, but it is usually not easy, if possible at all, to quantify the degree of certainty reached.

The only realistic way for deciding how far the criteria have been adequately met is for a group of informed "neutral" physicists and chemists to determine this, after study of the material presented and after consulting experts in the field.

II.5. The assignment of A can in principle influence the assignment of Z, which is one of the reasons why criteria for the assignment of A are included in the evaluation below. If this is the case, a later change in the A-assignment can throw doubt on the Z-assignment. It must be insisted, however, that the priority cannot be denied if a wrong A-assignment does not influence the Z-assignment.

II.6. In the specific cases under consideration, nuclides of supposedly new elements have been obtained by bombarding targets of known composition with known particles, sometimes followed by chemical purification. Impurities in the targets are known to have caused confusion in some cases. In the region of the transfermium elements, however, their influence is now known and can be rather easily recognized, since impurities only matter if they produce SF (spontaneous fission) or high-energy α-particle radioactivities.

The criteria developed below are also applicable to cases where a nuclide is obtained by chemically purifying natural material or debris of (thermo-)nuclear explosions. Chemical methods must then be used to purify the nuclides. As in the above case, these methods themselves might be sufficient for proving that a new element is present.

II.7. The highest Z elements that one can hope to produce in interactions between available stable or long-lived nuclides, even being very optimistic, have atomic numbers around 190. The production properties mentioned below cannot necessarily be expected to apply to higher Z cases.

II.8 Finally, we must have a word about publication. The TWG has a strong preference for publication in regular journals of international standing. However, it does not wish to take up a rigid position on this matter and would not wish to exclude from admissibility any form of bona fide publication of wide general accessibility.

III. PRODUCTION PROPERTIES

In the following list, we give properties connected with the preparation of nuclides as just described. The first five concern reaction properties, the others sample preparation. The note in the last column describes whether they are "characterization properties" C or "assignment properties" A(Z) for Z or A(A) for A or A(A,Z) for both (see section II.3).

Ei	Energy of bombarding particles	C
Cs	Cross section	C
Ey	Yield curve	C,A(A,Z)
Cb	Cross bombardments	C,A(A,Z)
Ad	Angular distribution	A(Z)
As	Angular selection	A(Z)
Ms	Mass separation	A(A)
Vf	Velocity filter	A(Z)
Tf	Time of flight selection	A(Z)
Ch	Chemistry	A(Z)

Notations and introduction. Let a new nuclide ${}^{A}Z$ be formed in the bombardment of a target ${}^{A_t}Z_t$ (it may be a mixture of isotopes) with particles ${}^{a}z$ of energy Ei, with a probability expressed as a cross section σ.

Two types of reactions *) are used to produce transfermium elements:

(i). Hot fusion reactions using ions with $4<z<12$ impinging on actinides produce compound nuclei with high excitation energies (typically about 40 MeV at projectile energies just above the fusion threshold).

(ii). Cold fusion reactions using ions with $17<z<29$ impinging on Bi, Pb or Tl produce compound nuclei with much lower excitation energies.

Such reactions in which γ-rays or neutrons are emitted accompanied by at most one proton or α-particle will be called evaporation reactions. So called transfer reactions, in which the final charge is significantly smaller than Z_t+z, are known to have produced unwanted and confusing backgrounds in measurements of evaporation reactions.

As to the target, the isotopic composition of the primary material is always known with sufficient accuracy in the experiments considered here. The presence of impurities in the target is not expected to be a source of uncertainty in cold fusion reactions. Impurities of, especially, Pb in actinide targets have been known to have produced confusion in the past.

****

*) We here disregard the reported production of a new element ascribed to secondary particles of unknown energy themselves produced by the bombardment of a target with an intense beam of high energy.

Comments

*E*i,*C*s *(Energy of bombarding particles and reaction cross section).* The minimum necessary and admissible information about nuclear reactions is the energy of the particles impinging on a possibly thick target (in which they lose energy before reacting) and some information on the yield.

Ey *(Yield curve).* The most complete information is a yield curve: production cross section as a function of energy of the particle impinging on a target nucleus.

