UNITED STATES ATOMIC ENERGY COMMISSION

AECU-2900

PROCEEDINGS

UNIVERSITY RESEARCH REACTOR CONFERENCE

Oak Ridge, Tennessee
February 17-18, 1954

Edited by
W. W. Grigorieff

Technical Information Service, Oak Ridge, Tennessee

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Edited by
W. W. Grigorieff

Presented by
OAK RIDGE INSTITUTE OF NUCLEAR STUDIES
and
OAK RIDGE NATIONAL LABORATORY

in cooperation with the
Unclassified Reactor Subcommittee
Committee on Nuclear Science
Division of Physical Sciences
NATIONAL RESEARCH COUNCIL

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FOREWORD

The proceedings of the University Research Reactor Conference held in Oak Ridge on February 17 and 18, 1954, cover the material presented in the formal papers, in the round table discussions, and in the question periods of the conference. The formal manuscripts and the verbatim recording of the meeting have been reviewed by the authors, compiled and edited by the Institute staff, and represent a complete summary of the information made available by the conference. The editors have taken the liberty of rearranging the sequence of some of the presentations in an effort to make the proceedings more meaningful to the reader who has not attended the conference.

The conference was planned with a threefold purpose in view:

- (1) To summarize the plans of educational institutions already owning, or planning to build reactors;
- (2) To discuss specific problems of low power reactor construction, such as availability of fuel, personnel requirements, and cost; and
- (3) To examine the educational significance of research reactors.

Delegates from 51 universities in 31 states joined with representatives of some 30 industrial concerns and of a score of government agencies to participate with Oak Ridge scientists in the two-day discussions, making a total attendance of approximately 150.

It is our hope that the conference has helped to give to the participants and to the readers of these proceedings a clearer understanding of some of the problems connected with university research reactors. The fact that this meeting provided an opportunity for a free discussion of:

- (1) the relative merits of reactors as compared to other research machines
- (2) the significant characteristics of several different types of reactors
- (3) the variety of research possibilities of nuclear reactors, does indicate that conferences of this type can be of distinct help in the continuing development of the peaceful utilization of atomic energy.

The sponsors of the University Research Reactor Conference are grateful to the National Research Council for its active cooperation in presenting the conference. Both the Washington and Oak Ridge offices of the Atomic Energy Commission contributed greatly to the success of this undertaking.

I would like to extend my warm appreciation to all of the speakers who made the conference possible and to all of the members of the contributing organizations who helped to conduct it. K. Kasschau, Director, and H. M. Roth, Assistant Director, of the Research and Medicine Division of the AEC Oak Ridge Operations Office have contributed generously of their time and advice. A. M. Weinberg, Research Director of the Oak Ridge National Laboratory, was extremely helpful in the planning work, conducted one of the panels, gave an enlightening talk on European reactors at the dinner, and made possible the conferees' visit to the ORNL uranium graphite and swimming pool reactors. C. K. Beck of North Carolina State College and L. B. Borst of the University of Utah were directly responsible for much of the planning

and they provided able leadership as chairmen of the two afternoon discussion sessions. D. D. Cowen, Superintendent of the Information and Reports Division of ORNL, and his staff were responsible for the smooth operation of most of the local arrangements. D. Johnson and L. McIlhenny, of the ORINS Information Department, assisted in the conduct of the conference and in the assembling and editing of the proceedings. W. C. Busby and N. Strange of this office gave untiringly of their time to the general work of arranging the conference. Last, but certainly not least, W. G. Pollard's leadership made the conference possible.

R. L. Metter, R. L. Cummins, E. C. Schulte, and the staff of the AEC Technical Information Service produced these proceedings in a skillful and efficient manner.

W. W. Grigorieff
Chairman, University Relations Division
Oak Ridge Institute of Nuclear Studies

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I. FACTORS BEARING ON REACTOR CONSTRUCTION

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STATEMENT OF AEC POLICY ON REACTOR OWNERSHIP BY NON-PROFIT INSTITUTIONS

by Thomas H. Johnson*

This conference affords an excellent opportunity to state the policy of the Atomic Energy Commission with respect to university research reactors.

Approval for the research reactor at North Carolina was given by the Atomic Energy Commission in 1949. It was given because it looked like a reasonable thing to do. Of course the Atomic Energy Commission in dealing with the public can't do things just because they are reasonable. It has to have a policy. It has to act consistently. So, although the approval of the reactor was a perfectly reasonable thing, the Commission was concerned about what it would do if other requests were submitted or if there were some variations in the type of requests.

When I came to Washington in the fall of 1951, one of the first chores ahead of me was to develop a policy for the Atomic Energy Commission in case it should have any other requests for research reactors. As a matter of fact, there were a few requests on the books at that time which were being held back while a policy could be developed.

One of the most important questions in developing this policy was whether it was reasonable and feasible to have reactors on university campuses. This of course was a question which could only be answered by the joint effort of the Commission and of the universities. So one of my first chores was to meet with people who were interested in acquiring reactors. I had a meeting with a committee of the American Society of Engineering Education in Chicago, I think it was in the fall of 1952, and I discussed the problem with many other people informally.

These studies culminated in a statement of policy which was approved by the Commission in the spring of 1953, about a year ago. However, at that time no public statement was made of the Commission's policy for two or three reasons. One was that the course which had been decided upon for lending financial assistance did not really offer anything new, so there wasn't anything in that respect to announce. Moreover, it was felt that the action that had already been taken on the Raleigh reactor made people pretty well aware of what our policy was with respect to research reactors.

However the invitation to speak to this group was obviously a good opportunity to make a statement of the Commission's policy. For this purpose I have prepared a formal statement which I ask your indulgence to read. I think this pretty well boils down the important considerations.

* Thomas H. Johnson is Director of the Division of Research of the Atomic Energy Commission. Prior to taking his present post, he was chairman of the Physics Department, Brookhaven National Laboratory. Dr. Johnson served as assistant director of the Bartol Research Foundation for several years. During World War II, he was chief physicist, ballistics research laboratory, Aberdeen Proving Grounds.

I would like to emphasize again that policy in this field is not something that the Commission can push ahead with alone, but it does require your cooperation; I am sure the last word has not yet been said with respect to policy. I would like to say that I think this conference can serve a very important function in developing national policy with respect to research reactors, in developing your policy as well as helping us in the Commission to think further what our policy should be. I think all would agree that it is not something that we should go into precipitously. I am sure that you are not anxious to go into it precipitously.

In talking with people, I find that they are concerned about how safe a reactor is, whether it really is the feasible thing to have, and they are looking to see what the other fellow is doing, and how he makes out. In this respect I think we all owe a debt of gratitude to Dr. Beck for going ahead courageously with the first privately owned reactor and leading the way.

I also would like to express my great appreciation for this opportunity which was brought about by Dr. Borst's efforts in the National Research Council, and by Dr. Pollard and Dr. Grigorieff in the Oak Ridge Institute of Nuclear Studies.

Lest the prepared statement that I have here fails to convey the right impression, I would like to state quite plainly that the climate in Washington now seems quite favorable towards going ahead with research reactors. I had the opportunity, a couple of weeks ago, to testify before the Subcommittee on Reactors, of the Joint Committee on Atomic Energy, where the approach was: What is holding us back in university programs? Why aren't we going ahead faster?

I had to say that people are hesitant for this reason or that, and that the Commission is developing its policy as fast as it can while trying to do it reasonably. We are anxious to build useful facilities and not monuments to stupid planning. I think it is interesting that the climate in Congress does seem quite favorable.

The President's speech on international assistance in atomic energy may have changed the Congressional climate somewhat. One question that was brought out in the hearing was, if we are proposing to give substantial quantities of fissionable material or loan substantial quantities of fissionable material to other countries, then why aren't we using it ourselves more extensively in connection with research and peaceful applications? The President's speech has had an important effect.

The Atomic Energy Act of 1946 directs the Atomic Energy Commission to distribute sufficient fissionable material to permit the conduct of wide-spread independent research and development activity to the maximum extent practicable, subject to a number of conditions and limitations.

In view of the rising tide of interest among the universities and other research institutions in acquiring reactors, the AEC has adopted a uniform policy for dealing with institutions requesting the loan of fissionable material for use in reactors for independent research and training. Only until recently has it been feasible for a university or a research institute to consider having a reactor of its own, or for the Commission to allocate materials for such purposes.

Reactor designs were classified; fissionable material was in short supply; and the safety of the reactors was unproven. Furthermore, facilities have not until recently been available to reprocess the material so it could be returned to the stockpile in case of emergent military need.

During the first decade of the atomic energy project, the only reactors available for research were therefore those in the national laboratories. These have proven of great value for research in several fields of science and they have been used for basic investigations by visitors from independent laboratories as well as by staff members of the national laboratories themselves.

The steady advance of the reactor technology has now reached the point where it is believed to be both feasible and in the national interest to permit a few reactors to be built in the universities and research institutions. As a result of work sponsored by the Commission, several reactor designs are available which provide simplicity, safety, and predictable operating characteristics at a cost well within the reach of some universities. These designs are either wholly declassified or the classified features are so limited as not necessarily to prevent their consideration for independent use.

Furthermore, fissionable material is in sufficient supply to permit some allocation for research to institutions where there is evident technical competence and other assurances that the facility will be utilized efficiently and for purposes which are clearly in the public interest. Fissionable material is too costly and its supply is insufficient to allow the Commission, in the national interest, to make indiscriminate distribution.

Furthermore, loans of material cannot be made without some cost to the Government. The burn-up of fissionable material in a low-powered reactor is small, but not negligible; and extra costs are associated with the preparation of the material and with its reprocessing. These factors indicate that the Commission must make a careful appraisal of the purposes for which fissionable material is to be used and of the competence of those to whom its use is entrusted.

It is of course not necessary that the use of material be restricted to those investigations which are intended to advance the immediate and limited objectives of the Commission. However, the Commission must be reasonably assured that the institution receiving fissionable material has the resources to make good use of it for a reasonable period of time, as represented in its applications for the material. The AEC has already made a loan of 999 grams of U-235 to North Carolina State College and Penn State University has been assured that up to 4 kilograms will be made available when its reactor is constructed and ready for operation.

