during periods of reduced financial support. Experience indicates that progressive suspension of the less valuable services preserves a higher degree of over-all system efficiency than across-the-board retrenchment in all services. Reduction in financial support will inevitably cause a corresponding reduction in staff, services, or coverage. The ordering of services according to their value to the user group is a desirable self-evaluative function. If this evaluation is incorporated into the system's fundamental operating paper, it can serve as the basis for consideration of orderly system contraction when necessary.

While a charter is recommended as an excellent control device for system installation and operation, the topics proposed as candidate provisions in the charter are only suggestions. There is probably no system, planned or now in operation, which should or could incorporate all the suggested components. This composite picture of observed systems, however, may help to reduce some duplication of information system planning and design the hard way.

Plutonium—The Development of its Literature*

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Even before its discovery, element 94—later to be named plutonium—was of concern to nuclear physicists, and between 1909 and 1940 at least a dozen articles about the possibility of its existence appeared in the scientific literature. It is interesting to note that in the early part of this period the articles published were three to one in favor of the position that transuranium elements could not exist. In 1934, however, Fermi[1] and his co-workers discovered that neutron irradiation of uranium produced a number of radioactive substances, and concluded that, indeed, there were such things as transuranium elements. That revelation seems to have settled the question once and for all; no further articles denying such existence are reported.

Before proceeding further with the discussion of the literature of plutonium it seems appropriate to digress briefly to summarize some information about the metal itself.

Plutonium-239, the most abundant isotope of that element, is formed as the result of the radioactive capture of neutrons by the uranium-238 isotope and the subsequent two-stage β-decay of the intermediate products, uranium-239 and neptunium-239. That is, in reactors fueled with natural uranium (containing 99.3% uranium-238 and 0.7% uranium-235), neutrons produced by the fissioning, or radioactive disintegration, of uranium-235 are captured in uranium-238 to transmute the uranium-238 to plutonium-239.

Plutonium was the first element to be produced synthetically in large enough amounts to be seen by man, and was initially identified as a result of investigations made at the University of California during 1940–1942 by Wahl, Seaborg, and Kennedy, who were then studying the tracer properties of neptunium. In 1942 the first pure compound of plutonium was prepared, and in 1943 the first minute beads of plutonium metal, weighing less than 50 millionths of a gram, were produced at the University of Chicago. Because of the importance of plutonium as a component of nuclear weapons, much of the early work with the metal was carried on under conditions of great secrecy, and it was not until August 9, 1945, that the successful production of plutonium was heralded to the world in the terrifying destruction caused by the explosion of the atomic bomb over Nagasaki.***

The first use of plutonium was in an instrument of destruction more powerful than the world had ever before seen, but, although it continues to be used in nuclear weapons, its proposed peaceful application as a source of energy in the nuclear power reactors of the future is by far the more important. Such application has been estimated to be capable of multiplying the energy contained in the world's uranium reserves by a factor of more than 100, by converting uranium-238 to plutonium in power producing reactors and then using the plutonium thus produced as fuel in other reactors. It is small wonder that considerable scientific effort has been directed toward understanding this unusual metal.

Plutonium is not easily produced and fabricated. Some difficulties arise from its unusual physical characteristics and others from its extreme toxicity. It is highly reactive in air, and at elevated temperatures it must be protected

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** Work performed under the auspices of the U. S. Atomic Energy Commission.

*** The atomic bomb exploded over Hiroshima three days earlier, on August 6, 1945, contained uranium-235, and the plutonium bomb tested on the ground near Alamagordo, New Mexico, on July 16, 1945, could hardly be said to have informed the world of the production of plutonium, because of the secrecy that accompanied that test.

by being surrounded by a vacuum or an inert atmosphere. The necessity for thus protecting plutonium from oxidation unavoidably complicates the procedures and apparatus used in its production. Plutonium also has the remarkable attribute of existing in at least six different crystal structure forms in the solid state. As the metal is heated from room temperature to its melting point at 640° it undergoes five successive changes in crystal structure and, over a considerably large temperature range, has the unusual characteristic of contracting appreciably during heating instead of expanding. Most metals expand continuously when heated in the temperature ranges in which they exist as solids, and undergo no more than perhaps one or two changes in crystal structure.