Yield curves for ($^a z$,xn) reactions tend to be peaked with widths of about 8 MeV, and at increasingly higher energy values for increasing values of x. Yield curves for ($^a z$,pxn) reactions are rather similar, but their maxima tend to be some two orders of magnitude lower.

Yield curves for ($^a z$, αxn) reactions tend to have tails and so can be distinguished from the previous two, if measured with good statistics. (Their maxima occur at higher energies than those for ($^a z$,xn) reactions). For hot fusion, the maxima for ($^a z$, αxn) reactions can be considerably larger than those for ($^a z$,xn) reactions, but for cold fusion they are found to be about two orders of magnitude smaller. Yield curves for transfer reactions are much broader. At least for hot fusion, the yield for transfer processes need not be small compared with those for ($^a z$,xn) processes.

The theoretical understanding of reaction cross sections, especially in the region where fission seriously competes with evaporation, is insufficient to allow extrapolation to unknown Z cases with the confidence necessary to establish absolute priorities. Empirical evidence for the ratios of different kinds of evaporation reactions as a function of Z and A, which is now available, is, however, a useful guide.

Cb *(Cross bombardments)* Comparison of the probability of production of $^A Z$ in different combinations of $^{A_t}Z_t$ and $^a z$ can sometimes give valuable assignment criteria.

Ad,As *(Angular distribution, Angular selection).* The dependence of the production of $^A Z$ in ($^a z$,xn) processes is strongly forward peaked, more than in (^{a}z,αxn) or transfer reactions. Thus, determination of angular dependences, or comparison of yields behind two different collimators, may yield a good criterion for assigning Z. This property can also be used to suppress unwanted backgrounds.

Ms *(Mass separation).* A well calibrated mass spectrometer with a resolution significantly better than ½ mass unit can yield an excellent criterion for assigning the mass number of the reaction products. One should, of course, be certain that one does not accidentally observe molecular fragments with the same ΣA.

Although in ion sources for mass spectrometry some chemical differentiation occurs, no useful information concerning Z can be drawn from A, except of course that an exceptionally high A would point strongly to a new (high) value for Z. Also, the value from evidence from other data might be strengthened by combination with mass spectroscopic evidence (e.g. when a possible daughter was observed.)

Even with limited resolution, a mass ("isotope") separator can be used to suppress unwanted backgrounds.

Vf *(Velocity filter).* A velocity filter can give a quite good (though not complete) separation of evaporation products from the results of transfer reactions. If combined with the result of an energy determination (e.g. by measuring the signal in a semiconductor counter catching the reaction product), it can act as a low resolution mass spectrometer. Its main use is suppression of unwanted backgrounds.

A variation of the velocity filter is to make use of the differences in range in matter between evaporation products and those resulting from transfer reactions.

Tf *(Time of flight selection).* Measurement of time of flight of the reaction products can replace or complement the use of a velocity filter.

Ch *(Chemistry).* Chemical methods can yield excellent assignment criteria. Observations of analogies of chemical properties of compounds involving the elements of unknown Z with those of compounds of the same chemical type of known elements may suggest specific Z-assignments.

Chemistry can be done with few, or even single atoms of an element. In these cases, many repeated reactions take place with those few atoms. This occurs in methods like ion exchange (Ci), gas chromatography (Cg), gas thermochromatography (Ct) or chemical vapour transport (Cv).

IV. RADIOACTIVE PROPERTIES

The following list mentions properties connected to the radioactive decay of the produced nuclides.

Ki	Kind of decay (α,β,γ, SF=spontaneous fission)	C
Br	Branching ratio	C
T	Half-life	C
E_α	Energy of α-particles	C
E_β	Maximum energy of β-particles	C
E_γ	Energy of γ-radiations	C
X	X-ray spectrum (K or L)	C,A(Z)
Fc	Fission characteristics	C
Gn	Genetic relation between ancestor and n^{th} generation descendant (there may be more than one)	C,A(A,Z)

Comments

Ki *(Kind of decay).* This property need not necessarily refer to the kind of decay of the new isotope itself, but to that of a descendant. In the latter case, though, proof is necessary that the hypothetical ancestor really occurred.

