Institute for Science and International Security

ISIS REPORT

March 19, 2012

Department 70 and the Physics Research Center: Extensive Interest in Nuclear Fuel Cycle Technologies

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On February 23, 2012, ISIS released the report, *The Physics Research Center and Iran's Parallel Military Nuclear Program*, in which ISIS evaluated a set of 1,600 telexes outlining a set of departments or buying centers of the former Physics Research Center (PHRC). These departments appeared to be purchasing a variety of goods for specific nuclear technologies, including gas centrifuges, uranium conversion, uranium exploration and perhaps mining, and heavy water production. Figure 1 is a list of the purposes of these departments. The telexes are evaluated in more depth in the February 23, 2012 ISIS report and support that, contrary to Iran's statements to the International Atomic Energy Agency (IAEA), the PHRC ran a parallel military nuclear program in the 1990s.

In the telexes, ISIS identified a department called Department 70 that is linked to the PHRC. This department tried to procure or obtained technical publications and reports from a document center, relevant know-how from suppliers, catalogues from suppliers about particular goods, and a mini-computer from the Digital Equipment Corporation. Department 70 appears to have had personnel highly knowledgeable about the existing literature on a variety of fuel cycle technologies, particularly gas centrifuges.

Orders to a British document center reveal many technical publications about gas centrifuges, atomic laser isotope enrichment, the production of uranium compounds including uranium tetrafluoride and uranium hexafluoride (and precursors such as hydrofluoric acid), nuclear grade graphite, and the production of heavy water. The Appendix categorizes the publications in the available telexes involving orders to the British document center, with full title and author citation, by nuclear technology. The telexes themselves are in a separate document.

Department 70 may have been responsible for creating a PHRC technical library on the nuclear fuel cycle. The linkage of this department to the PHRC is not as clear as in the case of Sharif University of Technology procurements to specific PHRC departments. However, the procurement of publications so clearly linked to PHRC departments increases confidence that Department 70 procured for the PHRC.

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As discussed in the February 23 ISIS report, Iran denies any PHRC involvement in the nuclear fuel cycle and denies nuclear weapons development or the center's involvement in this area. It maintains that there has not been any uranium enrichment project in Iran except that carried out by the Atomic Energy Organization of Iran (AEOI).[1] According to Iran, any PHRC procurements that might look nuclear-related were in fact not so.[2]

Iran stated to the IAEA that Sayyed Abbas Shahmoradi-Zavareh, the head of the PHRC, helped departments or laboratories at Sharif University of Technology to obtain goods because he was also a professor there. He used his business contacts abroad and the resources of PHRC in those endeavors. However, according to Iran, these procurements were not for any nuclear weapon, uranium enrichment, or uranium conversion purposes. These publications are clearly about nuclear subjects.

The activities of Department 70 are in stark contrast to Iran's declarations. Iran needs to reopen its discussions with the IAEA about procurements related to the PHRC and its activities.

Iran's recent effort to exclude such discussions of procurement activities was of course rejected by the IAEA. Iran's recent submission to the IAEA Board of Governors on a set of amendments to inspection arrangements about the alleged military dimensions of its nuclear program explicitly crosses out text discussing procurement activities.[3] Iran should reverse its position.

This ISIS report and the earlier one on the PHRC assess the type of procurement information that the IAEA wants to discuss with Iran. Part of ISIS's motivation to release these telexes is to allow the public and a broader range of governments to see the underlying evidence and judge for themselves its relevance and veracity.

Link Between PHRC and Department 70

Almost all of the telexes concerning Department 70 list Sharif University of Technology as the telex's sender. One lists Amir Kabir University. None explicitly mention the PHRC. However, in 1991, Department 70, purportedly of Sharif University of Technology, listed a PHRC P.O. Box number in a telex to one potential European supplier (telex 482).

ISIS noticed a common message numbering system on the Department 70 telexes that is based on a six-digit number, such as 010771 or 010830. ISIS assembled all the telexes that refer to Department 70 or have this message numbering system. The 49 telexes (plus duplicates) in the ISIS set are summarized in table 1. The first telex with this message number is 010770, from January 1991, and the last one is 010853, from January 1992, with most concentrated in mid-1991. The total number of possible message numbers in this range is 84. There are a few earlier telexes in the ISIS set mentioning Department 70 that date to July 1990, but they use an older message numbering system of five or more digits, such as 10352.0. Other departments of the PHRC also used this earlier message numbering

[1] IAEA Director General, *Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions 1737 (2006) and 1747 (2007) in the Islamic Republic of Iran*, GOV/2008/4, February 22, 2008, p.4
[2] IAEA Director General, *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*, GOV/2006/15, February 27, 2006, p. 7, paragraph 34.
[3] *Communication Dated 2 March 2012 received from the Permanent Mission of the Islamic Republic of Iran to the Agency*, GOV/INF/2012/4, March 2, 2012. In this document, the text at issue is in a section called "Clarification of Unresolved Issues" and is dated February 20, 2012: http://isis-online.org/uploads/isis-reports/documents/gov-inf-2012-4.pdf

system at this time, so it is not possible to assess the number of possible ones sent in this period by Department 70.

Shahmoradi, the head of the PHRC, is listed in a few of these telexes, which generally are devoid of individual names. He signed one telex that has this type of message number, namely 010791, that was sent from Sharif University (telex 1593). Although this telex does not list Department 70, it is in line with the activities of this department. Shahmoradi had written to Simid Books Limited on April 28, 1991 complaining that he had not yet received about 412 books that were in proformas (PF) "90085 through PF 90093." A telex from a computer supplier was addressed to Dr. A. Shahmoradi at the Polytechnic University, another name for Amir Kabir University (telexes 164). This telex discusses an impending visit to the supplier in Paris by Shahmoradi and his two colleagues, Dr. S. Akhlagpour and Dr. P. Boulaini, both of whom are also linked in the telexes to PHRC.[4] A telex sent by this same supplier about two weeks earlier is addressed to Department 70 of the Polytechnic University. A later telex to this supplier instructs that in proforma invoices the customer name should be changed from Amir Kabir University to Dr. A. Shahmoradi, identified as the head of the research department (telex 1252).

Both Shahmoradi and PHRC are linked to Department 70. Moreover, Department 70 and Shahmoradi are linked to both Sharif University and Amir Kabir University. This evidence supports that Department 70 is acquiring goods for the PHRC by using universities as fronts.

ISIS has not systematically tried to associate procurements by Department 70 with requests for specific goods associated with PHRC departments. But in one case, the use of a distinctive term shows one possible connection. Department 70 asked in early September 1991 for studies on a jewel bearing which could be related to learning about centrifuge bottom bearings (telex 834). On January 20, 1992, five months later, Department 2 of the PHRC, identified as related to centrifuge research and development, made a barrage of requests for catalogs and information regarding jewels (cups), needles, and stones (balls) from a range of suppliers. The use of relatively uncommon term "jewel" in both orders may reflect the procurement of literature followed by the ordering of parts of a bottom bearing of a centrifuge.

Department 70's Procurements

Publications and Reports

The majority of the telexes available that mention Department 70 are orders for publications and articles related to nuclear technologies and can be associated with major PHRC departments. The

[4] In telex 164, the name Akhlagpour may be misspelled. Telexes have frequent misspellings, thus the correct spelling is likely Akhlagpoor, a name which appears often in the telexes. The last name Boulanini could also have been misspelled by the French writer. This name could match a Mr. Boleyni or alternatively Boulini, Bolini, or Boleini (telexes 596, 171, 292, and 738), who is mentioned in many telexes as associated with Sharif University's purchasing department alongside Shahmoradi and Akhlagpoor. In one case, a supplier sent the telex to Sharif University's telex number but addressed the telex to Mr. Boleyni at the Physics Research Center (telex 752). Another telex links all three to the PHRC. A telex dated February 2, 1991 from the PHRC, Tehran to Drager Co. which discusses an upcoming visit and the need for an invitation, lists the delegation as composed of Dr. Abbas Shahmoradi (Director), Dr. Shahram Akhlaghpoor (Specialist), and Dr. Parviz Boulini (Commercial Director) (Telex 596). The telex abbreviation of the company sending the telex was TIR IR and its number was 212582.

telexes show that over a relatively short period of time in 1991, Department 70 acquired a considerable number of documents that are related to sensitive parts of the nuclear fuel cycle. These telexes, except in one case, do not involve orders for publications associated with the research and development of nuclear weapons.

This department spent tens of thousands of dollars on purchasing reports from a British document center with the acronym BLDSC, likely the British Library Document Supply Center, a well-known and reliable provider of a range of technical literature (telex 748). ISIS's set of data contains over 33 telexes sent by Department 70 to the British document center. About 20 of these were sent between March 1991 and September 1991 and have the characteristic six-digit message number. Based on an analysis of the subset of telexes with this message numbering system, ISIS found that Department 70 sent considerably more telexes during this six-month period than those in ISIS's possession. From early March 1991 to the end of September 1991, the numbers in this subset of telexes range from 010782 to 010841, implying a total of 60 telexes. Given that ISIS has about 20 of these telexes, Department 70 could have sent up to 40 more orders for documents to the BLDSC and elsewhere during this period.

Many of the publication requests demonstrate a detailed knowledge of nuclear fuel cycle engineering processes. When actual design information was not available, the department ordered material that would have provided useful theoretical support to the end user.

There are many publications about the theory and operation of gas centrifuges and related equipment, atomic laser isotope enrichment, the production of uranium compounds including uranium tetrafluoride and uranium hexafluoride (and precursors such as hydrofluoric acid), nuclear grade graphite (its properties, purification, and radiation damage), and the production of heavy water. These publications cover both basic and advanced topics on these subjects and appear aimed at creating a technical library.

The Appendix lists the publications categorized by a nuclear technology. Many of the telexes had only brief citations, sufficient for the document center to identify. ISIS added titles, authors, and other publication data to better understand the contents of the cited publications. In some cases, ISIS also added a brief summary of the report.

One would expect that that the AEOI would have already collected many of these documents. Its centrifuge research and development program was well developed by the early 1990s and it had already ordered centrifuge components for a prototype centrifuge from German companies.

Figure 2 shows a frequency distribution of the major publication categories. Many telexes are missing, so the chart is not complete. In the available telexes, most publications were concerned with centrifuges or equipment normally associated with centrifuges, including vacuum pumps and hysteresis motors. The largest centrifuge publication orders happened in May 1991. Department 70 also sought publications about heavy water and uranium conversion in early 1991. It regularly sought additional publications on uranium conversion while its interest in heavy water peaked in September 1991. The one high explosive publication was sought in September 1991. Laser publications were sought only once in July 1991. Graphite reactor publication requests occurred in April and May 1991.

Centrifuge The document requests include many studies about gas centrifuges and centrifuge plants. The intention appears to be the development of an understanding of gas centrifuges and the hardware associated with them such as hysteresis motors, vacuum pumps, and converters. The person

requesting the publications had an awareness that the best approach was to seek publications from a variety of countries. In essence, a worldwide search of publications could exploit differences in classification laws and practices and gain more information about centrifuges than focusing on one or a few countries' literature.

A centrifuge expert, who is an ISIS consultant and was active at that time, conducted an analysis of the list of publications in the telexes. He is familiar with many of them or the authors of these publications and personally authored several of them. He assessed that Department 70 sought the bulk of the unclassified literature that existed on centrifuges at that time. The publications included studies by many of the world's leading experts. Several of the publications were conference proceedings and reports that were not widely known, indicating a well organized search with the goal of assembling a comprehensive technical library on centrifuges, related equipment, and details of gas centrifuge plant design from the United States, Germany, Japan, France, and URENCO.

Department 70 sought a number of Japanese patents on centrifuges, which are a rich source of information regarding aspects of centrifuge design that are not widely available. Although the patents are not detailed in nature they do provide insight in the designs of centrifuge components and would be useful in the manufacturing process of these components.

Publications on vacuum pumps were sought. Vacuum pumps are key equipment in a uranium enrichment facility. The requestor was looking for information on pump speed, pressure measurements, and the "baking out" of pumps and systems, a process necessary if corrosive uranium hexafluoride is used. Understanding the proper procedures for "baking out" pumps is an important part of the design process. Residual traces of water vapor or other gases can react with uranium hexafluoride and cause damage.