The law restricts the distribution of fissionable material (a) to such quantities and to loans on such terms that no applicant will be enabled to obtain an amount sufficient to construct a bomb or other military weapon; (b) to applicants who are equipped to observe and who do not fail to observe such health and safety standards as are or may be established by the Commission; and (c) to an extent which will not prevent the Commission from making such provisions for its own needs and for such conservation of fissionable material as it may determine to be in the national interest for the future development of atomic energy.

Except for transfers to the military under Presidential directive, all fissionable material must remain under the ownership of the Commission and it will be subject to recall when needed by the Commission. These restrictions may limit the size or power level of reactors which can be independently operated. They will require rather rigid specifications on operating procedures and on features of the structure and equipment which have a bearing on health and safety; and they may limit the number of reactors which can be built in any year.

The principal obstacles to the off-site construction of reactors in my opinion have been, first, the uncertainty that a reactor can be safely operated on the average college campus. However, when recent tests relevant to the swimming pool type reactor have been fully evaluated, they may give the necessary assurance that reactors of this type can be operated safely at the desired power level.

The North Carolina reactor and the Penn State reactor have been carefully considered by the Reactor Safeguards Committee, and were judged to be safe under the operating procedures proposed. Let me interject here to say that one of the questions that the Congressmen had when I testified before them two weeks ago was whether we weren't impeding the program unrealistically and unnecessarily by the Reactor Safeguards Committee approach toward the evaluation of hazards.

My feeling is—and if this is not your feeling I would be pleased to hear about it in any discussion—that the average university administration wishes to get some expert advice on the safety of a reactor and the advice of a Reactor Safeguards Committee as a board of experts in these matters does provide a useful source of advice which is desired by the universities as much as it is by the Commission.

The second obstacle to the program of research reactors has been the legal restriction on the amount of fissionable material. This restriction limits the amount that can be distributed to less than would enable the recipient to make a bomb. This has never been defined in terms of kilograms in public, but I can say that it would take legislative action to remove this restriction and permit the outright loan of the amounts of fissionable material sufficient for the operation of some desirable reactor types.

Under the present law, however, it would be possible to allocate material under the custodianship of an AEC employee. This is an unsatisfactory way of doing it, but one that could be resorted to as an interim measure looking forward to possible legislative action.

I think most people who think about this problem believe that the law should be changed in this respect.

When material can be loaned in sufficient quantities and when confidence in the safety of the operation has been established, there is evidence that many universities may wish to acquire a reactor. Usually the interest is centered in the physics or engineering departments of the graduate school, but it invariably extends to the department of chemistry, biology, medicine, and even into geology. Most of the contemplated uses are associated with the research programs; and except in some of the engineering schools, there is little serious thought of using the reactor in connection with formal courses.

In its versatility for research of many kinds, in its capacity to accommodate several investigations at a time, and in its reliability of operation, a reactor should prove to be a very satisfactory facility for university research. Although I think no one would claim that a moderately powered research reactor would put a university in a position to make revolutionary scientific discoveries, yet in many fields of investigation which are accessible with such a reactor, there has been but little exploration; and substantial uses for it would be found on the campus.

Some investigations which might be started with a small reactor could then be taken in the later stages to a more powerful reactor in one of the National Laboratories. Interest in reactors in engineering schools is primarily associated with the desire to meet the immediate requirements of the atomic energy program for more engineers trained in nuclear science. There is, moreover, an underlying anticipation of the opportunities for engineering careers when industrial power from atomic energy becomes an economic reality.

The value of a reactor in the engineering school program lies chiefly in its indirect effect on undergraduate instruction through stimulation of research on the part of the staff and the graduate students. The existence of a reactor on the campus would enable the engineering school to attract a research-minded faculty with interests in atomic energy. The research of such groups might also lead to important contributions to nuclear technology. It may not be supposed that those directly employed in the program of the Commission have thought or will think of all of the possibilities for the release and utilization of atomic energy. The unorthodox approaches which might be taken by university groups could have very important consequences.

This thought leads to an important principle affecting the financing of university reactor projects. There is evidence that the benefit of unorthodox thinking might not be fully realized if the university reactors were operated under contract with the Commission. In research, and in education, as in industrial development, there is virtue in encouraging the use of private capital for making independent approaches to the problems of atomic energy.

It is therefore the intent of the Commission to limit the use of its funds to the bare minimum needed to ensure adequate increase in the number of independent reactors to keep pace with the growing interest in atomic energy; and at the same time to restrict their installation to those institutions which have the determination, the resources, and the technical competence needed for their successful operation and efficient utilization.

The ends of the program will be best served if all of the expenses of construction of the associated buildings can be met by the institutions without financial help from the Commission. Many of these advantages of an off-site reactor program would appear to be lost if the Commission were to contribute even the major share of the costs of such projects.

It is, I think, quite evident that if the Commission were to pay all the costs of reactor projects, we would soon have too many such projects underway. It would be impossible to discriminate between applicants in order to keep the number down to a reasonable level. I think every reasonable person would agree that we should go into this somewhat cautiously because, in the first place, it isn't entirely clear how many careers there are going to be in atomic energy; how many engineering students we want to train in this field; and we are also not sure what the best type of a reactor would be for the purpose.

So a cautious approach, looking at the problem nation-wide, is a judicious one. The requirement of independent financing is an automatic way of regulating the number.

Independence in operation is even more desirable than in the construction. Normally the Commission would not supply fissionable material for an independent reactor if its operation

were foreseen to depend upon AEC support. There are several basic reactor designs suitable for research purposes which have been demonstrated in AEC laboratories. Minor variations in design of any of these reactors could be made to meet special requirements of the university, but an institution would not be encouraged to embark upon a radical new design of its own since this might run into undesirable classifications as well as potential technical difficulty. While it is anticipated that programs will be conducted as far as possible on an unclassified basis, conditions may exist or may develop in such a way as to require the application of security measures for the protection of information and materials, including the safety of personnel and the establishment of appropriate physical barriers and the provisions for the guarding of areas and materials commensurate with the degree of security.

In any case, at least one individual associated with the university reactor project should be designated as the security monitor and be cleared for access to restricted data and thoroughly indoctrinated in the Atomic Energy Commission's security requirements. As we see it now, most of these reactors, will be entirely unclassified and no guards needed. The Commission must assure itself that fissionable material will not fall into the hands of unauthorized persons. Since material for a reactor would be inside the shield, and, after initial use, highly radioactive, reasonable measures taken to safeguard the instruments and equipment in the reactor building would probably provide adequate protection for the reactor core.

Regulations require that the Commission shall not distribute material to any applicant who is not equipped or who fails to observe safety standards to protect health and to minimize danger from explosion or other hazards to life or property. Therefore the Commission must be assured at all times that the operation of the reactor does not involve unusual hazards to life and property, either on the site or in the environs. The design of the facility and the operating procedures will therefore be subject to the inspection and approval of the Commission.

Exposure tolerances and means of monitoring radiation should conform with the safety standards approved by the Commission. Moreover, in the agreement under which the material is loaned, there should be no implication of responsibility on the part of the Commission for damages to life or property resulting from the operation of the reactor.

The Commission would expect full disclosure in the literature of unclassified results of scientific interest resulting from the use of an independent reactor; and patent rights and inventions made by the use of the reactor would comply with the provisions of the Atomic Energy Act. If information affecting the national security were developed as a result of the operations, it would be the duty of the security monitor to restrict its dissemination and refer it to the AEC for appropriate classification. The use and distribution of radioisotopes, regardless of where they are produced, are subject to the regulation of the Isotopes Division of the Atomic Energy Commission. The possession of the reactor would not give an institution any special prerogatives in this matter, and the regulations which have been developed for handling isotopes produced by the Commission would also apply to those produced in other facilities.

Summarizing the present policy, the Commission will loan fissionable material for independent reactors without charge for rent or processing when this material is not in immediate demand for military or other use by the Commission, provided the Commission is assured by an examination of the evidence that (a) the institution has a financial plan which adequately provides for the construction of the reactor and for its continued operation for a reasonable period of time; (b) the design and operation of the reactor will be in the hands of responsible and technically competent people; (c) the reactor will be used in a well-conceived research program which may be expected to contribute significantly to the training of students in nuclear research, in engineering or other fields of science; and the loan meets the requirements of the Atomic Energy Act and the regulations of the Commission as regards the amount of material, security classification, accountability, and health and safety.

With regard to the financing or financial help that can be expected from the Commission, the Commission will not commit itself to support the operation of the reactor, nor to paying the costs of the building which houses the reactor. But, subject to the availability of funds for this purpose, the Commission will consider partial support of the construction of reactors at non-profit institutions.

DISCUSSION

QUESTION: Is it possible to design a reactor without access to classified information?

MR. JOHNSON: Are you asking whether you can avoid getting into any classified information in the design of your reactor? I take it you prefer to avoid getting into any classified information. Of course in drawing up plans for a university reactor, the Commission is very glad to have members of the university staff cleared for access to classified designs, especially if they have a bearing on the university design. Of course declassification is often undertaken when there is some advantage to be gained from declassifying; at least this is one of the considerations.

If someone wants some information declassified, then this is often the incentive for having declassification considered; so that I think the fact that a reactor is now classified and seems to have desirable features for a university reactor is perhaps not sufficient reason for it not being considered. Of course there are some reactors which are completely declassified. There are others which are in the mill.

Dr. Beckerley will talk about that aspect of it. I think it would be possible for a university group which wants to avoid classification altogether to go ahead with their plan. I don't see why they would want to. It seems to me that the University of Michigan people put it very succinctly and clearly. They feel that classification is temporary and they are here to stay.

QUESTION: Would the AEC assume any liability associated with the operation of a private reactor?

MR. JOHNSON: I don't know that I would want to say anything but no to that question. There is also a problem in connection with university contracts where accelerators or other facilities are used that is also being posed. The general approach is to get the other party to assume the risks.

QUESTION: Is it the policy of the Atomic Energy Commission to demand a bond or other financial responsibility on the part of the university before the Commission would loan the material?

MR. JOHNSON: I am not sure I can answer that one. The Oak Ridge office has been handling these contracts. Perhaps Dr. Roth could answer. (Dr. Roth answered that the Atomic Energy Commission has not been requiring a bond in view of the fact that safety provisions are reviewed periodically and the material could be withdrawn at any time.)

QUESTION: I wonder whether the Commission would discourage or exclude foreign students, who usually are in rather large numbers at the larger universities. Will there be any policy recommendation in that respect?