As if these physical characteristics did not pose enough technical problems for those working with plutonium, it is one of the most toxic substances known. The extreme health hazard arises mainly from plutonium's radioactivity, it is an α-emitter, and from its tendency, when taken into the body, to become concentrated in the blood forming sections of the bones where even exceedingly small amounts may produce bone diseases. The maximum permissible body burden, or that amount of plutonium which it is thought can be maintained in an adult without eventually producing significant body injury, has been set conservatively at 0.6 μg. (six-tenths of a millionth of a gram), about the size of a single dust particle. Once plutonium has been absorbed in the body it is eliminated only very slowly. In fact, 50 years is the calculated length of time required to eliminate 20% of an absorbed dose of plutonium. Because of this health hazard, the handling and processing of plutonium must be subjected to rigorous control. Usually this control is achieved by confining plutonium to gloveboxes or well-ventilated chemical fume hoods. Under such conditions experience has shown that it is possible to work safely with plutonium.

As may be inferred from statements made above, the earliest work on plutonium was done at the University of California in Berkeley and at the University of Chicago. In 1943, however, Project Y was established at Los Alamos, New Mexico, and as soon as gram quantities of plutonium became available the major effort in plutonium metallurgical research was transferred to that location. Since then the Los Alamos Scientific Laboratory, operated by the University of California, has figured largely in the production of significant information about plutonium but has by no means been the only source of such information. A discussion of the subject of laboratory sources of plutonium information might be interesting but would be much too lengthy to include here. In the United States alone, information about plutonium has been contributed from Argonne National Laboratory, Hanford Atomic Products Operation, Mound Laboratory, Brookhaven National Laboratory, Knolls Atomic Power Laboratory, Rocky Flats Plant of the Dow Chemical Company, and the Lawrence Radiation Laboratory operated at Livermore, California, by the University of California, to mention only a few of the many government, university, industrial, and private laboratories that are or have been involved with plutonium. In addition, much information has also been produced in Canada, and abroad in France, Germany, Russia, the United Kingdom, and other countries. A number of references[2-8] that contain general information about plutonium are available, should the reader care to pursue this subject further.

To return to the subject of plutonium literature, Seaborg,[9] in his description of the discovery of plutonium in the cyclotron, mentions that McMillan and Abelson proved the existence of element 93, neptunium, in 1940 and that in the spring of 1941, Wahl and Kennedy identified one of the isotopes of plutonium. Public announcement of this important discovery was withheld, however, and work on the production and isolation of plutonium continued in self-imposed secrecy during 1941 and early 1942.

The first report on the chemical properties of element 94, which was written by Seaborg and Wahl, was issued as Report No. A-135 from the Department of Chemistry and the Radiation Laboratory, University of California, Berkeley, classified as secret and sent to the Uranium Committee, a group that had been coordinating the early work in the United States on the possibility of obtaining practical amounts of atomic energy from nuclear fission. This early report was prepared on March 19, 1942 and was later declassified and published[10] in 1949. It has special interest because it contains the suggestion that the new element be named "plutonium" (after Pluto, the second planet beyond Uranus). This suggestion followed the precedent established by McMillan who proposed the name "neptunium" (after Neptune, the first planet beyond Uranus) for element 93.

As an interesting sidelight it seems worthwhile to mention that the name "plutonium" had appeared earlier in the scientific literature, but not with reference to element 94. Webb[11] reported in 1947 that Edward Daniel Clarke, who was an English traveler and mineralogist living between 1769 and 1822, suggested the name "plutonium" in 1819 for the product he claimed to have obtained from the reduction of barium oxide with an oxyhydrogen blowpipe. Clarke thought that the name "barium," suggested earlier by Davy, was inappropriate because it comes from the Greek word meaning "heavy," while the metal to which it refers has a specific gravity of only about 4. In spite of Clarke's logic in proposing the name "plutonium," since "all proofs of its (the metal's) existence are owed to the dominion of fire," history would have it otherwise.