Department 70 sought publications on hysteresis motors, which are an essential component of gas centrifuges. These motors have many dual-use applications and the international literature is a rich source of information on these specialized motors.

Information about bearings was also sought, although the publications are not as extensive as would be necessary for a centrifuge program. Some well-known publications about centrifuge bottom bearings are missing from the telexes. It is possible that other telexes that are not in the ISIS set contained requests for other bearing publications.

Laser Enrichment The publications requested in this area were mainly theoretical but the information from Lawrence Livermore National Laboratory and the Institute of Spectroscopy, USSR indicates some knowledge relating to the laser isotope separation (LIS) process. Later information that came out of these two facilities would have provided further very useful information relevant to the design of a small LIS operation.

Uranium Conversion The majority of the articles requested in this category deal with uranium dioxide production methods. A number of formerly classified U.S. documents were requested that detail past U.S. production methods and technology that would greatly benefit any country looking to invest in the uranium conversion process. In addition, a number of foreign patents were also requested but these would probably provide minimal technological assistance to the Iranians. The patents would however provide further background information that could then be used in a new article request.

The uranium tetrafluoride studies would be extremely helpful in building a pilot plant and possibly even production facilities. An Oak Ridge National Laboratory document contains details on the hydrofluorination of uranium oxides, and this process can use feed provided from fluidized-bed reactor described in a declassified Hanford report. This Hanford report describes the installation and testing of a laboratory size facility that can be readily scaled to the pilot plant level.

A uranium tetrafluoride facility would utilize anhydrous hydrogen fluoride for the conversion process, and a number of the publications deal with the analysis, production, and safe handling of this material. Publications also cover the production for hydrogen fluoride (anhydrous) starting with the mineral fluorspar. The difficulty of producing the anhydrous was illustrated in a partially declassified document from the Mallinckrodt Chemical Works, which started large-scale uranium conversion for the Manhattan Project in World War II. Anhydrous hydrogen fluoride is also a key material for the production of fluorine gas, which is used in the conversion of uranium tetrafluoride to uranium hexafluoride.

The metallurgical properties of uranium alloys produced by extrusion and powder metallurgy are contained in U.S. (Y12, Oak Ridge) and French sources. One publication from Egypt on the bomb reduction method of producing uranium metal could have supported PHRC procurements for ovens and furnaces used in this process.

ISIS asked for the assessment of a technical expert who is familiar with many of the authors of these publications and was active at the time in production-scale fuel cycle activities. He said that the subject matter covered by these reports indicates an intention to use the wet solvent extraction process in the uranium preparatory procedures. This conclusion is based on the number of reports requested that deal with uranium oxide reduction with hydrogen and a apparent lack of any interest in fractional distillation to remove contaminants such as molybdenum and vanadium. A fractional distillation step is required if uranium conversion is done via the dry hydroflour process. He also said the reports on fluorine support the conclusion that the wet solvent extraction process was the one chosen. The selection of instruments and the study of the hazards in dealing with fluorine, while not limited to the wet solvent extraction process, are certainly a central part in the process design of that system. There are other signals that this choice has been made but these are the primary ones. To be fair, he added that although Department 70 was careful to obtain a fairly large number on reports that overlap on technical details, they missed one set of information, the Geneva Conference papers of the three meetings that took place during the 1950's that summarized much of this subject from 1944 onwards. This omission is not fatal, he added. Moreover, the PHRC may have already had these reports or they are requested in the missing telexes.

Refractory Metals One book was ordered in this area by R.E. Smallwood, a leading authority in the area of refractory metals. The goal could have been to improve knowledge of the behavior of corrosive liquid refractory metals such as zirconium and uranium.

Heavy Water Information was requested regarding a number of the processes for the production of heavy water. Useful publications originated in Canada at Chalk River. Although all of the major separation technologies were looked at, details pertaining to the GS process were only in one document. Distillation column articles are related to the design of heavy water facilities and come from leading experts in that field.

A technical expert, who also reviewed the procurements or attempted procurements in the department concerning heavy water, assessed the publications involving heavy water. He is personally acquainted with some of the authors of these publications and can attest to the reliability of their studies.

Earlier, this expert had assessed that the PHRC was putting together a capability to use a combination of ammonia-hydrogen exchange and distillation to produce heavy water. The current list of documents, while covering a number of production methods, does not refute that conclusion. The list includes a number of studies done to evaluate the various methods of producing heavy water that were done for the United States. These studies were done at a time when a new production facility was contemplated for the United States. It was never built but the studies were a comprehensive evaluation of the various methods that rated energy requirements, operating efficiency, and the use of existing other production facilities, (such as facilities in the petroleum refining industry), as an aid to making a decision as to what production path to take. He assessed that the list of documents demonstrated that Department 70 did its job well. It certainly looked at nearly every possibility.

Graphite A great deal of time and effort appears to have gone into finding information on the production of nuclear grade graphite and the effects of radiation on this material. Much of the information came from declassified U.S. documents and included information on the behavior of graphite in actual reactors. This information would have been of importance in the designing of a graphite moderated reactor. The information that came from Harwell, UK would have complimented that material which came from the United States and also helped to verify information from other sources. This set of publications is the only one not reflected in other PHRC departments or procurements.

A technical expert who reviewed the graphite publications noted that some of the requested reports dealt with the purification of graphite - primarily the removal of boron. Such purification would be necessary if Iran desired to build graphite moderated reactors to produce plutonium or tritium.

This expert also raised a related concern about Iran's current known stockpiling of large quantities of graphite, far beyond its legitimate production needs for its steel industry, the main use of such quantities of graphite. This type of graphite is left deliberately with boron impurities to prevent it from being used in graphite moderated nuclear reactors. Perhaps, Iran is hedging against sanctions. On the other hand, the studies on purification may have indicated an interest inside the PHRC in cleaning up industrial grade graphite for nuclear use, which requires the removal of the boron. Of on-going concern is that Iran may intend in the future to pursue this purification option either for its own nuclear program or another nation's nuclear program.

High Explosives The single report in this area would have provided background information on the design of shaped charges and indicates that the researcher might have been aware of other research published by R.G.S. Sewell. He was a leading U.S. expert in the design of explosive charges and worked with the military for many years.

Other than this one publication, the available telexes do not show a connection to or subjects associated with Department 1, a department of the PHRC suspected to be related to the research and development of nuclear weapons. One note of caution is that the PHRC or other Iranian entities may have hesitated to openly procure such publications for fear of dramatically increasing suspicion of a hidden nuclear weaponization program.

Vacuum Induction Furnace Technology and Information

In 1991, as mentioned above, Department 70 of Sharif University of Technology, but with a PHRC P.O. Box number, telexed AEG-Elotherm seeking technical information, catalogs, and the cost of purchasing and operating a vacuum induction melting furnace with a bottom pouring crucible (telex 482). Such a furnace is well-suited to produce uranium metal when there are contaminants. The contaminants would float to the surface, so if a tilt system were used to pour the metal, the contaminants would mix with the uranium metal. A bottom removal system allows for the drawing of pure uranium metal.

Department 70 also sent the same request to several other companies at about the same time based on telexes from companies responding to such an enquiry. Several said that they did not make such furnaces or did not have bottom-pouring models. Some of these companies referred Department 70 to German firms that did make them. It is unknown if PHRC obtained one.

Hydrogen Fluoride Production

As discussed above, Department 70 sought publications that would describe how to produce hydrogen fluoride or HF, made by combining sulfuric acid with fluorite, also called fluorspar. When mixed with water, HF gas becomes hydrofluoric acid. Prior to known efforts to acquire publications in this subject, in a December 27, 1990 telex, Department 70 of Sharif University sent an enquiry to Buss in the United Kingdom asking for detailed information and catalogs regarding producing hydrofluoric acid from fluorspar and sulfuric acid ASAP (telexes 751). This was followed a few weeks later on January 15, 1991 with a telex to Buss AG in Switzerland asking for the same thing (telex 667). Buss was well qualified to help. Nonetheless, Buss AG responded on February 7, 1991, declining to help because of "work overload" (telex 162). Despite the rejection, Sharif University asked again on October 6, 1991. There are no later telexes on this request. The known requests to the British document center about making HF in this manner occurred in September 1991.

Conclusion

Department 70 appears to have bought a considerable amount of technical literature related to nuclear fuel cycle activities. Department 70 does not seem to be a part of a university, and Shahmoradi's link to Department 70 is further evidence that the publications are not for Sharif University of Technology. The subject of the publications ordered from the British document center is related to PHRC departments and the goods ordered by these specific departments.

This case is further evidence that Iran has failed to declare all of the PHRC's and Shahmoradi's activities to the IAEA. Whatever nuclear activities the PHRC or Shahmoradi pursued in the early 1990s, they appear independent of those of the Atomic Energy Organization of Iran in the area of gas centrifuges, uranium exploration and possibly mining, and uranium conversion. Iran should explain to the IAEA why there appears to have been a parallel, organized nuclear program.

Despite the new information about Department 70's activities, it remains difficult to fully understand. An effort should be initiated to obtain more of its orders from the British document center.

The Iranian Covert Nuclear Sector

Technological disciplines relevant for the attainment of a nuclear weapon in PHRC

PHRC's Departments:

Dept. 1: Nuclear Physics or Neutronics

Dept. 2: Centrifuge Enrichment

Dept. 3: Laser Enrichment

Dept. 4: Uranium Conversion

Dept. 5: Geology, including Uranium Exploration

Dept. 6: Health Physics or Radiation Safety

Dept. 7: Workshop or Metallurgy

Dept. 8: Heavy Water Production

Dept. 9: Analytical Laboratory?

Dept. 10: Computing?

Dept. 20: Analysis?

Figure 1. A list of the Departments under the Physics Research Center (PHRC) and the portion of the nuclear fuel cycle that each was responsible for.