MR. JOHNSON: The Commission would not attempt to regulate either the personnel who had access to the reactor nor the program that was pursued. We would review the program as a whole to see that it was a reasonable program. We would like to look at the qualifications of the people who were directing the program to make sure that we had reasonable assurance that they would conduct a meaningful research program. But then there would be no attempt to regulate either the program or the people who have access to it.

QUESTION: To what extent will the Commission want to review the individual programs presented by the universities?

MR. JOHNSON: We would like to have an outline of your program, the kind of things that you will foresee as being of interest in your research program, merely from the point of view of assuring ourselves that it is a meaningful program, one that is worthwhile from the scientific point of view, and one that is not a misuse of valuable material.

Of course if a reputable group is committing their time to it, it would be presumed that it would be a meaningful program. However, we would want to avoid a situation in which someone goes into a program enthusiastically and without any thought, and then after a year or so finds that it really wasn't worthwhile after all, and lets the fissionable material lie in disuse.

QUESTION: The reason I asked the question is that in our previous history we had one disagreement with a Commission agency on the value of a particular experimental program. The reason I like to bring it up is that we won. I would not be talking about it if we had lost.

I mean we won in the sense that the program succeeded where there was quite a bit of doubt as to whether we would succeed or not.

I think one of the most valuable features of getting the reactors on to university campuses is that this type of disagreement will be stimulated. Maybe we are not ready to answer the question, but what will we do if there is a disagreement on the value of a particular research approach where there are reasonable people on both sides?

MR. JOHNSON: The Commission would not attempt to prevent a university from undertaking a research program. All we would want to be assured of is that there was some substantial program there that looks reasonable. I think I have covered in my statement the advantages of the unorthodox approach. I can certainly foresee that the independent and the unorthodox approach might result in very important consequences.

PROCESSING OF PROPOSALS FOR FISSIONABLE MATERIAL

by William J. Knox*

Dr. Johnson has discussed AEC policy with regard to research reactors for independent institutions. I would like to mention briefly some other aspects of the AEC's handling of proposals for fissionable material for use in research reactors.

First I would like to request that you inform the Commission of your plans as early as possible. The Commission, for example, tries to anticipate and plan for requirements for fissionable material for research purposes about a year in advance; and while these anticipated requirements are not entirely rigid, it is desired to make them as realistic as possible.

Research reactors for physical research, and nuclear engineering training purposes are handled by the Division of Research of the Commission, and those for medical and biological uses are handled by the Division of Biology and Medicine.

The Commission must give formal approval to each allocation of fissionable material for use in a research reactor; and, as has been stated, it desires to have assurances that there is an adequate financial plan for the construction and operation of the reactor; that the reactor will be used in a well conceived research and training program; that the reactor project is under the supervision of competent technical personnel; and that the requirements of the Atomic Energy Act are observed. Consequently, at some time in the course of the development of the reactor project a formal proposal should be submitted to the Commission discussing in some detail these points.

It has been the practice of the Division of Research and the Operations Office at an early stage, if the institution so desires, to enter into a no-fund contract or study agreement with the institution in order to help in the preparation of a proposal. The purpose of this contract is to provide for clearance of personnel, access to restricted data and some Commission facilities, and opportunity for consulting within the Commission on reactor design and operation.

Even though the intent may be to operate an entirely unclassified reactor facility, it is probably desirable to be aware of certain design and safety and operating procedures within the AEC, some parts of which may be classified. During the study phase, information may be obtained on such subjects as the Commission's standards for the protection of personnel from radiation; and its requirements regarding the distribution of isotopes and the storage and protection of fissionable material. These points have all been discussed.

*William J. Knox is on leave of absence from Yale University to serve as Physicist, Physics and Mathematics Branch, Division of Research, U. S. Atomic Energy Commission. Dr. Knox is a veteran of the atomic energy project, having worked at the plutonium project at the University of Chicago, Oak Ridge, and Hanford as well as serving as a part-time physicist at the University of California Radiation Laboratory while doing graduate work at the University.

A proposal worked out through a study agreement or otherwise should contain at least a conceptual over-all design of the reactor, a detailed summary of the hazards associated with the use of the reactor and the control and safety features designed to minimize the hazards—this for presentation to the Advisory Committee on Reactor Safeguards, about which you will hear more tomorrow, I believe; a general discussion of the research and training program associated with the reactor, and the personnel to be in charge of the reactor program and operations; and sufficient detail on the financial plan to ensure that the reactor can be completed and operated. The proposal should, of course, be formally approved by the institution which wishes to acquire the reactor. The institution or its contractor would be expected to present and discuss the hazard summary report before the Advisory Committee on Reactor Safeguards.

Upon consideration of a proposal and the comments of the Reactor Safeguards Committee, the Commission may agree to supply fissionable material in a form suitable for the operation of a reactor, usually subject to final inspection and approval of the safety and security aspects of the reactor facility as constructed.

This should, we believe, constitute sufficient assurance for the institution to proceed with its own plans and construct a reactor if it desires.

A question came up this morning about the amount of fissionable material which might be allocated to a university or other institution for a research reactor. It is already necessary to take special provisions in order to provide the amount of material necessary to operate a swimming pool reactor. This arrangement, as Dr. Johnson has mentioned, may be the assignment of an AEC custodian to the site to have control and supervision of the material. We hope that this will be a temporary situation and that the Atomic Energy Act will be modified, possibly in this session of Congress, to permit a suitable loan or licensing agreement for the use of the material.

But even under the present law, there is no arbitrary restriction on the quantity of material which can be allocated for a research reactor providing that these other special provisions are made. In other words, reasonable requirements for excess reactivity and burn-up and the use of extra fuel elements as gamma irradiation sources will be recognized as legitimate requirements. Any other quantities which are required over and above these amounts for specific research purposes can be justified on the basis of the program in which they will be used.

SECURITY AND CLASSIFICATION

by James G. Beckerley*

Were it not for the existence of an unusual law in this country, my comments would not be appropriate in the present conference. You would be better occupied in the consideration of the technical, safety and administrative problems of designing, constructing and operating research reactor facilities.

However, when the Atomic Energy Commission Act was written, fissionable material was scarce and the experience in its use was limited to manufacturing now obsolete weapons and to providing fuel for a few research reactors. Since the existence and performance of the weapons was public knowledge, and quite impressive, and since at that time almost nothing had been published on enriched research reactors, it was not unexpected that the law would develop as it did. Weapons were the primary destination for fissionable material; and obviously it was assumed that anyone interested in fissionable material was entering a weapons program.

To be sure, the law recognized other interests in the use of fissionable material; but all such uses bore the atomic weapons stigma.

It is important to realize that the requirements for attaching security and information control strings to research reactors is ultimately based on this premise, that either such units contain materials which might be incorporated into an atomic weapon, or that such units are first cousins of larger units capable of producing nuclear weapons materials at a rate which would be considered significant.

As a consequence, controlling reactor research information in order to conceal atomic weapons manufacture may appear to be akin to worrying about higher order terms in first approximation theory, but that is just the way the law happens to be written.

Perhaps the most important section of the Atomic Energy Act insofar as those interested in research reactors are concerned is that defining restricted data and the requirements for access to such data. You will recall that restricted data includes all information concerning the production of fissionable material and the use of fissionable material in the production of power. Research reactor information is caught in this definition, since the design of a research reactor requires access to much of the same technical data as are used in the design of a fissionable material producing reactor.

Moreover, certain research reactors could in principle be used for production purposes, although certainly somewhat inefficient by and frequently with some hazard.

Without basic technical data, the design of a research reactor is stymied at the very start. Until 1950 there was not available publicly sufficient technical data to make even a Chinese

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copy version, not to speak of actually designing such a unit. Beginning in 1950, the Commission, and the United Kingdom and Canadian projects, with whom we cooperate in these matters, undertook to declassify sufficient technical data to make possible the unclassified design, construction and operation of a multiplicity of low power research reactors.

It is the accumulation of these published data which has made possible the conduct of such conferences as the present one on a completely open basis.

Personally I believe that our declassification of research reactor information has been beneficial to the national security. I must say in retrospect that I feel it is unfortunate that the declassification action was not taken sooner. It took the Russian atomic weapons test in the fall of 1949 to shake all parties concerned out of the wholly unfounded but extraordinarily comforting belief that such knowledge could remain for any length of time in the exclusive possession of a few nations.

This dream of monopoly has not yet faded away and contributes to the present situation where declassification is somewhat out of phase with reality. At least this is a view that some of us take.

From these general remarks, I should like to proceed to a specific discussion of present declassification policy as it pertains to design construction and use of research reactors by universities. The basic premise in declassifying information related to university research reactors has been that for effective use of a reactor in research, it is necessary to have the maximum possible access to technical data on the reactor. It is difficult to see how a reactor could be put to best use if all that were available was the information such as "Push Button A. Then if shutter Omega is opened to position No. 4, there will be available a flux of 10^{10} thermal neutrons per second per square centimeter."

Of course it could be done this way. However, reactor operation by recipe would scarcely be attractive to researchers. Such black boxes are not welcome additions to research laboratories. Moreover, such a procedure would greatly limit the flexibility of reactor use.

It was with this intent—the intent of making the maximum information available for effective use of research reactors—that the first major reactor declassification in 1950 was made. This reactor declassification had some limitations. First of all, the reactors declassified in 1950 were all low power units. This is not particularly a cumbersome aspect as far as most university interests are concerned, since the expensive cooling facilities for high-powered units are somewhat of a disadvantage. Certainly it costs more money to run higher powered units unless you can secure useful power out of the units. In other words, the expense of cooling higher-powered units is substantial and would, of course, cut into funds available for research.

In addition, the hazards of higher powered units are a direct function of power level. In this latter connection, it should be noted that there is a declassification dilemma. Insofar as fuel element design is concerned, it would be preferable from a declassification angle to declassify designs incapable of high power operation. On the other hand, it is desirable from a safety viewpoint to declassify designs that are capable of high power operation so they can be used on unclassified reactors and can successfully withstand any transient increase in power.

In 1950, when we declassified a number of reactors in toto, we declassified the geometry of these reactors. This is fairly straightforward declassification action, and it was essential because if we held the geometry of a unit classified or tried to conceal it in any way, it would be necessary to incorporate a long length of troublesome red tape into the operation of the reactor. It might be pointed out that knowledge of the geometry of a reactor is not equivalent to providing sufficient information for the development of alternate designs.