A few words in explanation of the terms "classified" and "declassified" as well as some other security terms are appropriate at this point. "Classified" reports contain information that must be safeguarded in the defense interests and security of the nation. That is, access to such information is restricted to those who need the information in their work and who, when they have that information, are not likely to jeopardize the security of their country.

There are two general categories of classified information and three grades of classification. The major category is "Classified Defense Information," which usually includes military information that needs to be protected in the interests of national defense. Within and subordinate to this category is that of "Restricted Data," which includes certain information about atomic weapons and about the use of special nuclear materials in the production of power. The Atomic Energy Commission, by statute, is solely responsible for the declassification of information in the "Restricted Data" category. The classification grades are "Top Secret," "Secret," and "Confidential." The order of listing indicates the importance of the information involved and the extent of the safeguards used to protect it.

"Official Use Only" is not a classification grade. It designates information which is privileged and which should have only such limited circulation as is customary under standard academic, governmental, industrial, and professional practice. For example, an individual's medical report or employment application is normally handled as "Official Use Only" information.

"Unclassified" information is that which has been available without restriction since it was originated. It may be part of the open literature that is available to anyone. Finally, "Declassified" refers to information that had been previously classified but, for one reason or another, was later examined by a responsible reviewer and the classified restriction removed. Such information may also become part of the open literature.

COLLECTING THE DATA

The main purpose of this paper is to trace the growth of the literature of plutonium, and, in particular, to describe that growth in terms of interest to users of the literature. It will not be surprising to find that the growth has been accelerated and complicated by the high degree of urgency and secrecy that accompanied the early development of the metal itself.

To make a complete and comprehensive study of the literature of plutonium would involve the detailed perusal of many abstract sources. Notably, *Chemical Abstracts, Nuclear Science Abstracts, Abstracts of Classified Reports, Metallurgical Abstracts, Technical Abstract Bulletin, Review of Metal Literature, Applied Science and Technology Index*, and *Research Reports (U. S. Government Research Reports)* would be consulted as well as a number of other less familiar or minor sources. The study would then necessarily involve a tremendous amount of cross-checking to remove duplications and ensure that each published article on plutonium were to be included only once in the data.

Such a complete study would have been far too time consuming. Therefore, the present survey is based on only a few of the major sources of information. It is trusted that the results give a fairly accurate picture of the development of the literature of plutonium, but there are uncertainties as to the correctness of the quoted numbers of articles published.

In making this simplified survey, *Chemical Abstracts, Nuclear Science Abstracts, Abstracts of Classified Reports*, and the Report Library catalog of the Los Alamos Scientific Laboratory were used. Progress reports that are issued at stated intervals—such as the monthly progress reports listed in the catalog of the Report Library—and are intended for strictly internal laboratory use were not included. Presumably the significant items in such reports are eventually published elsewhere.

Obvious internal duplications were removed from the listings obtained from each of the sources, and, for three of the years investigated between 1940 and 1962, namely 1948, 1951, and 1960, duplications among the various sources were carefully searched for and eliminated. These data were then used to estimate the number of duplications that were likely to have occurred in other years, and the initial totals were adjusted downward accordingly.

The year in which an article was mentioned in an abstract was taken as the year of publication of the article, simply as a convenience to avoid the necessity for finding the true publication date in each of several thousand references. Of course this procedure introduced some further inaccuracies in the results, since an article must be published before it can be abstracted, but these inaccuracies are probably not serious. In any event, many readers may first learn of the existence of an article by reading about it in an abstract. In that sense we might reasonably consider that the information did not become generally available until the abstract was published.