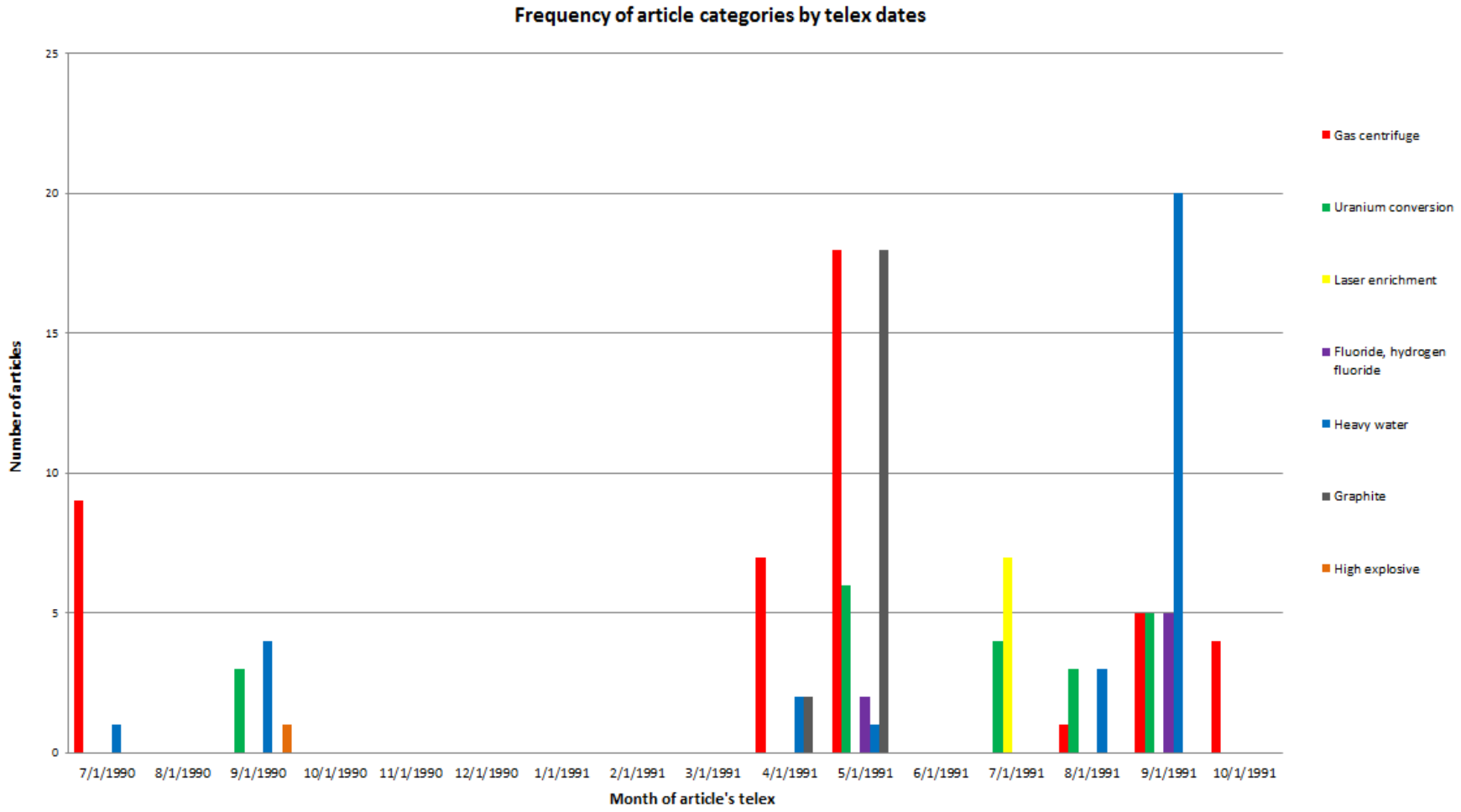

Figure 2. Telexes demonstrate that Department 70 sought or purchased nuclear publications from July 1990 through October 1991. This chart shows the frequency of these telex requests by major nuclear technologies from July 1990 through October 1991, categorized by the nuclear subject matter of articles. The category of centrifuges includes requests related to centrifuge-related equipment including hysteresis motors and vacuum pumps.

TABLE 1

Doc #	Msg. #	Date	Items	Supplier Company or Bank	Purchasing Dept. or Bank
613	10352.O	5/21/1990	SPECTROMETRY MATERIALS	VCH	SHFT (Sharif University)
574	10670.O	7/23/1990	Articles & publications	BLDSC (British Library Document	SHFT
582	10831.O	9/25/1990	Articles & publications	BLDSC	SHFT
162	01530/04	12/17/1990		BUSS AG, PRATTELN	SHFT
667	?	12/17/1990	HYDROFLUORIC ACID FROM FLUORSPAR AND	BUSS{UK} LIMITED	SHFT
706	010782	1/7/1991	Articles & publications	BLDSC	SHFT
674	010805-91	1/8/1991		SCINTREX LIMITED	SHFT
751	010773	1/15/1991	HYDROFLUORIC ACID PRODUCTION	BUSS AG	SHFT
748	010771	1/16/1991	Articles & publications	BLDSC	SHFT
143	?	1/22/1991	VAX6310 COMPUTER, SOFTWARE	DIGITAL EQUIPMENT FRANCE	SHFT
156	?	1/30/1991	Articles & publications	BLDSC	SHFT
177	?	3/27/1991	Articles & publications	BLDSC	SHFT
356	010782	4/10/1991	Articles & publications	BLDSC	SHFT
1	010790	4/27/1991	Articles & publications	BLDSC	SHFT
227	010791	4/28/1991	Articles & publications	SIMID BOOKS LIMITED	SHFT
251	010795	4/30/1991	Articles & publications	BLDSC	SHFT
253	010796	5/2/1991	Articles & publications	BLDSC	SHFT
254	010798	5/4/1991	Articles & publications	BLDSC	SHFT
255	010797	5/4/1991	Articles & publications	BLDSC	SHFT
256	010799	5/5/1991	Articles & publications	BLDSC	SHFT
24	010806	5/23/1991	Articles & publications	BLDSC	SHFT
32	?	5/28/1991	Articles & publications	BLDSC	SHFT
88	010814	7/3/1991	Articles & publications	BLDSC	SHFT
89	010815	7/3/1991	Articles & publications	BLDSC	SHFT
85	010816	7/6/1991	Articles & publications	BLDSC	SHFT
132	010821	8/3/1991	Articles & publications	BLDSC	SHFT
339	010814	8/3/1991	Articles & publications	BLDSC	SHFT
430	010823	8/17/1991	Articles & publications	BLDSC	SHFT
463	010828	9/3/1991	Articles & publications	BLDSC	SHFT
466	010829	9/4/1991	Articles & publications	BLDSC	SHFT
482	010830	9/9/1991	VACUUM INDUCTION MELTING FURNACE WITH BOTTOM POURING CRUCIBLE	AEG-ELOTHERM	SHFT
806	re: 010832	9/9/1991		EMA ELEKTRO MASCHINEN	SHFT
492	re: 010833	re: 9/9/1991	VACUUM INDUCTION MELTING FURNACES FOR STEEL AND NF METALS	OTTO JUNKER GMBH	SHFT
486	re: 010830	9/10/1991	VACUUM INDUCTION MELTING FURNACE	AEG-ELOTHERM G.M.B.H	SHFT
500	010837	9/17/1991	Articles & publications	BLDSC	SHFT
501	010838	9/17/1991	Articles & publications	BLDSC	SHFT
507	010839	9/18/1991	Articles & publications	BLDSC	SHFT
517	088214474	9/19/1991		LEYBOLD AG	SHFT
562	010831	9/25/1991	VACCUM INDUCTION MELTING FURNACE	ABB INDUSTRIE UND AUTOMATION	SHFT
566	010841	9/28/1991	Articles & publications	BLDSC	SHFT
413	010843	10/5/1991	Articles & publications	BLDSC	SHFT
1281	010842	10/6/1991	HYDROFLUORIC ACID PRODUCTION	BUSS AG	SHFT
164	re: 010775	11/2/1991		DIGITAL EQUIPMENT FRANCE	SHAHMORADI
1223	?	12/28/1991	Articles & publications	BLDSC	SHFT
411	010853	1/14/1992	Articles & publications	BLDSC	SHFT
266	?	?	Articles & publications	BLDSC	SHFT
577	?	?	Articles & publications	BLDSC	SHFT

Appendix: Documents Listed by Nuclear Technology

This appendix lists the publications requested by Department 70 categorized by the particular nuclear technology, including gas centrifuges, uranium conversion, uranium metal, heavy water production, and graphite. The numbers at the beginning of each entry refer to the file name of the telex. Appendix 2 lists the available telexes in chronological order. As noted in the report, only about one third of the suspected total number of telexes are listed below. As a result, this listing provides only a partial picture of the total number of publications obtained by Department 70 and likely does not include all the nuclear fuel cycle areas of its interest to this department.

With regards to the listing, entries all in caps are reproduced directly from the telexes. This was done when the title existed in the telex and was self-explanatory. In other cases, the article or report was found using the bibliographic information in the telexes. In many cases, summary information about the publication is included.

Gas Centrifuges:

1) J.J. Tennessee (Oak Ridge gaseous Diffusion Plant) - **Numerical study of the effects of curvature on the fluid dynamics of gas centrifuges**,International Workshop on gases in Strong Rotation, 1983
A finite element model for the approximate solution of the flow in rapidly rotating gas centrifuges is presented. The Osanger model, as amended by Maslen is used in deriving the model equations to be discretized.

1) T. Yamanaka, H. Onishi and M. Fujiwara **– End plates made of a composite material for the revolving drum of a centrifuge**
The present inventin relates to improvement of the end plates of centrifuges, especially those for centrifugal gas separators. End plates made of a composite material for the revolving drum of a centrifuge consists of a carbon-fiber-reinforced plastic laminate.

1) T. Fukai – **Revolving drum for a gas centrifuge**
The present invention relates to the improvement if gas centrifuges, especially for isotopes such as UF6. The improvement is attained by connecting two revolving drums with a flexible joint which decreases the primary natural vibration.

1) L.D. Cloutman and R.A. Gentry (Los Alamos) **– Numerical simulation of the countercurrent flow in a gas centrifuge**
We present a finite difference method for the numerical simulation of the axisymmetric countercurrent flow in a gas centrifuge. A time-marching technique is used to relax an arbitrary initial condition to the desired steady-state solution.

1) T. Fukai – **End plate of gas centrifugal separator drum**
The present invention concerns an improved end plate for a gas centrifugal separator drum, in particular, one designed for UF6. The end plate comprises ring-shaped reinforcement parts made using a filament-winding method with carbon fiber.

1) M.H. Berger (Oak Ridge Gaseous Diffusion Plant) – **Green's function for Onsager's pancake equation**

A Green's function has been derived for Onsager's one-dimensional pancake equation for the approximate internal flow in a gas centrifuge. Our new, exact solution has been verified by comparison with a previous solution for the flow induced by a point source of axial momentum.

1) E. Von Halle and S. Blumkin (Union Carbide Corporation, Nuclear Division, Oak Ridge) **– The behavior of the uranium isotopes in separation cascades, Part 5: review and appraisal**
A series of papers by Blumkin and Von Halle indicates that the enrichments are roughly 50 and 250 for 234U and 236U, respectively. A simple geometric extrapolation would therefore lead to an estimate of roughly 1250 for the enrichment of 235U in the same cascade.

17) Wataru Nakayama and Sampei Usui **– Flow in Rotating Cylinder of a Gas Centrifuge** , 1974

17) W.A. Fuhse (Urenco, Marlow, UK) – **The separation of uranium isotopes in gas centrifuges in the presence of light gases**

17) M. Lotz **– A method for calculating the separative power of countercurrent gas centrifuges**, Atomkernenergie, 1972, Vol. 20, p304-308, Translated as AAEC Report, LIB/Trans-533

17) Arai **- Isotope separation by gas-centrifuges with a circulation flow**, 1975

17) E. Dardel (Eidgenoessische Technische Hochshule, Zurich) – **Diffusion in an idealized gas centrifuge**, 1974

17) Y. Ohyama, Y. Takashima and N. Aoki – **Centrifuge for Separation of Enriched 235U**
The invention claim is for a centrifuge for enrichment of 235U characterized by: (1) a rotor provided with hollow upper and lower rotating shafts which serve respectively, as a feed conduit for a light inert-gas/UF6 gas mixture.

254) **Hexapartite Safeguards Project Team 3: Material Accounting and Control Questionnaire.**
Oak Ridge Gaseous Diffusion Plant, TN.
Page Count: 29 pages
Date: Jun 1981
Author: D. W. Swindle
Information provided in this report reflects the current design and operating procedures for the GCEP. However, since the installation is currently under construction, facility design and operating procedures discussed in this report are subject to change ...
Report Number: N/A
Contract Number: W-7405-ENG-26
NTIS announcement issue: 8408
NTIS Order Number: K/OA-5001
http://www.ntis.gov/search/product.aspx?ABBR=KOA5001

254) **Properties of Boundary Layers Generated by Mechanically and Thermally Driven Flows in a Centrifuge.**
CEA Centre d'Etudes Nucleaires de Saclay, Gif-sur-Yvette (France). Dept. de Genie Isotopique.
Page Count: 19 pages
Date: 1979
Author: C. Cortet P. Louvet

The flow of a compressible viscous perfect gas in a rotating cylinder closed at both ends is investigated by the linear theory. The Mach number is assumed to be of unit order and the Ekman number epsilon small enough so that boundary layers occur and asym ...
Report Number: COF-790329-3
Contract Number: N/A
NTIS announcement issue: 8114
NTIS Order Number: CEA-CONF-4683
http://www.ntis.gov/search/product.aspx?ABBR=CEACONF4683

254) **Procedures for the Calculation of the Separative Performance of a Countercurrent Gas Centrifuge.**
Oak Ridge Gaseous Diffusion Plant, TN.
Page Count: 71 pages
Date: Jul 1981
Author: E. Von Halle
The standard Onsager-Cohen gradient equation predicts reasonably well the separative performance of a gas centrifuge in which half the machine operates as an enriching section and half the machine operates as a stripping section and in which both the enri ...
Report Number: K/OA-5013 CONF-810845-1
Contract Number: W-7405-ENG-26
NTIS announcement issue: 8203
NTIS Order Number: DE81025448
http://www.ntis.gov/search/product.aspx?ABBR=DE81025448