For this reason it was easier to argue for the declassification of geometry than it was to argue for the declassification of the large number of nuclear constants and other data used in the design of these reactors.

In 1950 we began to declassify some basic nuclear data associated with reactor design. We released—or at least we intended to release initially; we found out later we didn't do so—all nuclear data necessary to design these reactors which we thought we had declassified. It turned out in 1951 that we had to release further information in order to fulfill the purpose which we had intended. This information is sufficient to design graphite, natural uranium air-cooled units, and sufficient to design small enriched homogeneous aqueous units.

We did not at that time, nor have we since then, declassified fabrication technology for fuel elements. This is consistent with the idea of making the reactor useful as a tool, but not declassifying sufficient information for reactor development. Obviously with time we are going to have to withdraw from this position. But initially the idea was to release sufficient information so that the reactor could be used as a tool in basic research.

I would like to just take a few examples to clarify the present situation on the release of information. So far as I am aware we have released all data on the CP-1 and the CP-2 reactors, the oldest ones, one and the same reactor in two places. This, of course, consists of dusting off old reports now and then and sending them through the mill. There hasn't been a great deal of interest in these except that they are useful in training programs. But as far as construction of such reactors for research use is concerned, I am not aware of any large interest in these units.

For swimming pool reactor, we declassified all the geometry of such units. However, I am not certain that sufficient nuclear data has been declassified to permit precise design of such units. We have declassified information on the water boilers. There we have run into trouble. We have on our books still the intent to withhold from publication certain radiation effects on aqueous solutions. It is my own feeling that we will have to get this off the books very shortly. It is a completely unreal position.

European reactors, for example, are now either building or are actually operating; and it is clear that people who are unfriendly to this country have sufficient knowledge to develop certain of the data which we are currently holding. However, the changes in rules are slow. I don't think the rules handicap universities, but I am certainly inviting questions after this talk so that we can define in what way our radiation effects declassification policy is handicapping university research use of the water boiler type of reactor.

I don't know if anything remains classified about X-10 except possibly some of the canning experience. This latter will be released, I am sure, before too long. It just takes time to convince people on some of these matters. We have some strings still tied onto the Brookhaven Reactor which we are considering now for declassification; so I hope ultimately this unit will be completely open.

The same is true for the Materials Testing Reactor. You are aware that we have declassified the entire radiation field of the MTR unit. This we felt was essential if we were to get any use out of the reactor for isotope production and things of this sort. Moreover, by having the entire radiation field available, it is possible to get quantitative discussions on potential experiments and on the results of experiments with biologists and researchers who may or may not have clearances, or who may or may not have facilities for handling classified information.

I might state in passing that, the performance of the reactor, if it is a low power unit, is such that the radiation effects on materials are not considered very significant, at least insofar as their relation to production units is concerned.

However, it is clear that the field of radiation effects on materials is one where the Commission should do its best to encourage research; and every time you throw some security worries into the situation or start to withhold little odds and ends, this tends to discourage research.

I recall during the war, for example, when I was not on the project, that I had what I thought was a good idea. I mentioned it to one of the fellows who was on the project. He told me the idea had been tried out nine months before, which immediately caused me to avoid thinking about anything that had a relation to the project.

Our present policy is to hold almost all radiation effects data related to specific materials, such as beryllium, graphite, zirconium, the alloys of uranium, thorium—and I think we have "mixtures thereof" or some other language. This is probably not a proper way to split up information. We might better consider holding only information on certain properties of certain materials, rather than blanking out all properties of certain materials.

In general the present declassification policy permits the use of reactors of the low power type, but it certainly does not permit reactor development to any great extent. In other words, the policy has been directed more towards making information available so people can use

reactors, rather than making information available so that reactors can be developed off project. I am sure that by the time reactors are relatively more plentiful on university campuses, declassification policy will probably permit such development work. Certainly if we are to get ahead in the nuclear engineering business, some of these data must be released so that the newer generation of reactor designers can begin their training in universities.

All in all, I believe it is true that those interested in the design and operation of research reactors for university use will find ample information in the open literature for the research staff. As far as the reactor designers are concerned, I believe they should be cleared for access to other reactor data not yet declassified. This appears essential for a thorough understanding of such considerations as alternate designs, behavior under unusual conditions, etc. In addition there is a psychological factor involved; one is more confident in a reactor design knowing that the designers were not arbitrarily limited by declassification rules in their access to necessary technical information.

Although my talk has been listed as including some discussion of the "security aspects" of university research reactors I should like to dispose of this part of the discussion with but a few comments.

If we define security in its narrow sense, that is, physical protection, then it is apparent that university research reactors may require some security safeguards for either or both of the following reasons:

a. The fuel, particularly if it is enriched material, is valuable dollarwise and should be protected from theft; it may also be of some military value if it can be converted into an atomic weapon part.

b. The reactor, especially after an extended period of operation, is a potentially hazardous device and should be protected from misuse whether intentional or otherwise.

The techniques of such protection vary according to reactor type. Those of you who have visited the Raleigh reactor at North Carolina State College have seen that the security measures are not necessarily onerous. There is no other present experience in these matters, since all other operating research reactors are incorporated in installations performing other classified work.

In these latter instances, the existence of site protection simplifies the problem of reactor protection. Standards for reactor security are set up by the Commission. In fact the public law will not permit ownership of fissionable material, so the Commission has an obligation over and above consideration of public safety to protect its property.

Since in most cases reactor fuel is too hot to handle, so that security protection can be accomplished with a few physical gimmicks plus some regulations on reactor use. In fact, it turns out that considerations of health and safety result in practices which simultaneously contribute to the security of the reactor material.

In short, it is difficult to foresee any situation where the security measures required by the Commission will handicap university research reactor operation. The biggest headaches will probably be during the initial loading of the reactor when it must be admitted that the fissionable material is vulnerable to misuse. I guess, however, that the contribution of security problems to start-up worries will be small compared to all other worries present at that time. Moreover, I would guess that the length of any security red tape would be small compared to the length of other red tape to be disposed of in getting materials and funds for the reactor facility.

I would like to close with a few comments on the desirability of unclassified research reactors. I feel very strongly that to have continued the practice of 1946 beyond the middle of 1950 would have been a great mistake. It is essential that these facilities be available to universities without the need of security clearances, security safeguards, classified material protection and so forth. Basic scientific work does not generally thrive in such an atmosphere.

Moreover, it seems rather questionable to spend money on security in such basic work. The training of future reactor engineers in the use of reactors in research appears to me to be a very important function of the universities and to be a function which contributes to national security. To withhold information on such reactors would, I believe, weaken this nation considerably. The effects wouldn't be felt initially, but in time it would certainly handicap this country in the developing nuclear business.

I would like to recommend that we all take a strictly critical view of classified information. Classification policies and practices change as a function of time. One of the greatest worries that I have personally is that we have lived with these things so long that we will feel they are here forever. This is not true. If a piece of information is classified and there is good reason for public release, then there is no reason to just sit idly by and let it remain classified. It may be hard; sometimes it is like pushing a rope to get the rules changed. But still it is worthwhile.

I feel that as far as the university research reactor situation is concerned, we are in fairly decent shape. But I would be the first to admit that as far as the longer range programs of the reactor development business and as far as the ultimate requirement for spreading reactor development work a little further than just to the national laboratories, we are not in good shape. I would also be the first to admit that some of our rules are probably handicapping basic research in certain fields such as radiation effects.

With these comments, I would like to invite some questions from the floor.

DISCUSSION

QUESTION: Do you have any special channels, or ways greased, you might say, to effect declassification? Either a person is in ignorance, let us say, of exactly what he wants or he is not in a position to discuss with cleared people exactly what information he wants. What is the situation on this?

MR. BECKERLEY: There is no formal mechanism for that. I would say in the case of a university, the cleared individuals there should do all they can to try and bridge the gap. If they are aware of information inside the fence that would appear to be useful to someone outside, they should then carry the ball with our declassification group.

I must admit this is a very serious problem. It is one to which Professor Wigner once called our attention. How do you get any pressures for declassification from people who could use the information but who aren't aware of its existence? I just don't know how one handles this other than by personal alertness of those inside the fence.

QUESTION: Could you state in your opinion what the trend is toward declassification? Is there afoot any move toward much more general declassification, or is it tightening up or what is the situation?

MR. BECKERLEY: It is very difficult to answer that because these things don't move uniformly. In other words, sometimes it tends to tighten up in certain fields and loosen up in others. I don't know how you can take an average of it. I don't know what weighting factors to put on these things. But insofar as the reactor business goes, I would say a general loosening is in process. One of the things that we are looking forward to is some legislative relief in the security requirements of the Act.

You will recall that we operate on a "black and white" basis. If the piece of information is restricted data, the Commission is required by law to clear individuals for access on the basis of full background investigations. If it is not restricted data, then of course it is fully available. There is nothing in between. For a long while there has been a desire to get some sort of an intermediate category of clearance so we can handle a lot of information which we are not quite ready to declassify; but which at least we would like to see get around more. This would help loosen it.

It may also tend to reduce declassification to some extent since it is always nice to put information into an intermediate limbo. Instead of making up your mind one way or the other, you throw it in there. I don't know whether this will happen. We have no experience because it isn't possible under the present law. There are proposals to provide for an intermediate security setup and I am sure Congress will consider these at its current session.

I would just like to make one comment on the basis of the question asked earlier. There appears to be some concern that university reactor work will be unclassified, and come next Tuesday it will suddenly become classified. I would like to say that I think the probability of that is extremely small, and that by the time such things would be possible the declassification policy will have changed. In other words, where it is more probable today to get into

classified information in power reactor studies, I would hope that in the future the probability will be less. At least the situation should ease up as a function of time.

So I don't visualize any university getting into a situation of suddenly finding its reactor classified and not being able to operate the reactor as an open facility.

QUESTION: You mentioned that the CP-1, CP-2 and the water boiler were rather completely declassified. What is the status of the swimming pool type, including the fuel elements?

MR. BECKERLEY: I don't propose to say there are no classification problems and then have you be disappointed. All the geometry is declassified. The physical appearance is no problem. It is a question of some of the details of the performance of fuel elements and canning and things of that sort, which we will probably relax on before too long. In any case, I don't see any handicap in the use of such a reactor for unclassified research.