Each literature item was categorized as to whether it belonged in the open or classified literature. In this respect the classified category was assumed to include all gradations from "Official Use Only" to "Top Secret." Also, each item was placed in one of four other categories: technology, application, health and safety, and properties. Because any one article might very well deal with more than one of these subjects, the decision as to which subject was most appropriate was made arbitrarily. In a few instances the first listing of the article in the abstract source was taken as the basis for choosing the subject. This procedure may have led to some slight unintentional weight being given to "technology," "analytical methods" being prominent as one of the first members in the alphabetical listing of subjects in the abstract sources. All reports and articles dealing with production details, processing techniques, methods of analysis, and general facilities and equipment were included under the heading of "technology." Those dealing with reactor and weapon applications and other uses of plutonium and its alloys were placed under the heading of "application." All items having to do with the toxicity of plutonium and with the special equipment and procedures that accompany work with plutonium were collected under the "health and safety" heading; those that reported details of nuclear, chemical, physical, metallurgical, and other properties of the element, its alloys, compounds, and isotopes were included under the heading of "properties."

RESULTS

A conservative estimate of the cumulative number of reports, papers, journal articles, books, and patents having plutonium as their subject, which had been published at the end of each year between 1940 and 1962, is shown in Fig. 1. During this span of 22 years, the number of published items increased from two in 1940 to nearly 8,000 by the end of 1962.

The sharp increase seen for 1956 is probably related to the 1955 International Conference on the Peaceful Uses of Atomic Energy (first Geneva conference). Subsequent conferences and symposiums at which plutonium

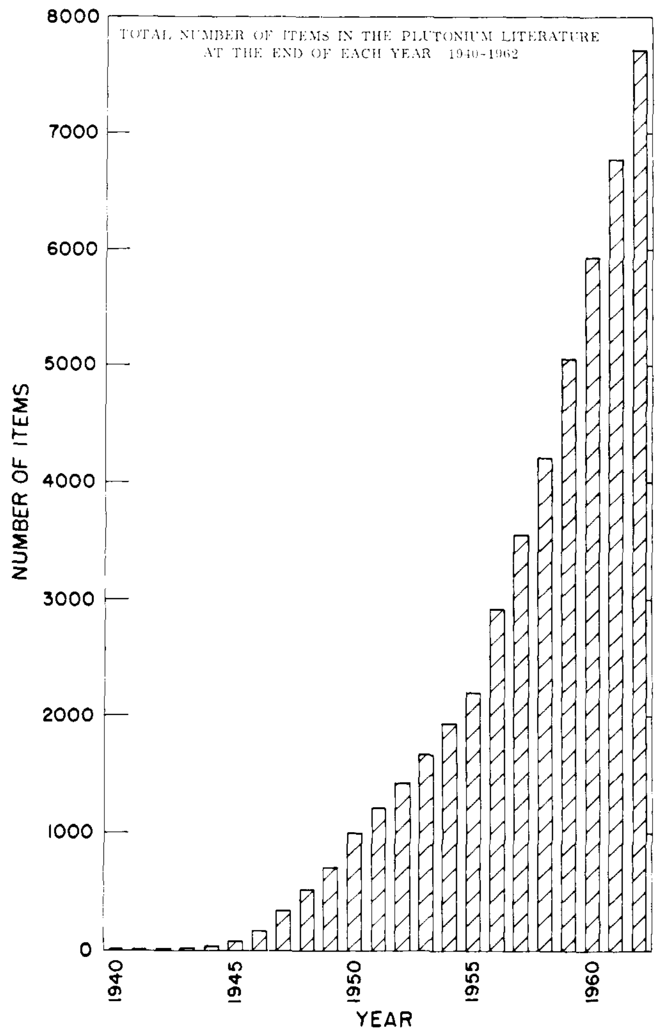

Figure 1.