254) **Onsager's Pancake Approximation for the Fluid Dynamics of a Gas Centrifuge**
Union Carbide Corp., Oak Ridge, TN. Nuclear Div.
Page Count: 60 pages
Date: Jan 1980
Author: H. G. Wood J. B. Morton
A previously unpublished theory for describing the internal flow in a gas centrifuge is presented. The theory is based on boundary layer type arguments on the side walls of the centrifuge with the additional approximation of neglecting radial diffusion of ...
Report Number: N/A
Contract Number: W-7405-ENG-26
NTIS announcement issue: 8015
NTIS Order Number: K/OA-4420(REV.2)
http://www.ntis.gov/search/product.aspx?ABBR=KOA4420REV2

254) **Numerical simulation of the countercurrent flow in a gas centrifuge**
Cloutman, L. D.; Gentry, R. A.
AA(Los Alamos Scientific Lab., NM.), AB(Los Alamos Scientific Lab., NM.)
Presented at the 4th Workshop on Gases in Strong Rotation, Oxford, 24-27 Aug. 1981
Publication Date: 00/1981
Category: Fluid Mechanics and Heat Transfer
Origin: STI
NASA/STI Keywords: CENTRIFUGES, FINITE DIFFERENCE THEORY, GAS FLOW, AXISYMMETRIC FLOW, BOUNDARY LAYERS, COUNTERFLOW, MATHEMATICAL MODELS, NUMERICAL ANALYSIS

A finite difference method is presented for the numerical simulation of the axisymmetric countercurrent flows in gas centrifuge. A time marching technique is used to relax an arbitrary initial condition to the desired steady state solution. All boundary layers may be resolved. It is concluded that this technique is capable of accurately predicting the performance of a wide variety of machines under all operating conditions of interest.
http://adsabs.harvard.edu/abs/1981gsr..work...24C

254) **MITS Initial Machine Startup Test Procedure (MITS Positions).**
Boeing Engineering and Construction, Seattle, WA.
Page Count: 98 pages
Date: Nov 1980
Author: J. Flinchem
This document contains procedures for startup, limited initial performance testing and shutdown of a single P-1c machine in a MITS position with monitor/control functions provided by MOD 15. (ERA citation 06:002019)
Report Number: D-348-15010-9
Contract Number: AC05-78OR05755
NTIS announcement issue: 8109
http://www.ntis.gov/search/product.aspx?ABBR=DOEOR05755T6

254) **MITS Integration Test Procedure.**
Boeing Engineering and Construction, Seattle, WA.
Page Count: 64 pages
Date: Nov 1980
Author: W. S. Brown
This procedure contains the steps required to integrate and to verify the operational readiness of the following subsystems: Feed and Withdrawal Subsystem, Sampling Subsystem, Flow Measurement Subsystem, Cascade Subsystem minus machines, Data Acquisition ...
Report Number: D-348-15012-1
Contract Number: AC05-78OR05755
NTIS announcement issue: 8109
http://www.ntis.gov/search/product.aspx?ABBR=DOEOR05755T6

254) **MITS Instrumentation Error Analysis Report**
Boeing Engineering and Construction, Seattle, WA.
Page Count: 20 pages
Date: Nov 1980
Author: D. W. Nelson D. D. Hillon
The MITS (Machine Interface Test System) installation consists of three types of process monitoring and control instrumentation: flow, pressure, and temperature. An effort has been made to assess the various instruments used and assign a value to the accu ...
Report Number: D-348-15007-1
Contract Number: AC05-78OR05755
NTIS announcement issue: 8109
http://www.ntis.gov/search/product.aspx?ABBR=DOEOR05755T3
(NOTE: this article is from 1979, whereas the article described in telex 254 is from 1980, but it's by the same authors and matching all the other metadata, so possibly a older version of a reprint/update)

254) **International safeguards at the feed and withdrawal area of a gas centrifuge uranium enrichment plant**
Authors: Gordon, D.M.; Sanborn, J.B.
Publication Date:1979 Jan 01
OSTI Identifier: 5462716
Report Number(s): BNL-27663; CONF-791117-27
DOE Contract Number: EY-76-C-02-0016
Resource Type: Conference/Event
Resource Relation: ANS topical conference, Kiawah Island, SC, USA, 26 Nov 1979
Research Org: Brookhaven National Lab., Upton, NY (USA)
Country of Publication: United States
Language: English
Format: Size: Pages: 18
Specific Type: Technical Report
Subject: 98 NUCLEAR DISARMAMENT, SAFEGUARDS, AND PHYSICAL PROTECTION; 11 NUCLEAR FUEL CYCLE AND FUEL MATERIALS; CENTRIFUGE ENRICHMENT PLANTS; IAEA SAFEGUARDS; ACCOUNTING; GAS CENTRIFUGES; MATERIAL BALANCE; NONDESTRUCTIVE ANALYSIS; SAMPLING; SLIGHTLY ENRICHED URANIUM; URANIUM 235; URANIUM HEXAFLUORIDE; ACTINIDE COMPOUNDS; ACTINIDE ISOTOPES; ACTINIDE NUCLEI; ACTINIDES; ALPHA DECAY RADIOISOTOPES; CENTRIFUGES; CHEMICAL ANALYSIS; CONCENTRATORS; ELEMENTS; ENRICHED URANIUM; EVEN-ODD NUCLEI; FLUORIDES; FLUORINE COMPOUNDS; HALIDES; HALOGEN COMPOUNDS; HEAVY NUCLEI; INDUSTRIAL PLANTS; ISOMERIC TRANSITION ISOTOPES; ISOTOPE ENRICHED MATERIALS; ISOTOPE SEPARATION PLANTS; ISOTOPES; MANAGEMENT; METALS; MINUTES LIVING RADIOISOTOPES; NUCLEAR FACILITIES; NUCLEI; RADIOISOTOPES; SAFEGUARDS; URANIUM; URANIUM COMPOUNDS; URANIUM FLUORIDES; URANIUM ISOTOPES; YEARS LIVING RADIOISOTOPES
Availability: NTIS, PC A02/MF A01.
Update Date: 2008 Aug 25
http://www.osti.gov/energycitations/product.biblio.jsp?query_id=1&page=0&osti_id=5462716
There are many other versions of this article, which can be found by searching for the authors name here: http://www.osti.gov/energycitations/basicsearch.jsp

266) Wataru Nakayama and Sampei Usui – **Flow in Rotating Cylinder of a Gas Centrifuge** , Journal of Nuclear Science and Technology, Tokyo, 1974, Vol. 11, p242-262
Thermal convection and weak forced flows in a rotating cylinder were studied theoretically to find the mass velocity distributions in a gas centrifuge.

266) W.A. Fuhse (Uranco, Marlow, UK) – **The separation of uranium isotopes in gas centrifuges in the presence of light gases**, Atomkernenergie, 1974, Vol. 24, p161-170

266) M. Lotz – A **method for calculating the separative power of countercurrent gas centrifuges**, Atomkernenergie, 1972, Vol. 20, p304-308, Translated as AAEC Report, LIB/Trans-533

266) Arai (Tokyo Shibaura Electric Company, Kanagawa, Japan) - **Isotope separation by gas-centrifuges with a circulation flow**, Atomkernenergie, 1975, Vol. 25, p47-52

266) E. Dardel (Eidgenoessische Technische Hochshule, Zurich) – **Diffusion in an idealized gas centrifuge** (Diffusion in einer idealistierten Gegenstromgaszentrifuge), 1974
Die dem Autor bekannten Publikationen welche Diffusionsprobleme in gegenstromungen auf analytischen Weg behandeln, beruhen auf einem Verfahre, das 1941 von Martin and Kuhn fur die Gegenstromgaszentrifuge vorgeschlagen wurde.

266) Y. Ohyama, Y. Takashima and N. Aoki – **Centrifuge for Separation of Enriched 235U**, BNWL-TR-144
The invention claim is for a centrifuge for enrichment of 235U characterized by: (1) a rotor provided with hollow upper and lower rotating shafts which serve respectively, as a feed conduit for a light inert-gas/UF6 gas mixture.

266) Wataru Nakayama and Takuji Tori (Mechanical Engineering Research Laboratory, Hitachi) – **Numerical analysis of separative power of isotope centrifuges** (I), Journal of Nuclear Science and Technology, 1974, Vol. 11, p495-504
A numerical method was developed to calculate the distribution of concentration of 235U in the rotating cylinder of a centrifuge. Satisfactory convergence was obtained by employing the formulation of convective terms devised for the computation of high Reynolds flow.

266) Hisashi Mikami (Research Laboratory of Nuclear Reactor, Tokyo Institute of Technology), **Thermally Induced Flow in Gas Centrifuges**, (II), Journal of Nuclear Science and Technology, 1973, Vol. 9, p580-583

266) J.W. Beams (Virginia University), **Early history of the gas centrifuge work in the USA**, NP-20433, May 1975

266) Soubbaramayer (Commissariat a l'Energie Atomique, Saclay, France), **Thermal Countercurrents in Centrifuges**, CEA-R-4185, January 1971, translated as AAEC-LIB/TRANS-582

266) W. Groth, **The enrichment of uranium isotopes in the gas centrifuge**
266) W.A. Fuhse (Urenco, UK), **Separative power of gas centrifuges for large scale uranium enrichment**, Atomkernenergie, 1974, Vol. 23, p28-33

266) Hertz and Nannn, EP-4422 (worked with Groth and Beyerle)

Hysteresis Motors

24) G. Cannistra (University of Bari, Indonesia**), A Model for the Hysteresis Motor Analysis**, Electric Energy Conference 1987, An International Conference on Electric Machines and Drives
This paper presents a hysteresis motor model for synchronous operation which takes into account the M.M.F. stray-losses in the rotor. Moreover the modeling of hysteresis loops by geometrically similar parallelograms simplifies the model parameters considerably.

24) P.T. Jowett (Ferranti Defense Systems, Scotland), **Aspects of Control of Small Hysteresis Motors**, Official proceedings of the Ninth International MOTOR-CON '86 Conference, October 27-31, 1986

24) D. Schieber (Faculty of Electrical Engineering Technion, Israel), **Asynchronous performance of hysteresis motor**, Journal of the Franklin Institute, 1975, Vol. 299, p433-447
A simplified model of the hysteresis motor is introduced and analyzed; field analysis is undertaken at hand of Maxwell's stress tensor and Poynting's theorem. The suggested approach provides deeper insight into the power interchange process between stator and rotor.

24) S. Gavril and A. Mor (Faculty of Electrical Engineering Technion, Israel), **Eddy Current Effects on the Asychronous Performance of the Hysteresis Machine**, Journal of the Franklin Institute, 1982, Vol. 314, p77-93
An analysis of the asynchronous behavior of the hysteresis machine is undertaken based on a rectified model of the structure.

24) S. Gavril and A. Mor (Faculty of Electrical Engineering Technion, Israel**), An analysis of the hysteresis motor**, Electric Machines and Power Systems, 1983, Vol. 7, p215-230
The analysis of the hysteresis motor is undertaken on the basis of a rectified presentation of the structure.

24) S. Gavril and A. Mor (Faculty of Electrical Engineering Technion, Israel**), On the Salient Properties of the Hysteresis machine – I. Non-conducting rotor**, Journal of the Franklin Institute, 1983, Vol. 315, p103-119
The properties of the hysteresis machine are analyzed on the basis of the cylindrical model.

24) S. Gavril and A. Mor (Faculty of Electrical Engineering Technion, Israel), **Influence of Hysteresis Performance of Single-Sided Finite-Length Linear Induction Motor**, Electric Machines and Power Systems, 1983, Vol. 8, p57-67
The performance of the single-sided finite-length linear induction motor is analyzed with special emphasis on the influence of hysteresis effects in the rotor yoke – whose contribution to the working parameters is significant, especially in the low slip region.