COMMENT FROM AUDIENCE: In response to the question, I would like to point out that we have the national laboratory well stocked with people who are fully acquainted with classified information, and I think they could be used as reference or consultants to discuss the problem. You should be able to get answers as to where the classified information does exist. It is not going to be easy, as Dr. Beckerley has already said, because even the knowledge that the classified information exists doesn't mean that it can be declassified or can be made available. But I think here is another bridge for the gap that does exist.

QUESTION: Did I understand you to be referring to my question when you referred to the question in Dr. Johnson's speech? You did not hit the point I was interested in. My question was whether a water boiler of the North Carolina type could be executed without access to restricted data. This is important to me in the university because I want to use graduate students in the preparation of such information. As far as the engineering design is concerned, I feel I have that under control.

But my question is: With regard to the negotiation for the reactor, the documents that must be presented to the Commission, the calculations which must be made, can these be made by graduate students without the necessary clearance arrangements?

MR. BECKERLEY: I believe that where you run into trouble is in such things as preparation of a safeguards report, where I am not sure whether we declassified enough information to make the safeguards report completely unclassified. I think this is something which ought to be brought up in connection with the discussion of the North Carolina reactor. I believe they have some experience now. As I understand it, their students did participate in quite a bit of the work on the reactor; and perhaps Dr. Beck can give an indication of what headaches he ran into.

I would like to say I would hope that this could be done; that the entire design work for a research reactor and the reports which are prepared for safety considerations could be performed on an unclassified basis. We would appreciate having some specific proposals for papers to release the information or changing the rules in that direction. The point I would like to make is that sometimes the rules prohibit declassification of information where the intent is not to withhold it. This is simply a characteristic of the fact that you can't foresee, when the rules are made, all the situations that are going to arise in the use of technical information.

ADMINISTRATIVE CONSIDERATIONS ON UNIVERSITY RESEARCH REACTORS

By Herman M. Roth*

Before I begin this talk, I would like to clarify a couple of questions that were asked earlier, to be sure that we were talking about the same thing. First was the question of public liability. In our agreements with universities, the Commission assumes no financial liability in the matter of accidents or other events. This responsibility is entirely upon the shoulders of the university.

In fact, there is a "hold harmless" clause in the contract. The other question is related to it, but is not exactly the same. The question was concerned with the commission's requirements of a performance bond. We do not require a performance bond.

The Operations Office in the commission operation in this business is the firing line. The Operations Office is the principal contact between the Institution and the Commission, once the Washington approval has been established, the Operations Office negotiates and administers the contract. We are responsible for seeing to it that all Government rules and regulations in effect are carried out, at the same time trying our best, as most of us are scientific people, to assure that an adequate research and development program is carried out. This is sometimes a little difficult, but we manage.

The administrative aspects of a program involving institution research reactors come about by virtue of the fact that the Commission is supplying or will supply the fuel for these reactors. The justification for furnishing fuel by the Commission is, of course, that the operation of university research reactors will contribute a part to the "continued conduct of research and development activities in the fields" which the Commission by law is directed to assist and foster. As a result, the Commission has chosen to make some loans of fissionable materials to institutions wishing to construct their own research reactors.

In making these loans the Commission must be guided by (1) certain general principles of government operation and (2) certain direct provisions of the Atomic Energy Act, generally known as Public Law 585—79th Congress.

Let us consider the general governmental requirements first. The federal government operates on the basis that all citizens or groups of citizens should be treated alike in doing business with the government. Hence, prior to the award of any contract or making any purchase the government agency must be assured first that competition among all citizens has been obtained or, if competition in the strictest sense is not possible, that all possible citizens would be treated in a similar manner if similar conditions existed. A loan of fissionable

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materials to a institution is not one for which competition, in ordinary sense, can usually be achieved. However, the supply of fissionable materials is limited; hence, the Commission must establish a set of criteria or policies upon which it makes a determination for the selection of those institutions to whom it will loan fissionable materials. Fulfillment of these criteria, of course, must be documented and, hence, the requestor of fissionable materials generally submits a proposal and other pertinent data from which the Commission makes a decision. These criteria, as Dr. Johnson pointed out, form the Commission policy on the loan of fissionable materials. Included in them are the various aspects which will assure the Commission that a satisfactory research program will be undertaken and maintained, that the group is capable of achieving a satisfactory reactor design, that the operations of the reactor and design when operated will be safe and not create any undue hazards, and finally that the material will be appropriately safeguarded and accounted for.

I must omit, not because of its lack of importance, but because of the time limitation on this talk, the preliminary period during which the institution has a study contract. This contract provides for the institution to design a reactor, to make a hazards study of the operation of the reactor at the proposed site, and to develop an operational plan including security for the operation of a reactor. Excluding the study contract period, the Operations Office comes into the picture once the decision in principle has been made to loan the material. By this time the institution has a broad picture of a type of reactor it wishes and has made a study of the hazards involved and has received concurrence of the Advisory Committee on Reactor Safeguards and is proceeding to undertake detailed designs.

The Operations Office then undertakes to assure that all of the requirements of the Atomic Energy Act and special requirements placed on the tentative approval by the Commission are carried out. Further that any data or further study required by the Reactor Safeguard Committee are supplied by the university or college and presented to the Committee, that provisions have been made for continuing study and observation of radioactive hazards, that the security groups are brought in to review and approve the security plans for the fissionable materials and that the operating plans include sufficient information to assure safe operation. They are not necessarily done in this order. In the meanwhile, the Operations Office negotiates a contract with the institution. This contract, of course, must be acceptable to the college and, at the same time, permit the Commission to carry out its responsibilities under the Atomic Energy Act. It is my belief that the development of a contract between the Commission and the institution can be accomplished with much more dispatch if both sides understand the problems and requirements of the other. We, of the Commission staff, approach the problem from the point of view that the institution wishes to undertake its own research program with as little intervention on the part of the Commission as possible. We further feel that we should not interpose any more limitations on the operation of the reactor than necessary to assure the safe operation and the security of the materials. The requirements placed on the Commission are stated in the law. The contract merely states those things which the Commission must do in order to make the loan of fissionable materials legal.

There are three provisions within the Act, Sections 4(c)(1), 4(c)(3), and 4(a)(4), which limit those things which the university may do with the reactor using fissionable materials.

Section 4(c)(1). The Commission would be required to own all facilities which produce fissionable materials, unless the facilities are used for research and development and, further in the opinion of the Commission, do not enable the operator to produce an atomic bomb or other atomic weapon in a reasonable time.

Section 4(c)(3). Permits fissionable materials to be produced incidentally to research and development activities in facilities not owned by the Commission.

Section 4(a)(4). Permits the Commission to distribute fissionable materials on loan to applicants requesting it for the conduct of research and development activities and for medical therapy. However, no applicant will be enabled to have an amount sufficient to construct a bomb or other military weapon.

These are the reasons why the Commission insists on adequate documentation of the research and development program to be undertaken by the institution. Without this assurance the Commission is not authorized to loan fissionable materials nor is the institution author-

ized to own a reactor. Further, in the conduct of the research and development program under Section 4(d) the operators are authorized to increase the supply of radioactive materials by exposing materials to any kind of radiation, incidental to the processes of producing or utilizing fissionable materials. The Commission, under 5(d), is not authorized to distribute fissionable materials which is not under or in the jurisdiction of the United States.

The Commission is directed to establish by regulation or order such standards and instructions to govern the possession and use of fissionable and by-product materials, as necessary to protect health and minimize danger to life and property. In the matter of security we have been operating on the basis that the reactor complex excluding the fuel is unclassified. Existence of the fuel and the quantity required to fuel a reactor of the kind considered here is or will be unclassified. However, the material itself in the quantity required to operate a reactor is classified and, hence, there is a physical problem of safeguarding this material from theft or diversion. This problem must be considered in the design of the reactor in order to assure the security of the fuel. Outside of the reactor the security provisions for less than a kilogram have been just a little more than those required for the establishment of a facility for the storage of classified documents. With larger quantities of fissionable material being requested, some additional provisions may be necessary. Security of the fuel is a physical problem of preventing unauthorized access to the material, and if considered at the appropriate time can be solved.

I should like to spend a little time in discussing specific contract provisions. In developing a contract—the legal term is negotiating a contract. The first consideration is conformance with the Law of the Land. Neither the Commission nor its representatives wish to compromise this. We also try to reach a common ground between our directives and the wishes and needs of the institution. As I have stated before, the purpose of the loan of fissionable materials is to assist and foster research and development. Hence, any restriction or limitation which retards the research and development program must be avoided if at all possible, since we would be defeating our own purpose. We do not wish to get into the institution's business any more than we have to in order to carry out the provisions of the law.

Not being a lawyer, I am not in a position to start out with the provisions in the order that they appear in a contract. Contracts are written in various ways, depending on the attorney making the draft. I should like to approach this subject from a simple point of view: (1) What the Commission will do. (2) What strings are attached. (3) What the institution will do. It is realized that there will be some overlap.

1. What does the Commission agree to do

We furnish the fuel—thus far it has been Uranium in the weight and composition required. For the NCSC reactor as you all know, it was uranyl sulfate with the uranium containing about 90% U-235. In general, it may be stated that the Commission agrees to furnish the fuel in a form suitable for direct insertion in the reactor, without additional processing or fabrication by the institution. In the case of the uranyl sulfate, it was desirable to furnish a more concentrated fuel and perform dilution at the site. This would not be necessary for metal fuel elements, since they may be fabricated in the form suitable for direct loading. The use of existing designs of reactors usually implies that the Commission has the facilities for providing the fuel in the form requested. This point should be checked before proceeding too far along with your design.

It is not expected that institutions will undertake chemical processing of the fuel. Hence, the Commission considers the need for replacement of fuel in the initial proposal. In general, of course, the rate of burnup is dependent on the reactor power level. For low power levels, the Commission will consider replacement as a new loading and since we furnished the fuel in the first place, we will either furnish new fuel or reprocess the old. As the program progresses and if higher power levels are approved, other considerations may enter the picture.

a. We furnish an analysis of the material.

b. We will process any wastes contaminated with fissionable materials, at the institutions' expense, if such charges are appropriate.

c. We continue to provide information as required to keep the Security Monitor up to date on classification, arranging for visits to Commission installations, either classified or unclassified, as required by the research and development program.

d. We furnish appropriate security guards for the transportation of the fuel to the institutions' site, at the institutions' expense.

e. We furnish those materials or services for which the Commission is the only source at cost.