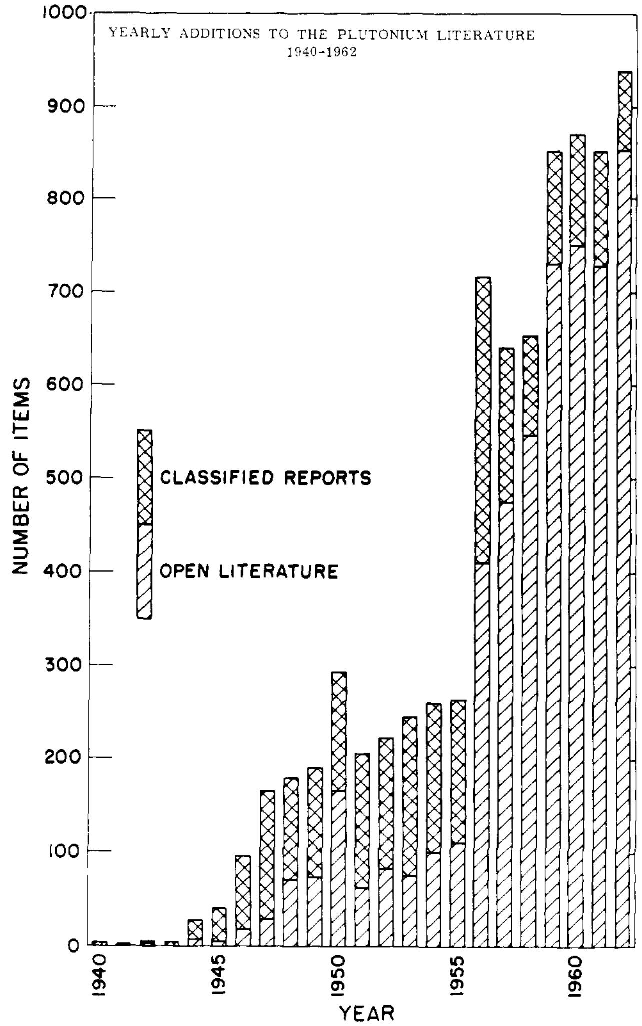

Figure 2.

was formally discussed undoubtedly helped to sustain the continued high level of production of plutonium information. Some of these meetings were the First International Conference on Plutonium in 1957, the Second International Conference on the Peaceful Uses of Atomic Energy in 1958 (second Geneva conference), the AIME plutonium symposium in 1959, and the Second International Conference on Plutonium in 1960. Of course, these were only a few of many gatherings. In addition, the increase in the number of laboratories and people involved with plutonium as more of the metal became available served to swell the number of contributions to the literature.

The proportion of classified articles relative to those that appeared in the open literature is illustrated in Fig. 2. In this figure the total height of a bar gives the number of additions to the plutonium literature during that year. The peak at 1950, during which year the number of unclassified articles first exceeded the number of classified items added to the literature (except for 1940 and 1941), probably is due to the easing of declassification restrictions at about that time. Again, the peak at 1956 can be correlated with the first Geneva conference. Very likely the decrease in the production of information from the 1956 level, observed for 1957 and 1958, was a natural result of the all-out attempt to produce information for the Geneva conference. Obviously, a great deal of work must precede the publication of information, and any exceptionally large production of information is likely to be followed by a period of smaller production while new information is being gathered.

The continued high level of production that started in 1959 is probably due to the numerous conferences and meetings that were held during the past four years as well as to an increased number of people who have been studying the metal both here and abroad. From a low of two articles published in 1940 and one in 1941, the yearly rate of production had increased to well over 900 by 1962.

Figure 3 illustrates the production of plutonium information relative to four categories: technology, application, health and safety, and properties. Starting at the bottom of the figure, "application" accounts for a relatively small number of papers. This is the expected result, since application of a metal necessarily depends on the development of its technology and the determination of its properties. The importance of health and safety considerations in working with plutonium is indicated in the next higher line, which represents the relatively larger amount of information that has become available on that subject. Information about the technology and properties of