24) A.K. Chattopadhyay and N. Meher (Department of Electrical Engineering, Indian Institute of Technology, Kharagpur), **Microprocessor implementation of a state feedback control strategy for a current source inverter-fed induction motor drive**, IEEE Transactions on Power Electronics, 1989, Vol. 4, p279-288
The realization of a microprocessor-based controller which implements a complete state-feedback control strategy for a current source inverter-fed induction motor is reported.

24) M. Unno and H. Okachi (Osaka University), **Controlling Hysteresis Motors**, 1989

132) Article Title: **Phase-locked loop control system design for a hysteresis synchronous motor**
Publication Proceedings of the National Electronics Conference : the Conrad Hilton Hotel, Chicago, Illinois, December 9, 10 and 11, 1968
Author: Gerald T. Volpe
Pages: 52-57
CISTI Call number : TK5101.A1 N27 1968

413) **Mechanial factor of merit with reseet to electrical instruments**
General Electric Review, VOL 36, NO. 4, 1933
TX 700220-4

413) **A stability analysis of voltage source inverter-fed hysteresis**
Ishikawa 'T. Sdataoka, T, Scripta Technica INC .53-62,1985.

Bearings

413) **Instrument bearing friction**
Nylander A.L, General Electric, July 1946
TX 700220-2

413) **A new jewel for indicating instrument**Cocvne, E. K. Goss J.H, AIEE Trans. VOL. 61 ,″1942
IX 700220-3

266) Ralph Burton (Conference Chairman), **Bearing and Seal Design in Nuclear Power Machinery**, The Symposium on Lubrication in Nuclear Applications, June 5-7, 1967

466) A.B. Jones and H.A. Rothbart, **Mechanical Design and Systems Handbook**
- Hardcover: 1824 pages
- Publisher: Mcgraw-Hill (Tx); 2 Sub edition (September 1985)
- Language: English
- ISBN-10: 0070540209
- ISBN-13: 978-0070540200

R.H. Warring (Design Consultant, London), Calculating Frictional Losses in Jewel Bearing Movements, Design News, 1957, Vol. 29
In jewel-bearing movements energy losses due to friction are influenced by the position of the pivot axis, the load on the pivot, maximum contact pressure developed and minimum working torque available. These losses are at a minimum when the spindle axis is vertical, and in this situation both pivot and jewel radii are significant factors.

466) A.C. Lawson (Meter and Instrument Department, General Electric, MA.), **Design Factors for Jewel Bearing Systems**, 1954, Vol. 26
Moving systems of indicating instruments must be supported to allow the desired degree of rotation with a limited amount of friction and eccentricity between fixed and moving parts. This article will describe differences of application of the two most common type of instrument jewel bearing systems and will discuss the design considerations of each.

466) **Knife-edge bearings**; A bibliographical survey (B. S. I. R. A. Research report M.20. Bibliographical survey of instrument parts) [Unknown Binding]
P. J Geary (Author)

466) **Knife-edge bearings**: A bibliographical survey (British Scientific Instrument Research Association. Bibliographical survey of instrument parts; no.2) [Import] [Unknown Binding]
Peter John Geary (Author)

466) **Knife-edge Bearings** (Survey of Instrument Parts S) [Import] [Hardcover]
Peter J Geary (Author)

J. L. Lubkin: **Handbook of Engineering Mechanics**, ed. W. Flügge (McGrawHill, New York, 1962)

Vacuum Pumps and Molecular pumps (not the centrifuge component)

574) E. Apgar, G. Lewin and D. Mullaney (Princeton Physics Laboratory), **Selective Pumping of Light and Heavy Gases with a Molecular Pump,** Review of Scientific Instruments, 1962, Vol. 33, p985-6
For some plasma experiments high purity hydrogen or deuterium at pressures of 10-3 Torr or less is required. It is shown that a molecular pump can be used as a combination pumping, gas injection and gas purification system.

574) J.W. Beams, **Bakeable molecular pumps**, Transactions of the 7th National Symposium on Vacuum Technology, American Vacuum Society, 1960

574) O. Boettger and H. Pingel (AEG-Forschungs-institut, Frankfurt am Main), **Isotope Separation with the Molecular Pump**, Vakuum-Tech., 1963, Vol. 12, 33-37
The separating factor and separative power of a molecular pump with simple geometry were calculated. Calcuations were made for a pump with two pump slits ; one of them is used for enriching the light component of binary gas mixture and the other for enriching the heavy component. The separation of UF6 is discussed as a numeric example of isotope separation.

574) Sigvard Eklund (Stockholm), **Some measurements of ultimate vacuum and pump speed of molecular pumps**, Arkiv for matematik, astronomi och fysik, 1942

574) M. Hablanian**, The Axial-Flow Compressor as a High Vacuum Pump**, Advances in Vacuum Science and Technology, 1960, Vol. I, p168-172

574) Charles H. Kruger (Department of Mechanical Engineering, MIT), PhD Thesis, **The Axial-Flow Compressor in the Free-Molecule Range**, 1960

574) Manne Siegbahn, **A new design for a high vacuum pump**, Arkiv for matematik, astronomi och fysik, 1944

574) Sten von Fressen (The Research Institute for Physics, The Academy of Sciences, Stockholm**), Large Molecular Pump of the Disk Type**, Review of Scientific Instruments, 1940, Vol. 11, p362-364

574) C.E. Williams and J.W. Beams, **A magnetically suspended molecular pump**, Transactions of the 8th National Vacuum Symposium Combined with the Second International Congress on Vacuum Science and Technology, 1962, Vol. 1, p295-299

Other Enrichment Documents, including those involving gas centrifuges in addition to gaseous diffusion and documents concerning the aerodynamic process and laser enrichment

1) USDOE Office of Energy, **Energy Research Advisory Board – Report of the Energy Research Advisory Board Study Group on Advanced Isotope Separation**
The panel reviewed Advanced Isotope Separation (AIS) technology and Advanced Gas Centrifuge (AGC) programs in the context of potential needs and costs for uranium enrichment.

1) K. Miyasaki, N.E. Pobanz, D.B. Warren, R.E. Eby and J.R. Jamison (Bechtel Petroleum) – **Dynamic simulation and verification of a compression-liquefaction system for material withdrawal from a uranium-enrichment plant**
Dynamic simulation was used to evaluate the design of the tails (depleted/235U assay) withdrawal system for an uranium enrichment plant. Desirability of a simulation to check the design was indicated by requirements for a very high system reliability (99.995% availability) over a wide range of system throughput (85:1).

1) J.G. O'Brien (Westinghouse Electric Corporation, Pittsburgh) – **Uranium enrichment program, Electric utility engineering conference, 1974**
Westinghouse's involvement in the field of uranium enrichment is discussed. The gaseous diffusion and gas centrifuge processes are covered. The Cascade Improvement Program is briefly covered.

17) W.J. Wilcox, Jr., D.M. Lang and S.A. Levin (Oak Ridge Gaseous Diffusion Plant) – **Process selection for new uranium enrichment plants, International Conference on Uranium Isotope Separation**, March 1975, UK
Over the years the group at Oak Ridge has given consideration to many uranium isotope separation processes. From the United States viewpoint, the leading established candidates for process selection for new plants are the gaseous diffusion and gas centrifuge processes. The principal factors used in evaluating all processes are discussed and examples are given of the kind of evaluation made of ideas, proposals, or processes when relatively little information is available.

254) **Uranium Enrichment. 1980 Annual Report.**
Department of Energy, Washington, DC. Office of Uranium Enrichment and Assessments.
Page Count: 34 pages
Date: May 1981
Author: N/A
This report contains data and related information on the production of enriched uranium at the gaseous diffusion plants and an update on the construction and project control center for the gas centrifuge plant. Power usage at the gaseous diffusion plants ...
Report Number: ORO-822
Contract Number: N/A
NTIS announcement issue: 8126
NTIS Order Number: DE81026350
http://www.ntis.gov/search/product.aspx?ABBR=DE81026350

266) W.J. Wilcox, Jr., D.M. Lang and S.A. Levin (Oak Ridge Gaseous Diffusion Plant) – **Process selection for new uranium enrichment plants**, International Conference on Uranium Isotope Separation, March 1975, UK
Over the years the group at Oak Ridge has given consideration to many uranium isotope separation processes. From the United States viewpoint, the leading established candidates for process selection for new plants are the gaseous diffusion and gas centrifuge processes. The principal factors used in evaluating all processes are discussed and examples are given of the kind of evaluation made of ideas, proposals, or processes when relatively little information is available.

266) Ichiro Yamamoto and Akira Kanagawa (Department of Nuclear Engineering, Faculty of Engineering, Nagoya University), **Analytical Solutions for Real Cascade Equation in Steady State**, Journal of Nuclear Science and technology, 1975, Vol. 12, p120-127

Steady state real cascades are analyzed. The method adopted is based on two difference equations representing the conservation of the total flow and the desired material flow, respectively.

Hidenori Kokubu (Sumitomo Atomic Energy Industires), **Mixing Loss in a Step Cascade**, Journal of Nuclear Science and Technology, 1973, Vol. 9, p544-550
The total value of the separative work is provided by separators in a step cascade, in which mixing cannot be avoided, is larger than that provided by a corresponding ideal cascade operated under the same conditions (rate and concentration) of product, feed and waste.

1) A.J.A. Roux and W.L. Grant (Atomic Energy Board, Pelindaba, South Africa) **– South African uranium enrichment project**

17) A.J.A. Roux and W.L. Grant (Atomic Energy Board, Pelindaba, South Africa) – **South African uranium enrichment project**, INIS-MF-1825, 1975 (repeated request)

266) A.J.A. Roux and W.L. Grant (Atomic Energy Board, Pelindaba, South Africa) – **South African uranium enrichment project**, INIS-MF-1825, European Nuclear Conference, April 1975 (repeated request)

Laser enrichment related research:

85) D.B. Pearson, R.R. Freeman, J.E. Bjorkholm and A. Ashkin (Bell Telephone Laboratories, New Jersey) – Applied Physics letters, 1980, Vol. 36, p99**-, Focusing and defocusing of neutral atomic beams using resonance-radiation pressure**
We demonstrate strong focusing and defocusing of a sodium atomic beam using the transverse resonance-radiation pressure of a superimposed CW dye laser tuned near the atomic resonance.

85) Steven Chu, J.E. Bjorkholm, A. Ashkin and A. Cable (AT&T Bell Laboratories, New Jersey), Physical Review Letters, 1986, Vol. 57, p314-317, **Experimental observation of optically trapped atoms**
85) We report the first observation of optically trapped atoms. Sodium atoms cooled below 10-3 K in "optical molasses" are captured by a dipole-force optical trap created by a single, strongly focused, Gaussian laser beam tuned several hundred gigahertz below the D1 resonance transition.

85) Bertam Schwarzchild, Physics Today, June 1985, p17, **Laser Beam Focus Forms Optical Trap for Neutral Atoms**

85) Bertam Schwarzchild, Physics Today, September 1985, p17, **Atomic Beams Stopped by Laser Light and Trapped**

85) C. Salamon, J. Dalibard, A. Aspect, H. Metcalf and C. Cohen-Tannoudji (Laboratoire de Spectroscopie Hertzienne de l'Ecole Normale Superieure et College de France) – Physical Review Letters, 1987, Vol. 59, p1659-1662**, Channeling atoms in a laser standing wave**
We report the experimental observation of laser confinement of neutral atoms in optical-wavelength-size regions. A well collimated atomic beam was crossed at right angles by a one-dimensional standing wave and atoms were observed to be channeled into paths between the peaks of the standing wave.

85) V.S. Letokhov (Institute of Spectroscopy, Academy of Sciences, USSR), Optics Communications, 1973, Vol. 7, p59-60, **Possibility of the optical separation of the isomeric nuclei by laser radiation**
The possibility of using laser radiation for fast optical separation of isomeric nuclei is considered. The proposed method of separation is based on selective two-step photoionization of atoms or photodissociation of molecules.

85) A.F. Bernhardt, D.E. Duerre, J.R. Simpson and L.L. Wood (Lawrence Livermore) , Optics Communications, 1978, Vol. 16, p169-171**, Multifrequency radiation pressure laser, isotope separation**
Isotope separation by laser deflection of an atomic beam is limited in its efficiency by the accumulation of atoms in metastable states. This restriction can be removed with the use of lasers which excite metastable atoms to states from which spontaneous decay to the ground state is allowed.