2. Strings attached

The fuel may only be used in the reactor as planned for research and development purposes and for medical therapy as defined in the Act.

Any fissionable material made during the process of operating the reactor becomes the property of the Commission. The fission products which are recovered in the process of decontaminating the fuel also become the property of the Commission. Of course the new fissionable material produced in the low powered enriched fuels will be small. However, if normal or slightly enriched uranium is used at higher power levels, the recovered fissionable materials may be comparable to the fuel burned. The legal basis for this is logical—in that, since we cannot give away the fuel, but can only loan it—as long as there exists fissionable material or material of value within the fuel, all of it belongs to the government. These values are part of the consideration for reprocessing. Apparently this argument does not apply to the neutrons which escape from the fuel and which are the prime interest of the institution building the reactor.

Irradiation of materials, other than the fuel which produces fissionable materials, are forbidden without the prior written approval of the Commission.

The Commission retains patent rights to the extent determined by Commission and executive policy of the government.

3. The Institution agrees to

a. Observe such safety standards and instructions including the power level of the pile operation as agreed to be necessary to protect health and minimize danger to life and property.

b. Comply with instructions on accountability. For fabricated fuel elements, this can be only very simple. Someone must count the number of fuel elements on hand periodically and assure himself that they are the ones actually furnished by the Commission. For liquid fuels, there is a little more difficulty. The Commission does not require any more information than that necessary for good reactor operation.

c. Accept the responsibility for the operation of the reactor and those monitoring activities which are included in the operation plan of the reactor which has been approved by the reactor safeguard committee.

d. Monitor the activities from the security point of view and not disclose any classified information to unauthorized persons.

e. Accept the classification of information as directed by the Commission. However, if the operation should become classified, continuation would be subject to mutual agreement.

f. Appointment of a Project Director and an Assistant Project Director, are subject to the approval of the Commission.

HEALTH AND SAFETY

Another part of the administration of these contracts is the so called orders and regulations. Under Section 10c of the Atomic Energy Act the Commission is charged with the responsibility of issuing appropriate orders to protect the Health and Safety personnel. Some standards and instructions governing the possession and use of fissionable materials can be made in the contract. These provisions are those which have the element of mutually advantageous considerations and mutual agreement. The orders or regulations, however, take

the form of directives and, in a sense, federal regulations. As a minimum penalty, failure to comply could form the basis for withdrawal of the material.

These statements may sound foreboding. In actual practice, the institution is directed to do those things which in general he has already agreed to do. However, there are a few limitations. The first of these is a limitation on significant changes in any features of the reactor facilities without the approval of the Commission. The institution is also directed to operate under a reduced power level or curtail operations entirely if the actual operation discloses the inadequacy of any feature to assure safe operation, unless approval is obtained from the Commission. A second point is the production and distribution of radioisotopes must conform with the tie into the Commission's Radioisotopes system. I should like to discuss this in three parts, (1) production, (2) use in the institution's facilities, and (3) distribution outside.

Production. The institution has the limitation on the production of fissionable materials so that the irradiation of uranium (other than that in the fuel) and thorium is prohibited. From a safety angle the irradiation of explosives is prohibited unless specifically authorized. Further, at the moment, gem material irradiations are prohibited. There are no prohibitions which limit the experimental work per se. With the limitations on only uranium, thorium, gems, and explosives there remains an exceedingly broad field for the research worker to direct his interests. This will be on tomorrow's program.

Use in the Institution's Facilities. The use of the radioisotopes in the institution's facilities is expected to be governed by the issue of a general authorization to use radioisotopes similar to those issued to the Commission's own laboratories. Between these two authorizations, except for the few limitations noted, it is believed that the institution will be enabled to undertake almost any desirable research program, using the health and safety precautions which he would normally take anyway. The safe limits and maximum permissible doses of radiation are those generally accepted by health physicists. This, of course, precludes the intentional exposure of human beings above the general accepted safe levels for operating personnel without Commission approval. In cases of industrial hazards, we have accepted the NBS Handbook 52 as the standard. Inasmuch as these are generally accepted no problems have arisen.

Distribution Outside. The transfer of radioisotopes to others, normally involves direct contact with the Isotopes Division. It is the present Law of the Land that except for certain small quantities, no one can possess or use isotopes without appropriate authorization. Hence, prior to the shipment of any isotopes off the institution's site, the institution must assure himself that the receiver has an authorization to possess and use the isotopes. This system has a two way advantage. First, it will be the Isotopes Division responsibility to determine if the use is legal and also to police the eventual use. Second, the contractor need only concern himself with whether or not he wants or is able to assist the other party. With the authorization in hand, he can ship the materials.

We believe that that program of research and training has proceeded without serious, or, as far as I know, any interference on the part of the Commission. I hope that the next contract we are starting to work on now, namely, with Pennsylvania State University, will proceed as smoothly. We hope that we will not have to ask as much patience on the part of the university there as we did with North Carolina State because the second one comes along faster than the first.

DISCUSSION

QUESTION: Dr. Roth, I just wonder—since the maximum amount was mentioned several times which an institution could have in its possession—if in either the present or the future the institution would like to have some more fissionable material for other purposes, they could get it if they haven't already got the maximum amount in their reactor?

MR. ROTH: I believe that is somewhat hypothetical, for this reason. The quantity generally required for research reactors is thought about in terms of kilograms. The quantities required for other purposes are generally in grams. I don't believe we can figure the weapons requirement that close. My personal concern with the matter is that Los Alamos is going to

get this minimum weapons requirement down so low that we won't even be able to make a "research issuance," (on the amount of grams). I think this is the real problem.

At the moment we have not faced this. I think these are separate considerations. There are many possibilities one could think of, none of which I could speak of as the answer, such as separation of materials by kinds and that sort of thing. I don't see this as the logical answer to question.

If you think in terms of fission chambers, this is milligram quantities, or gram quantities at the most. Incidentally, while I think about it, when you request your approval for fuel, don't forget your fission chambers. That is U-235, too.

MR. BECKERLEY: One general comment. This question of the one kilogram being the limit of material classified "Secret." That number is strictly pulled out of the hat, and in any case where you get somewhat more than that, there is no reason we can't change the rule.

The basis for considering larger quantities classified is simply that access to larger quantities would be tantamount to having weapons data because in principle, anyway, you could play around with it and get some data which we are unwilling to have declassified at this time. But the boundary lines are quite arbitrary and I should think in any specific case you could either stretch the rules or change them.

MR. WIDDOES (U. of Michigan): I think this problem is a very real one. For example, I can think of a case where you might like to have more fissionable material than exactly enough to make your reactor go critical. We at the University of Michigan, I think will ask for more than enough to make it go critical. We would like two things here. One is, we would like to rotate the fuel from the reactor into a subcritical area which we could use for gamma radiation. It forms an intense gamma source similar to the cobalt source we already have. The second advantage of this is that it would allow your fuel to decay and the fission products to decay, and therefore allow you to operate at an essentially lower average power level and increase the safety of your reactor at a given power level.

MR. ROTH: I hope I didn't give the impression that the only fuel you get is that which is just sufficient to make your reactor go critical. In addition to that, you must also have sufficient excess K to take care of your neutron leakage and absorption for experiments and other uses. In addition, as I say, there will always be some that you will want outside, as in the case of the North Carolina State College, where their bare critical is 785—and 999 grams were supplied.

My answer to this is that you must consider the problem and what you want to do in terms of a research program and the type of reactor you want. When that is done, that is your total requirement, not just enough fuel to make the reactor go critical.

SAFEGUARD CONSIDERATIONS

by C. Rogers McCullough*

I want to tell you gentlemen that I very much appreciate this opportunity to join in the discussion of reactors for research purposes, especially for universities. I am here as a representative of the Advisory Committee on Reactor Safeguards because this committee is concerned with reactors of all kinds and all nuclear assemblages which can go critical, except weapons.

In discussing with you the role of the Advisory Committee on Reactor Safeguards, I hope to tell you how we are functioning and how we hope to function, especially in the field in which you are interested; namely, reactors for university research.

I would like to explore with you rather briefly the problems that you as universities will face when you come to the design, construction, and operation of reactors. As I say, after I outline my few thoughts, I hope we can have some discussion and I will do my best to answer as freely and frankly as I can any questions which you may have.

In the terms of the Atomic Energy Act of 1946, the responsibility for safety of reactors lies with the Atomic Energy Commission. The Advisory Committee on Reactor Safeguards is a committee of the Commission, and we report to the General Manager, giving him our opinion as to the hazards and problems of reactors and all nuclear assemblies, except weapons. The general manager or his appropriate deputy takes whatever action he deems desirable, taking into consideration the advice which our committee has given.

Please note that this committee is advisory. We have no power to initiate any design. We have no power to change any design, nor to approve or disapprove the operation of a reactor. We advise the general manager or his deputy.

As a matter of practical operation, the committee is asking that all proposals be brought to its attention just as soon as the problems and the probable hazards connected with this reactor can be foreseen and the concept of the reactor which is desired can be reduced to a few sketches, diagrams, and notes. At the time this preliminary information is brought to the attention of the committee, an attempt is made to list all of the problems which can be foreseen which must be settled and data which must be obtained before any valid evaluation of the hazards can be made.

Finally, a formal hazards summary report is submitted to the committee for its final judgment and recommendations. If we have done this job properly, when the hearing and study and consideration of this hazards summary report is made, there will be no major problems

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left to be solved. This is because, we hope, we have agreed what the problems are in our preliminary meeting; and you go back and work out the answers to these questions so that when we come together at our final meeting, there is already a basis of agreement.

If this is done properly and successfully, the reactor then can go into operation without any worry on the part of either the operators and owners of the reactor or the Atomic Energy Commission or any of its agencies. I might add that this procedure which we are trying to follow actually makes more work for the committee because we have to review a reactor twice, in effect. The hard job is really to sit down and come to an agreement as to what the problems really are, what the hazards are and how you are going to solve these problems.

Nevertheless, I think it is the right way to go at it, especially in this interim period when reactor science is in a growing and formative state and there are a lot of unknowns still left in the design, construction and behavior of reactors.

Steps are being taken, however, to take care of this load on the committee by organization and the proper help, so that this procedure will in no way be a stumbling block or a delaying factor in the design, construction and operation of reactors. It is hoped that we will evolve before too long a code which will be a pattern, a map, a plan, a procedure, or at least, an outline, for people who wish to design reactors. It must be realized that it is up to the Atomic Energy Commission to set policy, subject, of course, to the provisions of the Atomic Energy Act.