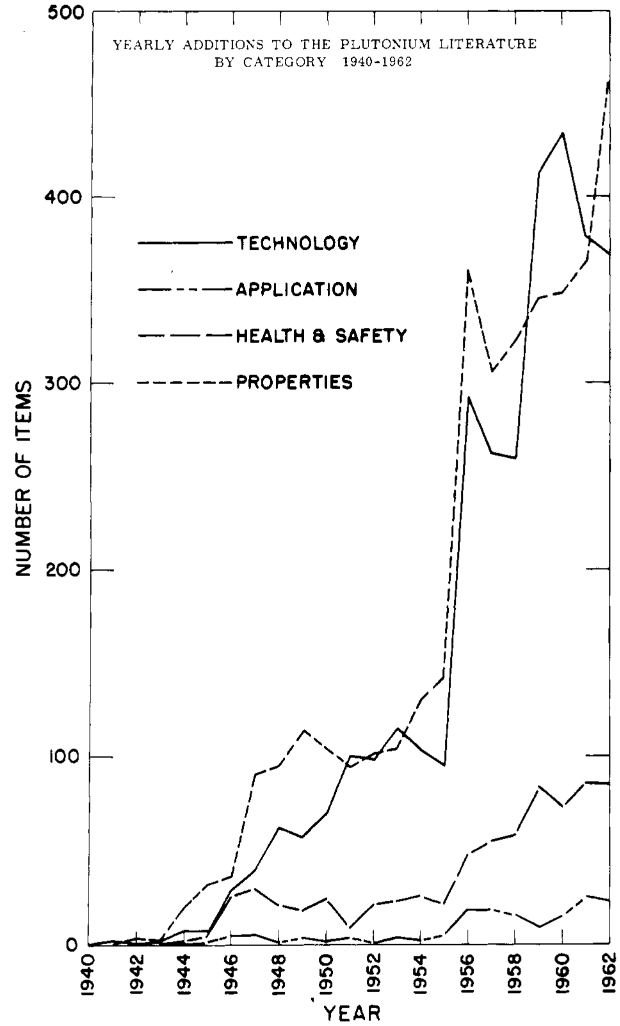

Figure 3.

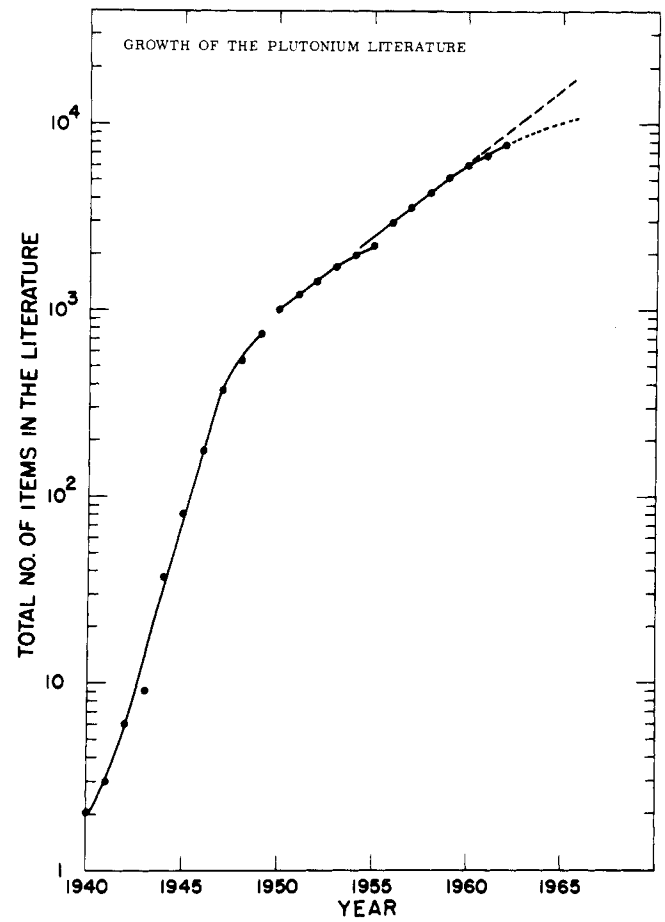

Figure 4.

plutonium accounts for the greatest number of additions to the literature, and is represented by the two upper lines in Fig. 3. In general, the number of articles devoted to properties exceeds the number concerned with technology.