Uranium conversion:

88) C.W. Kuhlman (Malinckroft Chemical Works) – **Reduction of uranium trioxide to uranium dioxide with hydrogen, reduction rates at various temperatures**, MCW-142, declassified in 1957

88) C.W. Kuhlman (Malinckroft Chemical Works) **– Reduction of uranium trioxide with hydrogen-nitrogen mixtures**, MCW-215, declassified in 1957

Kuhlman wrote at least 33 reports which are now publically available. The majority of the reports deal with uranium oxide conversion and processing to uranium tetrafluoride.

88) R.H. Moore, R.F. Maness (GE, Hanford Atomic Products Operation) – **Reduction of UO3 to UO2 with hydrogen**

88) Journal of Physical Chemistry, 1960, 64(1), p132-133, R.E. DeMarco and M.G. Mendel
The Reduction of High Surface Area Uranium Trioxide

339) C.W. Kuhlman, Jr. (Mallinckrodt Chemical Works), Reduction **of Uranium Trioxide to Uranium Dioxide with Hydrogen – Reaction Rates at Various Temperature**s, MCW-142, October 1948

339) C.W. Kuhlman, Jr. (Mallinckrodt Chemical Works), **Reduction of Uranium Trioxide with Hydrogen-Nitrogen Mixtures**, MCW-215, September 1949

339) **R.H. Moore and R.F. Maness, Reduction of UO3 to UO2 with Hydrogen**, AEC report No. HW-38321, 1955

463) J.S.L. Leach (Imperial College of Science and Technology, London), **Hydrogen and the Corrosion of Uranium and other Oxide Covered Metals**, NP-10541, September 1960
The model of the corrosion process in oxide-covered metals which is being developed suggests that the electronic conductivity of the oxide plays a much greater part than was previously believed. The dependence of this conductivity on the presence of hydrogen in the oxide appears to be most important in explaining corrosion rates and hydrogen pickup during corrosion of oxide covered metals and alloys.

463) B.M. Johnson (General Electric Company, Hanford Atomic Products Operation, Richland, Washington), **Development of a Laboratory-Size, Fluidized-Bed Reactor**, HW-51834, November 1957
The installation of a laboratory-size, fluidized-bed reactor was undertaken to provide on-site facilities for testing the behavior in a fluidized-bed reduction unit of UO3 produced in an agitated trough calciner.

463) K.J. Notz, C.W. Huntington and W. Burkhardt (National Lead Company of Ohio), **Hydrogen Reduction of Uranium Oxides: A Phase Study**, TID-11146, January 1960
The successive phase changes which occur during the hydrogen reduction of uranium oxides were studied in situ by means of a controlled-atmosphere , x-ray diffractometer hot stage, at temperatures of 480 and 750 deg C.

463) W.R. DeHollander (General Electric Company, Hanford Atomic Products Operation, Richland, Washington**), A Kinetic Study of the Reduction of Uranium Oxides with Hydrogen**, HW-46685, November 1956
Data and a theoretical analysis are presented which demonstrate that the reduction of uranium oxides with hydrogen is essentially a zero point reaction with regard to the fraction remaining to be reduced.
463) N.C. Orrick, C.F. Hale, C.G. Jones, K.E. Rapp and E.J. Barber (Oak Ridge Gaseous Diffusion Plant, TN), **An Improved Thermobalance Reactor for the Study of Reduction and Hydrofluorination of Uranium Feed Materials**, K-1617, September 1964
Two thermobalances have been constructed which make use of an improved reactor design for the study of gas-solid reactions as they apply to the conversion of uranium oxide materials to uranium tetrafluoride.

463) V.H. Heiskala (Department of Nuclear Engineering, Michigan Technological University), **Kinetics of Hydrogen Reduction of Uranium Trioxide**, Journal of Physical Chemical, 1965, Vol. 69, p2012-16
The reaction between uranium trioxide and pure hydrogen was investigated in the temperature range 575 to 700 C. it was determined that, after an induction period in which the reaction rate reached its maximum value, the reaction proceeded at a constant rate which was independent of the thickness of the reduced uranium dioxide layer.

577) **URANIUM DIOXIDE MANUFACTURE**
CHENEBAULT,P. N CAILLAT,R.,
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TX BS04030

577) **URANIUM DIOXIDE MANUFACTORE**
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577) **PROCEDURE FOR PRODUCTION OF URANIUM,**
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577) **URANIUM DIOXIDE**

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TX BS04033

577) **CONVERSION OF NUCLEAR FUEL METAL NITRATE SOLUTIONS TO OXIDES ,**
- HAAS,PAUL,A.
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577) **URANIUM DIOXIDE WITH HIGH DENSITY**
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577) **REDUCTION OF URANIUM COMPOUNDS TO URANIUM DIOXIDE POWDER BY CALCINATION**
COLE,EDWARD,A,ET.AL., ,GER,OFFEN.2,459,29
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582) **PRODUCTION OF URANIUM DIOXIDE BY FLAME DENITRATION N REDUCTION OF AQUEOUS URANYL NITRATE**
HEDLEY,O.H.,ET.AL., MCW-1470,P.49
TX ES04002

582) **PREPARATION OF URANIUM TETRAFLUORIDE FROM $U0_3$ OF URANYL SALT**
SANLAVILLE,J.
PROC. U.N. INTERN. CONF. PEACEFUL USES
AT. ENERGY,2ND,GENEVA,1958,4,102-6
TX ES04003

582) **PROPERTIES OF URANIUM DIOXIDE**
- BELLE,J. LUSTMAN,B., ,U.S.AT.ENERGY COMM.,WAPD-184 ,
″1957,P.140
″214474 SHFT IR =
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TX 10787

Uranium Metal

1590) F.H. Hammad, A.A.A. Zahra and F.M. Haggag (Egypt AEC), **Uranium Metal Preparation by the Bomb Reduction of Uranium Tetrafluoride with Ca or Mg** – a Semi-Pilot Plant Scale, Proceedings of the 1st Egyptian Conference on Mining and Metallurgical Technology, 1977

Fuel Fabrication

1590) R. Petitet, A. Beaubron, and C. Pruner**, Ultrasonic Grain Size Measurement of As-extruded Uranium** Rods, ASNT 37th National Fall Conference, 1977
The authors discuss a technique using ultrasonics with a rotating head, integrated into the production line and carried out as soon as possible in a succession of various manufacturing operations of bars,

allowing elimination of faulty products. The technique is based upon acoustic energy attenuation through the material which increases with grain size.

1590) James W. Corbett and Louis C. Ianiello**, Radiation Induced Voids in Metals: Proceedings**, US Department of Energy, 1972

1590) S.K. Mehta, K. Anantharaman, S.M. Chaudhary and K.R. Srinivasan (Reactor Group, BARC), **Design Aspects of Metallic Fuel for Research Reactors and Ceramic Fuel for Boiling Water Reactors**, Material Science Forum, 1989
The performance of reactor fuel under normal operation, transient and abnormal conditions is the key factor for the success of the nuclear reactors. Therefore, the development of analytical capacity for the fuel design and in predicting its behavior under various conditions continues to draw high degree of attention and pursuit of R&D work

1590) R.K. Holbert and M.W. Doughty (Fairchild Space Company, Germantown, MD), **Welding of a powder metallurgy uranium alloy**, Welding Journal, 1989, Vol. 65
The interest at the Oak Ridge Y-12 Plant in powder metallurgy uranium parts is due to the potential cost savings in the fabrication of the material, to achieving a more homogenous product, and to the reduction of uranium scrap.

1590) A.Garlick (UK Atomic Energy Authority, Windscale Nuclear Power Development Laboratories), **Microstructural Examination of Fuel Rods Subjected to a Simulated Large-Break Loss of Coolant Accident in Reactor**, ASM International Conference on Fatigue, Fracture Mechanics, and Failure Analysis, December 2-6, 1985, Published in Journal of Materials Engineering, 1987, Vol. 9, p93-100
A series of tests have been conducted in the National Research Universal reactor, Chalk River, Canada, to investigate the behavior of full-length 32-rod PWR fuel bundles during a simulated large break loss of coolant (LOCA).

Refractory Metals

89) R.E. Smallwood (Allied Corporation) Refractory metals and their industrial applications, 1977
This is one in a series of articles, books and conference where Smallwood presented information regarding the application of refractory in industrial applications such as the nuclear industry.

Fluorine, Hydrogen Fluorine

255) **A CONTINUOUS BOILING POINT ANALYZER AND ITS APPLICATION TO THE HYDROGEN FLUORIDE-WATER SYSTEM**
Authors: Pappas, W.S.
Publication Date: 1960 Feb 10
OSTI Identifier: 4175308
Report Number(s): K-1354
DOE Contract Number: W-7405-ENG-26
Resource Type: Technical Report
Resource Relation: Orig. Receipt Date: 31-DEC-60
Research Org: Oak Ridge Gaseous Diffusion Plant, Tenn.
Country of Publication: United States

Language: English
Format: Size: Pages: 15
Subject: ENGINEERING AND EQUIPMENT; BOILING; EFFICIENCY; HYDROGEN FLUORIDES; INSTRUMENTS; LIQUID FLOW; LIQUIDS; MEASURED VALUES; MIXING; RECORDING SYSTEMS; VAPORS; VELOCITY; WATER
Availability: NTIS
Update Date: 2008 Feb 05
A simple and inexpensive instrument is described which provides a continuously recorded analysis of binary liquid or vapor mixtures by measurement of the boiling point. The instrnment is insensitive to flow rate within broad limits. The response lag is less than one minute. The instrument may be applied to a sample loop of a liquid or vapur process stream, returning the sample to that process stream. This instrument has been applied to the corrosive hydrogen fluoride-water system. Precisions of plus or minus 0.5% absolute in the hydrogen fluoride concentration ranges 0 to 30% and 45 to 100% are obtained. (auth)
http://www.osti.gov/energycitations/product.biblio.jsp?query_id=45&page=0&osti_id=4175308

255) **REVIEW OF LITERATURE ON HEALTH HAZARDS OF FLUORINE AND ITS COMPOUNDS IN THE MINING AND ALLIED INDUSTRIES**
Authors: Davenport, S.J.; Morgis, G.G.
Publication Date: 1954 Jun 01
OSTI Identifier: 4403795
Resource Type: Journal Article
Resource Relation: Journal Name: U.S. Bur. Mines Inform. Circ.; Journal Volume: Vol: 7687; Other Information: Orig. Receipt Date: 31-DEC-54
Research Org: U.S. Bureau of Mines, Washington, D.C.
Country of Publication: Country unknown/Code not available
Language: English
Format: Size: Pages: 55
Subject: CHEMISTRY; BIBLIOGRAPHY; BODY; FLUORINE; MAN; MINING; REVIEW; SAFETY
Update Date: 2009 Dec 15
http://www.osti.gov/energycitations/product.biblio.jsp?query_id=28&page=0&osti_id=4403795

463) T.A. Baggett, R. Culter, E.N. Nelson and J.A. Kennelley (Mallinckrodt Chemical Works, St. Louis), **An Investigation of the Water Gas Reaction as a Means of Upgrading Aqueous HF**, MCW-1417, August 1958
The water gas reaction C + H2O = CO + H2 has been investigated as a method converting 70% HF to anhydrous HF. The feasibility of this process has been demonstrated in a laboratory-sized apparatus, but associated problems such as heat transfer and materials of construction would make large scale applications of the process unattractive.

463) R.H. McBride (DuPont de Nemours, Engineering Department, Wilmington, Delaware**), Metering of HF and Fluorine**, Final Report on BPX-5, AECD-3690, October 1945

463) R.M. Yabroff and J.C. Smith (Cornell University), **Thermodynamic Properties of HF**, Journal of Chemical & Engineering Data, 1964, Vol. 9, p178-82

An enthalpy-temperature diagram and an entropy-temperature diagram for anhydrous hydrogen fluoride were prepared by critical evaluation of published data for temperatures between -40 and 240C and absolute pressures between two and 1000 lb force/in2.