As I understand the situation at the present time, the Atomic Energy Commission cannot divorce itself from the responsibility for safety where fissionable material is involved. In fact, there are five specific references to safety in the Act itself. At the same time, as long as we are dealing with responsible people, it is equally clear that the owners and operators of reactors are just as anxious to avoid undue hazards to the reactor, to their employees, or to the public as is the Atomic Energy Commission, the Advisory Committee on Reactor Safeguards, or any other agency of the Commission.

Any major differences of opinion arise chiefly because of a lack of agreement on the basic information as to exactly what the hazards are. Unfortunately one can never be absolutely certain of the numerical value of any hazard, and there are large areas of uncertainty in any field as new as that of reactors.

It is the desire of the Advisory Committee on Reactor Safeguards to so conduct its operations that the problems and hazards are as definitely stated as possible and the realm of uncertainty is reduced to a minimum. For purposes of this discussion we may class reactors into three groups: One, our government reactors, both for propulsion or for the production of fissionable material; two, industrial utility reactors, which we hope some day not too far in the future will be actualities; and, three, reactors for research.

Obviously we are concerned here with reactors for research. I think it is rather obvious to us all that a research reactor should not be a major hazard to the public. Moreover, I think it is a sensible point of view that there should be no significant hazard to the employees or the students working around a research reactor; and, finally, obviously you don't want the reactor to be sufficiently dangerous or unstable to damage itself.

It is suggested that in the case of reactors owned by universities or other non-federal government groups, especially research reactors, the committee satisfy itself (1) that there is a sufficiently low probability of any injury or death to the public—and I can't give you a number for this probability because safety just doesn't go that way; but I think there can be a meeting of minds as to the area of what is a sufficiently low probability; (2) the committee should satisfy itself that the employees or students are subjected only to what are acceptable hazards; and (3) that the owners and operators of the reactor are responsible and able to meet any damages or any liabilities which they might incur to the public.

What I am trying to say is that when we are dealing with privately owned reactors or privately controlled reactors—this is a suggestion on my part; it is not formal Commission policy—that we satisfy ourselves that the public is protected. We leave it up to you to determine whether your investment, including your liabilities to the public, is adequately protected. That may seem like a hard-boiled attitude, but actually it is one of the best ways we know of to bring the facts of reactor hazards home to the people who design, own, and operate them,

and at the same time avoid a super-cautious attitude which would likely be assumed by any committee which is advisory and therefore lacks any incentive for being anything but perfectly safe.

Make no mistake, there will still be many arguments and areas of disagreement about what the hazard really is and how much you should assume. But we hope that these will be minor points and not major ones.

There are two main hazard problems in reactors. You will forgive me if I repeat things you already know, but I want to emphasize these.

The first problem is the possibility that the reactor will get out of control; we will have a nuclear run-away; the power will rise to a very high level in an exceedingly short time; parts of the reactor will melt or vaporize. As far as we know, there is little chance of any existing or proposed reactors causing blast damage as a result of a run-away nuclear reaction, and certainly no university campus should consider installing a reactor that has this possibility.

The second problem, of course, is the fact that reactors store fission products, and fission products are exceedingly poisonous materials. If these exceedingly toxic materials are permitted to get out of the reactor enclosure, even in minute amounts, persons and other forms of life will be seriously damaged. In talking about this problem, I believe it is useful to refer to fission products as "toxic" or "poisonous" materials rather than radioactive substances. This will convey to the lay person the problem we are really facing here. I say this even though the word "poison" has come to have a specific meaning in reactor technology as a substance which has a parasitic capture of neutrons. The toxic effect of fission products is three million to two billion times as great as the most potent industrial poison, chlorine. Even compared to cancer formers, benzidine and naphthylamine, they are two million to 20 million times as deadly. For a complete comparison, note the table following:

Poison	Air Concentration	Ingestion
	Tolerance Mgm/M ⁻³	Tolerance Mgm/Kg
Chlorine	2.9	
Bromine	3.3	
Arsine	1.6	
Cyanogen chloride	1.3	
Hydrogen selenide	0.3	
Stibine	0.5	
Iodine	1.1	
Phosgene	3.0	
Benzidine	0.015	
α Naphthylamine	0.01	
β Naphthylamine	0.01	
Be	1.5×10^{-5}	
Sr ⁹⁰	1.3×10^{-9}	1×10^{-7}
Pu ²³⁹	32×10^{-9}	20×10^{-7}
U ²³³	500×10^{-9}	100×10^{-7}

This table deals with tolerance dosage and we are using here a tolerance dose of 0.3 roentgens per week. Irrespective of what we think about an official tolerance dose, it is my opinion that for any long-time exposure of workers or the public it will be extremely difficult to live with any value in excess of the official tolerance dosage, no matter what this may be. To be realistic, there should be certain emergency tolerance dosages, but I am not aware that any official value has been set for this. I am aware that the British Civil Defense has set 25R and there is some supposition that even as much as 100R would be tolerable in extreme emergencies. But I want to emphasize that there is no official sanction in this country for

such values. The table is admittedly incomplete and it would be very useful to compare lethal dosage of industrial and radioactive poisons and, of course, one would prefer a relationship between dosage and injury. This information is not available on the radioactive substances and is also sketchy for our common industrial poisons. There is one difference between chemical poisons and radioactive ones which should be mentioned. This can be illustrated by comparison with chlorine. Even in the case of bad gassing by chlorine, if the victim recovers, the recovery is substantially complete, whereas in the case of a serious exposure to radioactivity, the damage is considered to be permanent and there is the possibility of genetic changes, the full effect of which may not be apparent for several generations. It is obvious, therefore, that means must be taken to keep the escape of fission products to an exceedingly small amount.

It turns out that reactors of the type that are of most interest for research purposes, when properly designed and operated, are quite stable and controllable from a nuclear point of view. The potential hazard turns out to be the possibility of chemical reactions—for example, the possible reaction of aluminum with water. If such a reaction should occur to any extent, the possible heat release, and even explosion, might be sufficiently great to rupture the shield and cause the release of fission products. Whether such reactions can, in fact, take place, how probable they are, and what the consequences might be are matters of considerable controversy. Gradually we are accumulating data on this subject and hope we can arrive at some reasonable appreciation of this problem and find means of designing and operating so that this is not a hazard. In this connection, the work carried out by Dr. Zinn of the Argonne National Laboratory last summer at the Reactor Testing Station is a very great contribution to an understanding of the problem. In fact, the report of this work reached me a week ago and I have reviewed it with great interest. I commend its study to all of you. In this connection any suggestions that anyone in the reactor business has as to ways in which we can settle this question of chemical reaction, by experiment or otherwise, will be welcomed. Certainly we wish to put ourselves in the position of knowing what the situation is rather than to continue to discuss it.

One must not lose sight of the fact that the amount of fission products is directly proportional to the integrated heat power of the reactor between fuel unit changes. Therefore, the lower the power at which one can operate a reactor the smaller the amount of fission products. Ideally, one would like a reactor in which the fission products are continuously removed. However, this may not be practical or convenient especially for university reactors. The hazard of a reactor can be reduced also by so designing and operating it that it has a minimum of excess reactivity, it is an inherently stable machine from a nuclear point-of-view, it has a low probability of chemical reaction and is in an enclosure which practically guarantees that no fission products will escape. Without being dogmatic it would seem that at this stage of the art of reactor technology that reactors even in universities should be in charge of an operating group who are thoroughly trained in the operation of these machines. The operating procedure should be carefully worked out and rigidly adhered to and even minor deviations should not be tolerated without review by more than one thoroughly competent person.

In working with reactors we are dealing with hazardous and expensive machines which can react very quickly to produce most unpleasant conditions. At this time, I would like to show a set of slides which will give some idea of the consequences of the NRX reactor accident at Chalk River a little over a year ago. This accident was a minor one as compared to what one can consider happening. The first slide (Fig. 1) gives a general view of the building housing the NRX reactor on the Ottawa River. Figure 2 shows the reactor in full operation with all of the experimental facilities prior to the accident. Figure 3 is another view showing these experimental facilities. Figure 4 gives a cross-section of the NRX reactor and shows the fuel channels with cooling water, moderator, shielding, and graphite thermal columns. Figure 5 shows a plan view of the core, graphite reflector, steel shield, and concrete shield. Figure 6 is another cross-sectional view showing the fuel rods and the schematic diagram of the cooling water plus the control rod. Figure 7 shows the detail of the fuel rod and its aluminum cladding, the annular space for the light water (which is the cooling water), the air space between the cooling water channel and the fixed calandria tube, and finally the heavy water moderator. Figure 8 is a diagram of a damaged fuel rod after the accident. Please notice that

Fig. 1 — Building housing NRX reactor.

Fig. 2 — NRX reactor in full operation.

Fig. 3 — Another view of NRX reactor.

Fig. 4—Cross-section of NRX reactor.

Fig. 5 — Plan view of NRX reactor.

Fig. 6—Another cross-sectional view of NRX reactor.

Fig. 7—Detail of fuel rod and aluminum cladding.

Fig. 8—Diagram of damaged fuel rod after accident.

the uranium fused with the cladding of the fuel rod, and also with the aluminum tube containing the water flow, and finally with the fixed calandria tube. Actually this diagram was made to show how it was planned to remove the fused and broken rods.

Figure 9 shows one of the men from the U. S. Naval Radiological Defense Laboratory and an unidentified worker in protective clothing working on decontamination. Figure 10 is another view of the decontamination work under way, again showing the protective clothing, gas mask, monitor, etc. This gives you some idea of the elaborate equipment required and of the difficulties under which decontamination must be carried out. Figure 11 shows workers attempting to withdraw one of the broken rods. In addition to the protective clothing, please notice the mirror and flashlight required to see what they are doing. Figure 12 is a sketch of the planned calandria removal. Since this was such a difficult operation, it had to be planned out in great detail beforehand. Notice in View No. 1 the calandria is in place within the reactor shielding. Step No. 2 is the calandria lifted free of the shielding preparatory to being lowered onto the skid shown in View 3. After lowering, the canvas bag is pulled up around the calandria by remote control. The skid is then turned over as shown in View 4 and dragged away. Figure 13 shows a miniature mock-up of the reactor and calandria. Operators who were to be involved in the operation practiced the removal on this model before undertaking the real thing. Figure 14 shows the actual calandria removal. The calandria is now hoisted free of the reactor and is ready to be lowered into the bag. Figure 15 shows the bag being pulled up around the calandria. Figure 16 shows the calandria in its bag on the skid being dragged away to the burial ground. This calandria when lifted out of the reactor had an activity of 700R at 3 feet. The actual removal was done in the evening when there were only a few employees at the project. A team of 70 men had been trained for the removal procedure and there was a reserve crew of 12 standing by to handle emergencies.