Above, β stands for all weak interaction processes (β^-,β^+,ε), γ for all electromagnetic ones (e.g. also for conversion electrons and emitted electron-positron pairs) and X also for Auger electrons. For SF see also under Fc.

Br *(Branching ratio).* A nuclide might show more than one decay mode. Their intensity ratios, if determined with reasonable accuracy, are rather characteristic properties.

T *(Half-life).* The information on *T* is sometimes very imprecise, e.g. in the case of poor statistics, or if it is only known that the descendant has been seen after a specified time which may then be much longer than the half-life of the hypothetical parent. Some information of this kind is inevitably available. Evidently, *T* is a more distinctive property the more precisely it is known.

With few exceptions, a half-life cannot be used as an assignment property. Theoretical understanding of half-lives is insufficient for this purpose. Combination of a very high α-particle energy with a relatively long half-life is a strong indication for $Z>100$. Cases are known, however, where high spin isomers with *Z* around 84 combine the same characteristics. Similarly, fast SF occurs not only for transfermium elements but also for SF isomers with *Z* around 94.

The hindrance factor in α-decay is known to be nearly equal to 1 in ground state transitions between nuclei with even *A* and even *Z*. In other cases, it may (but not necessarily must) be much larger. Thus, observation of a relatively long half-life (high hindrance) in α-decay excludes assignment to a transition between ground states of even-even nuclides. Such a hindrance can be considered to be an assignment property. Also in other cases, half-lives can sometimes be used to *exclude* specific assignments.

E_α *(Energy of α-particles).* The energy of an α-particle can often be determined very accurately and can then be a very distinctive characterization property. For nuclides with a complex α-spectrum, good counting statistics may be necessary. Rare cases do exist where different nuclides have quite similar combinations of E_α's and *T*.

E_β *(Maximum energy of a β-spectrum).* The maximum energy of a continuous β-spectrum, if present, can be determined with moderate precision and is then a rather characteristic property.

E_γ *(Energy of a γ-radiation).* The energy of a γ-radiation, if present, can be determined accurately and is then a good characterization property.

X *(X-ray spectrum).* The energy of X-rays can be determined in the same way as those of γ-rays. They can be distinguished from γ-rays if observed with reasonable statistics, since X-rays (both K and L) show very characteristic patterns. Similarly, Auger electrons might be distinguished from conversion electrons. The presence of X-radiations of the correct energy is an unambiguous assignment property yielding the atomic number of the atom emitting those X-rays.

Fc *(Fission characteristics).* SF allows use of a sensitive technique for the detection of the presence of several actinide and trans-actinide nuclides. But most fission characteristics (such as total kinetic energy (TKE) and fission fragment mass distribution), even if measured with reasonable statistics, are not good assignment properties. If the nuclear charges of coincident fission fragments could be measured, this would determine the *Z*-value for the fissioning nuclide.

Gn *(Genetic relations).* (with n^{th} descendant.) This can yield an excellent assignment criterion, but only in the case that the descendant has a well assigned value of *Z* and, preferably, also of *A*. The reality of the proposed genetic relation, which must be well established, can be demonstrated (even in the case of poor statistics) by the observation of one or, preferably, all of the following properties:

Tc time correlations between the decays of a parent and a daughter,

Ic a correct ratio of parent and daughter decay intensities,

Pc a position correlation (e.g. observation of two α particles -assigned to an ancestor and a descendant- starting from the same place) .

V. CONCLUDING REMARKS

In this Phase (i) Report we have enumerated various characterization properties and assignment properties that are relevant to the discovery of new elements having atomic numbers greater than 100. We have not referred specifically to earlier publications in this field. In Phase (ii) we will apply these ideas so as to develop discovery profiles for each of the individual transfermium elements. In the Phase (ii) Report, we will refer in detail to all relevant publications on those elements and also mention earlier reviews dealing with the discovery of the transfermium elements.