463) R. Vieweg, **Examination of the system HF-H_2O**, Chemical Technology (Berlin), 1963, Vol. 15, p734-740

463) D. Candido and G.P. Mathu (Department of Chemical Engineering, University of Windsor, Canada**), An Investigation into the Kinetics of Reaction between Fluorspar and Sulfuric Acid**, Industrial & Engineering Chemical Process Development, 1974, Vol. 13, p20-26
The reaction between fluorspar and sulfuric acid has been investigated in a batch as well as a continuous system. The continuous reactor was designed for operation under conditions that closely simulated industrial practice. Three rate models were found to yield equally satisfactory correlations for both the batch and the continuous reactor data.

Heavy water and Its Production:

1) W.G. Brown and A.F. Daggett – **A plant for the production of heavy water**
A description is given of a plant for the production of deuterium oxide by the electrolytic method which operates with a higher efficiency than has been previously reported for the method. The fractionation factor, uncorrected for evaporation, averages 8.6. Steel cells, which also serves as the cathodes, are used and the entire construction is explosion proof.

1) H.A. Smith, C.O. Thomas and J.C. Posey – **The separation of hydrogen and deuterium by the reaction of iron with water**
In the decomposition of water by reaction with iron, as in the electrolysis of water, the residual water is enriched in deuterium. Since the separation factor is an inverse function of the temperature, an attempt was made to increase the reaction rate at low temperatures.

254) **Hydrogen-Amine Process for Heavy Water Production**
W. J. HOLTSLANDER
Atomic Energy of Canada Ltd., Chemical Engineering Branch, Chalk River Nuclear Laboratories, Chalk River, Ontario
W. E. LOCKERBY
Atomic Energy of Canada Ltd., Heavy Water Projects, Tunney's Pasture, Ottawa, Ontario
Separation of Hydrogen Isotopes
Chapter 3, pp 40–52
Chapter DOI: 10.1021/bk-1978-0068.ch003
ACS Symposium Series, Vol. 68
ISBN13: 9780841204201eISBN: 9780841205192
Publication Date (Print): June 01, 1978

566) TSING-LIEN CHANGHTSIN-HUAWANG,J. of the Chinese Chemical Society.16,1949 On the electrolytic separation of hydrogen isotopes at high current densities, Journal of the Dilute solutions of D2O containing NaOH are electrolyzed at room temperature with smooth Pt wire as a cathode. At current density between 1 and 13 amp/sq. cm., the separation factor is approximately 6.5; this confirms the Eyring-Glasstone theory of overvoltage.

566) **,""PLANT FOR THE PRODUCTION OF HEAVY WATER .**
BROWN,W.G. DAGGETT,A.F.,J.CHEM.PHYS.3 ,
″1935
TX 70H107-35
A description is given of a plant for the production of deuterium oxide by the electrolytic method which operates with a higher efficiency than has been previously reported for this method. The fractionation factor, uncorrected for evaporation, averages 8.6. Steel cells, which also serve as the cathodes, are used and entire construction is explosion-proof.
566) TOPLEY,B. EYRING,H.,NATURE 133,1934 ,
TX 70H107-36
Electrolysis of H2O with various metals as electrodes gave good values for the electrolytic separation factor ranging between 7.9 and 2.8. The metals studied were; smooth Pt, Pb, Fe, Cu, Ag, Ni, W, Pt black, liquid Ga and Hg.
566) HONNY,J.,SULZER TECH.REV.(SWITZ)42,NO.2, A low temperature plant for the production of heavy water,1960 .
TX 70H107-37

566) **STUDIES ON THE PRODUCTION OF HEAVY WATER AT J.E.N**
- ALVAREZ,J. ET AL,PROC.INTERN.CONF.PEACE FUL USES AT.ENERGY,3RD,GENEVA,1964,12 .
TX 70H107-38

566) ″**SEPARATION OF HYDROGEN AND DEUTERIUM BY THE REACTION OF IRON WITH WATER .**
1959. SMITH,A.H.,ET AL,J.ELECTRICHEM.SOC.106
TX 70H107-39
In the decomposition of water by the reaction with, as in the electrolysis of water, the residual water is enriched in deuterium. Since the separation factor is an inverse function of the temperature, an attempt was made to increase the reaction rates at low temperature.
566) **PREPARATION OF HEAVY WATER**
ALEKSANDROVICH,V.A. SHELUD,KO,M.K ,.
J.APPLIED CHEM.(U.S.S.R.13)(IN FRENCH ,
"" ″448),1940,""
TX 70H107-40

566) **PEAK POWER AND HEAVY WATER PRODUCTION**
HAMMERLI,M.,ET AL.ENERGY CAN LTD,1976
FROM ELECTROLYTIC HYDROGEN AND OXYGEN USING CANDU REACTORS .
TX 70H107-41
A combined energy storage – heavy water production system is presented. Off-peak nuclear energy is stored in the form of electrolytic H2 (and O2) from which a large fraction of the deuterium has been transferred to water in an H2/H2O deuterium exchange catalytic column. The main features and advantages of the combined electrolysis-catalytic exchange D2O process are discussed.
566) **"CONCENTRATING HEAVY WATER .**
BRODSKII,A.I. ET AL.,COMPT.REND.ACAD .
SCI.U.R.S.S.3,1934,
TX 70H107-42

566) **"" PRODUCTION OF HEAVY WATER "" ..**
ALEKSANDROVICH,V.,NOVOSTI TEKNIKI
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TX 70H107-43

566) **A COMPARISON OF THE METHODS OF PREPARAING HEAVY WATER .**
BRODSKII,A.I.,J.APPLIED CHEM.(U.S.S.R)13
IN FRENCH 676
TX 70H107-44

566) **SEPARATION AND PROPERTIES OF THE ISOTOPES OF HYDROGEN .**
HAROLD C.UREY,SCIENCE.78,1933 ,
TX 70H107-45

,""ENRICHMENT OF HEAVY HYDROGEN ISOTOPE
WOLFRAM UHLMANN,NATURWISSENSCHAFLEN 22 ,″1934.
TX 70H107-46

566) **CONCENTRATION OF THE HEAVY HYDROGEN ISOTOPE BY ELECTROLYSIS .**
ERLENMEYER,H. CARTNER,H.,HELV.CHIM.ACTA
″17,1934,""
TX 70H107-47

566) **ELECTROLYSIS OF WATER**
OTA,I.Y.,MEM.FACULTY.SCI.AGR.TAIHOKU 10 .
TX 70H107-48

566) **THEORETICAL AND EXPERIMENTAL STUDIES ON THE METHOD OF OBTAINING HEAVY WATER**
KAMIENSKI,B.,ROCZNIKI CHEM.14.,1934 ,
TX 70H107-49

566) **"" CONTRIBUTION TO HYDROGEN TECHNOLOGY "" .**
KRELL,E.,ROESSLER,M.,ZFT,MITT,1982

574) A.R. Bancroft (Atomic Energy of Canada Ltd., Chalk River, Ontario), **Heavy Water GS R and D Achievements,** AECL-6215, 1978
R&D support of Canadian heavy water production plants during the past five years has mainly involved AECL and Ontario Hydro and their contractors.

582) **EXPERIMENTAL STUDIES ON THE SEPARATION OF DEUTERIUM OXIDE IN CONTINUOUS THERMAL DIFFUSION COLUMNS FOR LOW CONCENTRATION RANGE**
YEH,HO MING YANG,SHYH CHING,
SEP. SCI. TECH.,1985,20{9-10},687-98{ENG
TX ES04005

582) **METHABOLISM KINETICS OF BIOLOGICAL EFFECTS OF HEAVY WATER**

PULYAEVOSKII,A.G.,
{ GIG SANIT,1986{3},63-6{RUSS
TX 10788

582) **INDUSTRIAL PRODUCTION OF DEUTERIUM**
MURRENHOFF,A.P., ,KERNTECHNIK,6,558-60,1964{GER
TX ES04008

582) **CHEMICAL EXCHANGE PROCESSES FOR HEAVY WATER**
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507) J.R. Fair and W.L. Bolles, **Modern design of distillation columns**, Chemical Engineering, April 1968, Vol. 75, p156-175

507) R. Kern, **Layout arrangements for distillation columns**, Chemical Engineering, August 1977, Vol. 84, p153-191

507) C.J. Liddle, **Improved Short-Cut Method for Distillation Columns**, Chemical Engineering, 1968,
Vol. 75, p137-

430) R.K. Badhwar, **Quick sizing of distillation columns**, Chemical Engineering Progress, 1970, Vol. 66, p56-

430) J.S. Eckert, **Selecting the proper distillation packing**, Chemical Engineering Progress, 1970, Vol.
66, p39-44

430) M. Leva, **Film tray equipment for vacuum distillation**, 1971, Vol. 67, p65-

Graphite/graphite reactors

251) **THE EFFECT OF REACTOR IRRADIATION AT TEMPERATURES BETWEEN 400 AND 700 C ON THE THERMAL CONDUCTIVITY OF GRAPHITE**
Authors: Durand, R.E.; Klein, D.J.
Publication Date: 1956 Jul 15
OSTI Identifier: 4352789
Report Number(s): NAA-SR-1520
DOE Contract Number: AT(04-3)-49
Resource Type: Technical Report
Resource Relation: Decl. Mar. 1, 1957. Orig. Receipt Date: 31-DEC-58
Research Org: Atomics International Div., North American Aviation, Inc., Canoga Park, Calif.
Country of Publication: United States
Language: English
Format: Size: Pages: 33

Subject: CHEMISTRY; FLUID FLOW; GRAPHITE; HEATING; IRRADIATION; MEASURED VALUES; MODERATORS; NEUTRON FLUX; REACTORS; SGR; TEMPERATURE; THERMAL CONDUCTIVITY
Availability: NTIS
Update Date: 2008 Feb 05
The thermal conductivity of AGOT-CSF graphite has been measured both during and after neutron irradiation at temperatures between 350 and 650 deg C. A radial heat flow measurement during irradiation in the high flux region of the MTR showed that the thermal conductivity saturated at a value breater than one- third the initial value; this was borne out by post-irradiation measurements made in the laboratory. The graphite moderator of the SGR should therefore not cause heat-transfer problems due to deterioration of its conductive properties, since it will operate in the temperature range investigated and in a similar neutron flux. (auth)
http://www.osti.gov/energycitations/product.biblio.jsp?query_id=8&page=0&osti_id=4352789

251) **Purifying route to nuclear-grade graphite**
Cronan, C. S.
Chemical Engineering (1959), 66 (No. 4), 114-17.
Production of nuclear-grade graphite is described with the aid of a pictured flowsheet. Trace quantities of impurities such as B and V are removed by forcing CCl2F2 gas through graphite bars heated to 5000-5400°F.; the CCl2F2 decompose to F and C which react with the impurities to form volatile gases.

251) **Large interstitial loops in graphite containing boron**
R M Mayer 1966
British Journal of Applied Physics 17 431
doi:10.1088/0508-3443/17/3/118
When graphite single crystals irradiated to 4centerdot1 × 1019 neutrons/cm2 at 50-100°C are doped with boron at 1450°C and then annealed at temperatures greater than 2100°C, large interstitial loops are observed. These are not observed in crystals into which boron had not been deliberately introduced.
http://iopscience.iop.org/0508-3443/17/3/118

253) **PURIFICATION OF GRAPHITE**
Authors: Sermon, G.T.
Publication Date: 1948 Jun 16
OSTI Identifier: 4357902
Report Number(s): AECD-3912; UCP-1
DOE Contract Number: AT-30-1-GEN-127
Resource Type: Technical Report
Resource Relation: Decl. Dec. 8, 1955. Orig. Receipt Date: 31-DEC-56
Research Org: United Carbon Products Co., Inc., Bay City, Mich.
Country of Publication: United States
Language: English
Format: Size: Pages: 26
Subject: CHEMISTRY; BORON; CARBON TETRACHLORIDE; CLEANING; DENSITY; GRAPHITE; HIGH TEMPERATURE; IMPURITIES; ORGANIC FLUORINE COMPOUNDS
Availability: NTIS
Update Date: 2008 Feb 05
http://www.osti.gov/energycitations/product.biblio.jsp?query_id=4&page=0&osti_id=4357902

W.L. Kosiba, D.H. Gurinsky, and G.J. Dienes (Brookhaven National Laboratory) – **Evaluation of BNL Pile Graphite**, October 1953, BNL-255

253) E. Fast (Phillips Petroleum Company, Atomic Energy Division, Idaho Falls, Idaho) – **Graphite Damage as an Index to the Integrated Damaging Neutron Flux**, September 1954, IDO-16182

253) W.C. Riley and E.M. Woodruff (Hanford Atomic Products Operation, Richland, Washington) – **Thermal Expansion of Pile Graphites**, May 1956, HW-43395

253) J.M. Davidson, E.M. Woodruff and H.H. Yoshikawa (General Electric Company, Hanford Atomic Products Operation) – **High Temperature Radiation Induced Graphite Contraction**, February 1959, HW-57900
Information concerning graphite contraction applicable to high-temperature, graphite-moderated reactors is presented. The scope includes relevant data from all available sources, interpretation and extrapolations as can reasonably be made, and a discussion of the effects observed in terms of current radiation theory.