The decrease in the number of technological articles added to the literature in 1961 and 1962 is probably temporary. It is notable that the sharp increases that occurred earlier in the production of this type of information were usually followed by temporary periods of lower production. This is also true, but to a somewhat lesser extent, of the production of information about properties.

Another method of examining the sort of data presented in Fig. 1 is to plot the points on a logarithmic scale. Then, trends not seen as clearly in the linear scale plots may become discernible. Figure 4 is such a logarithmic graph. Any point on the curve represents the total number of items that had been accumulated in the plutonium literature at that particular time, and the steepness of the curve indicates the rapidity with which the literature was being increased during a given period of time.

The two approximately straight portions of the curve reveal the exponential growth of the literature during the first and second decades following the discovery of the metal. During and closely following the war years, the maximum rate of growth of the literature was seen. During the next decade the growth was also exponential, as is indicated by the straight line, but at a lower rate than had been experienced earlier.

The tapering off of the curve in three places, starting at about 1947, 1953, and 1959 seems to be real. Probably if it had not been for some unusual external influence taking place about 1950 and 1956, the curvature would have continued and caused the line to become flatter. In 1950 this influence may have been due to an easing of declassification restrictions, which encouraged the production of more articles, and in 1956 it may have been due to the large number of papers published as a result of the first Geneva conference.

If we assume that two conferences proposed for 1964, the Third International Conference on the Peaceful Uses of Atomic Energy and the Karlsruhe Plutonium Conference, actually do take place and will provide an impetus similar to that seen in 1956, then the curve suggests that as many as 15,000 published items (indicated by the dashed line) may exist in the plutonium literature by the end of 1965. On the other hand, if the conferences are not held, or if they are held but such an impetus does not occur, a smooth extension of the curve (dotted line) indicates that about 10,000 items will have been added to the literature by that date.

DISCUSSION

Because of the secrecy that attended the early work with plutonium, well over three-quarters of the information published prior to 1950 was contained in classified reports issued by various laboratories and agencies. Even during the years since 1950, when most of the plutonium information has been contributed to the open literature, the tendency to publish information in report form has continued. In *Nuclear Science Abstracts* alone for the years 1959 through 1962, more than half of the nearly 1,500 items concerning plutonium are referenced to the report literature. Classified information must necessarily be published as reports, but the 1,500 items mentioned above were contributions to the open literature.

The various and numerous reports are characterized by the complicated and confusing manner in which they are coded for identification. During the course of this survey 250 different report series codes were noted, many agencies being responsible for more than one code and several codes being attributable to more than one agency. It is not surprising that users have been confused at times about the sources of certain reports. Who, except an experienced report librarian, would guess that the letters "AM" prefixing a report number stand for "American Miscellaneous?" And from what source would a librarian obtain such a report? This example, which pertains to plutonium, points out only one of many similar difficulties that concern not only the literature of plutonium but that of the entire scientific and technical field.

Mrs. Helen F. Redman[12] has recently written an excellent article entitled "The Report Number Chaos" in which she very effectively describes the coding system complications as they affect librarians. Here it would be superfluous to dwell further on the confusion that stems from ambiguous report identification codes. Publication of the "Dictionary of Report Series Codes"[13] is an attempt to solve this problem.

CONCLUSION

This survey has shown that the development of the literature of plutonium has been rapid, perhaps unusually so, but very likely in keeping with the urgent and rapid development of the metal itself. The large amount of information that has been published during the two decades since the metal was first produced, nearly 8,000 individual items, serves to emphasize the metal's unique characteristics, which continue to be of primary interest and concern to the chemists, metallurgists, physicists, and many others who work with plutonium and are attempting to understand it.

From the standpoint of the librarian, and of the people who depend on the librarian to provide information, the greatest problem associated with the literature of plutonium is the ambiguous and confusing coding system that has been used to identify the large volumes of reports issued by many agencies. The importance of the librarian in attempting to solve this problem and in continuing to provide quick access to the published information cannot be overemphasized.

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