253) G.T. Sermon (United Carbon Products Company, Bay City, Michigan) **– Purification of Graphite, June 1948**, AECD-3912

253) H.B.F. Gow and W.R. Marsh (UKAEA, Atomic Energy Research Establish, Harwell, UK) **– The Effect of Temperature on the Carbon Dioxide-Graphite Reaction Under Pile Radiation**, November 1958, AERE-C/M-361
The rate of the reaction between carbon dioxide and graphite under the influence of pile radiation was studied at 350 and 500 C. No significance was observed in the rate of the reaction at these two temperatures.

253) M. Tomlinson (UKAEA, Atomic Energy Research Establish, Harwell, UK) – **Comparison of Data on the Oxidation of Graphite in Reactors,** April 1959, AERE-C/R-2619
Various reported values for the rate of oxidation of reactor-grade graphite when irradiated in air in a reactor at normal operating temperatures (60 to 200 deg C) show seemingly wide discrepancies, i.e. oxidation rates ranging 0.024 to 4.5% graphite weight loss per IO20/neutrons/cm2. It is shown how these apparent discrepancies can be reconciled in terms of the reaction scheme proposed. The apparent discrepancies arise because the oxidation rate is critically perdeat upon the geometry of the system and the gas flow rate.

253) N.S. Corney and R.B. Thomas (UKAEA, Atomic Energy Research Establish, Harwell, UK) **– The Effect of Pile Radiation on the Reaction between Hydrogen and Graphite**, June 1958, AERE-C/R-2502
The effect of pile radiation on the reaction between hydrogen and graphite was studied in a apparatus in BEPO. The apparatus was an all glass circulating system, with the graphite specimen at a controlled temperature in the core of the reactor. The results can be accounted for qualitatively if it is assumed that the reaction proceeds through very short lived active intermediates which are formed by the action of pile radiation on hydrogen.

253) E. Goodman and R. Thompson (Value Engineering Company, Alexandria, Virginia) **– Electrodeposition of erosion and oxidation resistant coatings for graphite**, March 1963

253) J.C. Bokros and R.S. Price (General Atomics Division, General Dynamics Corporation, San Diego) – **Dimensional Changes Induced in Pyrolytic Carbon by High-Temperature Fast-Neutron Irradiation,** January 1967, GA-7339

253) G. Hennig (Argonne National Laboratory) – **A Comparison of the Effects of Oxidation and the Effects of Neutron Irradiation on Graphite**, February 1952, ANL-4765

253) **FINAL REPORT. PART II. TECHNICAL**
Authors: Brooks, L.; Sermon, G.T.
Publication Date: 1949 May 20
OSTI Identifier: 4371868
Report Number(s): AECD-3913; UCP-2
DOE Contract Number: AT-30-1-GEN-127
Resource Type: Technical Report
Resource Relation: Decl. Dec. 7, 1955. Orig. Receipt Date: 31-DEC-56
Research Org: United Carbon Products Co., Inc., Bay City, Mich.
Country of Publication: United States
Language: English
Format: Size: Pages: 20
Subject: CHEMISTRY; BORON; CARBON TETRACHLORIDE; COMBUSTION; GRAPHITE; HIGH TEMPERATURE; IMPURITIES; ORGANIC FLUORINE COMPOUNDS; SEPARATION PROCESSES
Availability: NTIS
Update Date: 2008 Feb 05
http://www.osti.gov/energycitations/product.biblio.jsp?query_id=31&page=0&osti_id=4371868

253) **RESEARCH ON GRAPHITE. Annual Report, July 1, 1971--June 30, 1972, and Summary of Program Since Inception.**
Authors: Engle, G.B.
Publication Date: 1972 Jan 01
OSTI Identifier: 4664030
Report Number(s): GULF-GA-A--12138
DOE Contract Number: AT(04-3)-167.
Resource Type: Technical Report
Resource Relation: UNCL. Orig. Receipt Date: 31-DEC-72
Research Org: Gulf General Atomic Co., San Diego, Calif.
Sponsoring Org: USDOE
Country of Publication: United States
Language: English
Format: Size: Pages: 55
Subject: N50340* --Metals, Ceramics, & Other Materials--Plastics & Other Materials--Radiation Effects; ANNEALING-- DEFORMATION-- DIFFUSION-- FABRICATION-- FAST NEUTRONS-- FRACTURES-- MICROSTRUCTURE-- PYROLYTIC CARBON-- RADIATION EFFECTS-- RECOILS-- THERMAL CONDUCTIVITY-- THERMAL EXPANSION-- THORIUM-- TRACER TECHNIQUES-- URANIUM; BINDERS-- FABRICATION-- GRAPHITE-- HOT WORKING-- IMPREGNATION-- MECHANICAL PROPERTIES-- MICROSTRUCTURE-- PHYSICAL PROPERTIES-- RESINS; DIFFUSION-- FISSION PRODUCTS-- FUEL PARTICLES-- URANIUM CARBIDES

Related Subject: CARBON/fabrication and structure of pyrolytic; CARBON/ radiation effects on properties and stability of, fast neutron; FISSION PRODUCTS/ diffusion from uranium carbide fuel spheres, kinetics of; URANIUM CARBIDES/ fission product release from spherical fuel particles of, kinetics of; NEUTRONS, FAST/effects on properties and stability of graphite and pyrolytic carbon; GRAPHITE/microstructure of, research on factors controlling; URANIUM/diffusion in pyrolytic carbon, tracer studies of; THORIUM/diffusion in pyrolytic carbon, tracer studies of; GRAPHITE/radiation effects on properties and stability of, fast neutron; CARBON/diffusion of thorium and uranium in pyrolytic, tracer studies of; CARBON/properties of pyrolytic, mechanical and thermal
Availability: Dep.; NTIS.
Update Date: 2009 Jul 06
http://www.osti.gov/energycitations/product.biblio.jsp?query_id=21&page=0&osti_id=4664030

253) **GRAPHITE OUTGASSING**
Authors: Eggleston, R.R.; Carter, R.L.; Greening, W.J.; Durand, R.E.
Publication Date: 1955 Jan 21
OSTI Identifier: 4290424
Report Number(s): NAA-SR-Memo-1240
Resource Type: Technical Report
Resource Relation: Changed from OFFICIAL USE ONLY Sept. 9, 1958. Orig. Receipt Date: 31-DEC-58
Research Org: North American Aviation, Inc., Downey, Calif.
Country of Publication: United States
Language: English
Format: Size: Pages: 14
Subject: CHEMISTRY; ADSORPTION; GASES; GRAPHITE; MECHANICAL PROPERTIES; QUANTITATIVE ANALYSIS; ZIRCONIUM
Availability: NTIS
Update Date: 2008 Feb 25
The amounts and composition of the gas evolved from various types of graphite under SRE operating conditions were determined. The information is of importance in design of SRE Zr moderater cans because of possible pressure build- up in the cans or the deleterious effects of the gas on the mechanical properties of Zr. Gas realisorption is discussed, along with results of gas analysis, emphasizing the implicaticns of the gases found by analysis. (J.R.D.)
http://www.osti.gov/energycitations/product.biblio.jsp?query_id=15&page=0&osti_id=4290424

253) **OXIDATION OF GRAPHITE UNDER HIGH TEMPERATURE REACTOR CONDITIONS**
Authors: Dahl, R.E.
Publication Date: 1961 Jul 01
OSTI Identifier: 4798328
Report Number(s): HW-68493
DOE Contract Number: AT(45-1)-1350
Resource Type: Technical Report
Resource Relation: Orig. Receipt Date: 31-DEC-62
Research Org: General Electric Co. Hanford Atomic Products Operation, Richland, Wash.
Country of Publication: United States
Language: English

Format: Size: Pages: 38
Subject: METALS, CERAMICS, AND OTHER MATERIALS; ACTIVATION ENERGY; CHEMICAL REACTIONS; EXCITATION; GAMMA RADIATION; GAS FLOW; GRAPHITE; HIGH TEMPERATURE; NEUTRON FLUX; OXIDATION; REACTION KINETICS; REACTORS; SURFACES; TEMPERATURE; VOLUME
Update Date: 2008 Feb 05
A kinetic study was conducted to provide information on oxidation of reactor graphites in the temperature range of 450 to 675 deg C and on the effects of reactor environment on oxidation rates. Among the parameters studied were chemical reactivity of the graphite, prior oxidation, a high intensity gamma flux during oxidation, variation of the surface-to-volume ratio of the graphite specimens, neutron bombardment prior to oxidation exposure, and gas flow rates. Rate equations showed apparent activation energies of 50 kcal/mole in the absence of radiation and 30 kcal/mole in the presence of a 1 x 10/sup 6/ r/hr gamma flux. (auth)
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253) **SURFACE STUDIES OF IRRADIATED GRAPHITE**
Authors: Spalaris, C.N.
Publication Date: 1953 Jul 14
OSTI Identifier: 4326551
Report Number(s): HW-29082
DOE Contract Number: W-31-109-ENG-52
Resource Type: Technical Report
Resource Relation: Decl. Feb. 7, 1957. Orig. Receipt Date: 31-DEC-57
Research Org: Hanford Atomic Products Operation, Richland, Wash.
Country of Publication: United States
Language: English
Format: Size: Pages: 28
Subject: CHEMISTRY; GRAPHITE; MEASURED VALUES; OXIDATION; POROSITY; RADIATION EFFECTS; SURFACES
Availability: NTIS
Update Date: 2008 Feb 05
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Publication Date: 1955 Nov 22
OSTI Identifier: 4361007
Report Number(s): HW-40142
DOE Contract Number: W-31-109-ENG-52
Resource Type: Technical Report
Resource Relation: Orig. Receipt Date: 31-DEC-56
Research Org: Hanford Atomic Products Operation, Richland, Wash.
Country of Publication: United States
Language: English
Format: Size: Pages: 52
Subject: CHEMISTRY; ALUMINUM-- CARBON DIOXIDE-- CARBON FLUORIDES-- CARBON MONOXIDE-- CARBON OXIDES-- CHEMICAL REACTIONS-- CONCENTRATION--

DECOMPOSITION-- EFFICIENCY-- GASES-- GRAPHITE-- HELIUM-- IONIZATION-- IONS-- IRRADIATION-- LOW TEMPERATURE-- MEASURED VALUES-- MIXING-- NITROGEN-- NUMERICALS-- OXYGEN-- POLYMERS-- PRODUCTION-- QUANTITY RATIO-- RADIATION CHEMISTRY-- RADIATION DOSES-- RADIATION EFFECTS-- RADIOLYSIS-- REACTION KINETICS-- REACTORS-- REDUCTION-- SOLIDS-- TABLES-- TEMPERATURE-- VAPORS-- WATER-- WATER COOLANT; ALUMINUM-- CARBON DIOXIDE-- CARBON FLUORIDES-- CHEMICAL REACTIONS-- IRRADIATION-- MEASURED VALUES-- PRODUCTION-- QUARTZ-- RADIATION CHEMISTRY-
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