These photographs give some idea of the amount of work and the difficulties of the reconstruction of the NRX reactor.* Remember it was out of service for about a year and a large number of the men at the laboratory had to be put on this work to the exclusion of all other activities. A very large number of persons were involved including personnel from the U. S. Atomic Energy Commission and the U. S. Naval Radiological Defense Laboratory.

The possibility of an accident to a research reactor and the procedure to be followed should be studied by all persons responsible for reactors. A disaster plan should be worked out. Unfortunately, outside of the U. S. Naval Radiological Defense Laboratory there are very few persons in the country who have the training or equipment to do a major decontaminating job. Another lesson learned from NRX was that one should have a suitable disposal plan for large quantities of contaminated water.

CONCLUSION

The Advisory Committee on Reactor Safeguards is involved in reactors even for research purposes at universities. It is hoped that the Committee will not delay any worthwhile reactor project while at the same time making sure that the public is adequately protected. The Committee hopes to be able to participate in reactor projects at the start and to be helpful in solving the problems which may arise. When the "Hazards Summary Report" is reviewed, all concerned should agree that all important hazard questions are settled. There are possibilities of serious losses and delays from reactor accidents but the Committee believes that by proper design and operation these can be minimized. The Committee plans to be helpful and to do what it can to advance reactors for research without being reckless or supercautious.

* Reconstruction of the NRX Reactor at Chalk River, J. L. Gray, M.E.I.C. The Engineering Journal, October 1953.

Fig. 9—Decontamination work.

Fig. 10 — Another view of decontamination work.

Fig. 11 — Workmen attempting to withdraw a broken rod.

Fig. 12—Sketch of planned calandria removal.

Fig. 13—Miniature mock-up of reactor and calandria.

Fig. 14—Calandria removal.

Fig. 15—Bag being pulled around calandria.

Fig. 16—Dragging calandria to burial ground.

DISCUSSION

QUESTION: Dr. McCullough, lots of people here may not understand the vague rumors they heard about the exclusion formula. Could you elaborate on that a little bit in connection with university reactors?

MR. McCULLOUGH: I don't remember the classification now. I will talk about it this way. There is a formula which has been used to judge certain reactors. This formula was derived for a specific reactor in a specific location and has been used as a yardstick sometimes for other types of reactors. There has been a recent study which has not yet been published, a very good study, which shows that the same formula is arrived at by an entirely different derivation. It turns out that the formula has rather general application.

This formula assumes that the reactor has come to power and equilibrium. It also assumes that of all the fission products that are stored up in the reactor, half of them escape. The exclusion radii turn out to be very fabulous distances for large power reactors.

The key to this is that the fission products either do or do not escape. So if you are talking about a reactor that cannot let the fission products escape either by its inherent design or inherent stability or because it is in an enclosure, then obviously the formula doesn't apply. So this says you have to consider each reactor, each design, on its own merits, looking at the kind that it is, the stability and the enclosure that may be around it. Does that answer your question? Notice again that the lower power you can operate at, the less trouble you may get into.

CHAIRMAN BORST: Thanks for the plug for the water boiler. Are there any further questions?

QUESTION: It seems to me that there is somewhat of an issue as to how, in certain controversial cases of safety, the matter should be decided. Is the Safeguards Committee in a position to ask the AEC's laboratories to check the point in question, possibly either by a mock-up, critical experiments, or even more elaborate experiments?

MR. McCULLOUGH: We have no authority to get any such information, but we certainly can recommend it, and do. For example, say it turns out that the exclusion area that is available is sufficient for operating at something like a half, a third, or a tenth of the power one is asking for. Then until this controversy is cleared up, you can limit your power to that level, which is a practical way of proceeding.

Wherever possible, we try to get someone interested in working out these problems experimentally. I might come back to this reactor safeguards formula. If all the fission products get in the air, or half of them, this exclusion area is based on 300 r at the perimeter—and it is not the most pessimistic case. Of course there is rain-out and there are other things that can happen. As one fellow put it, who used to be a member of the committee, "Within this area we can guarantee you are in trouble. Outside of it, you may be in serious trouble or you may not."

By enclosures, by designing an inherently stable reactor—and they are beginning to show that there are some inherently stable reactors—this formula can be modified. I am not trying to scare you all to death. I just want you to face what your problems are and come up with reactors which you can guarantee will behave themselves within reasonable probability.

QUESTION: I would like to ask you a question, Dr. McCullough. In view of the low power at which presumably a great many university reactors would like to operate, would you consider it necessary to have a meteorological study made of the sites?

MR. McCULLOUGH: It has been our practice to make meteorological studies of all sites.

QUESTION: Regardless of the power level?

MR. McCULLOUGH: Until you get to critical experiments, in effect.

CHAIRMAN BORST: It is quite evident that Professor Diddle, if he chooses the reactor, will find it does not have the flexibility of operation of a cyclotron. That is, one cannot send the graduate student to work from 11:00 p.m. to 3:00 a.m. and leave him on his own to twiddle knobs as he chooses. This is just not the kind of a critter you have in the reactor. It is just not like a cyclotron.

MR. McCULLOUGH: Again let me remind you what happened to NRX in a very short time. You don't want this to happen to you, and neither do we.

II. PLANNING FOR AND OPERATING A REACTOR

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THE NORTH CAROLINA STATE REACTOR

by Clifford K. Beck*

It is a real pleasure for me to speak to this group because one of the happy recompenses of having worked in the reactor program has been the association with many of you in one way or another, and the prospect of looking forward to working with you further in the future.

I have been asked to talk about the problems encountered in building a university reactor. All the problems we encountered have now disappeared, or most of them have. There are no longer any serious problems to be encountered in building reactors. One just goes out and builds it, gets the fuel from the AEC, and starts operating!

However, to offer a few guides along the way, it might be of some value to outline some of the procedures we followed and some of the events which were encountered as we chose the design and built our reactor.

In 1949, when the idea of building a reactor was conceived, the situation was vastly different from that in existence today. The most striking difference, I think, along with the extension declassification which has taken place is the vastly different general attitude now in evidence toward reactors. In 1949 a general feeling of apathy, indifference and pessimism was prevalent toward the possible usefulness of these processes in general, in contrast to the general optimism and alert, aggressive interest evidenced almost everywhere today.

Many factors have entered into the cause of this change in attitude, but the change itself is the most striking difference which can be cited.

Our first real hurdle, therefore, was the decision to attempt the project at all. In idle moments I am still amazed that we made the decision to do it and wonder sometimes, if I had suspected the trouble involved, if we would ever have launched the project. I think, however, that we would have, for I am convinced that it is a step in the right direction.

There were two basic factors in 1949 which led to the decision to attempt the project. These were the underlying beliefs which furnished the necessary courage to go ahead with the program. The first one was a belief in the essential "rightness" of building a university reactor. This feeling of "rightness"—that it was the right thing to do—was itself an outgrowth of opinions I remember expressing at that time somewhat as follows: Nuclear processes would eventually become important in our civilian economy as they were then already in our military security. I think no one would disagree with this today. There were many who might have disagreed with this opinion four years ago, but the general feeling today is that nuclear processes will become important factors in our civilian economy and in our general cultural and technological development.

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Another opinion was that the established universities and colleges had a responsibility for training students and undertaking research explorations in this field of technology, as they traditionally have had in other fields. I am even more convinced of this today than I was then. As the need for trained men in this field becomes greater, it becomes increasingly clear that the job of providing foundation skills in this field is the responsibility of the universities and colleges.

Concurrently, the universities also have the responsibility of exploring within the areas of basic science the applications of nuclear processes and filling in the gaps of basic information which may be overlooked by programmatic activities in various phases of the Government's endeavors.

This belief in the "rightness" of a university reactor was not unique, even though there was widespread apathy and inertia. I recall that just before these ideas crystallized, David E. Lilienthal, who was then the chairman of the Atomic Energy Commission, published an article in which he urged very strongly that there be developed increasing participation in nuclear projects on the part of industry and the educational institutions in order that America might maintain her place of leadership in this field. It is quite clear now that he was right. This same general belief was one of the factors out of which our venture grew.

The second belief, or perhaps it should be called an article of faith, was the conviction which I had at that time that the AEC would come through with their part of the project. No one had ever asked them specifically whether they would approve an outside reactor project or not, and I don't know what their answer would have been if the question had been put directly. But it was sufficiently clear then and has been without any exception since, that the AEC did approve and was favorable to and in sympathy with such a project.

At every point along the way I have found that when commitments were really needed for the next step of the program, the AEC was willing to make the necessary commitments. Not only were they willing, they also gave sympathetic support and personal encouragement where these were needed, and they frequently were. I have yet to find an occasion when a problem encountered in our negotiations has not been considered intelligently and reasonably.

There have been for example a number of instances in which AEC spokesmen have expressed a personal feeling and a desire on their part to render a decision or to change a circumstance not permitted by policies or regulations. This should by no means be interpreted to imply, however, that there wasn't a lot of red tape to unravel or that every interpretation of the existing regulations has been in our favor, or even to say that the present law establishes the best framework for an AEC research reactor relationship. We haven't found this to be the case. The people who wrote the present law did at one place direct that outside participation in this program was to be encouraged. But at other places there were conflicting statements which tended to prevent the carrying out of this policy or made unclear what the intention really was.

I realize that in carrying out this first negotiation for an outside reactor project, there were many problems which arose from the fact that the law did not deal at length with this specific problem in its original formulation. I know that the Commission did a lot of soul-searching in trying to find solutions to the problems. Dr. Johnson indicated that they stayed awake at night. This, I wasn't aware of. In fact, there were many occasions when I wondered if they were awake even in the daytime!

On the whole, however, there has been very clear, right from the first, an overriding desire on the part of the Commission to encourage the building of this project, the first university reactor. This desire has been evidenced not only in the written agreements, but also throughout the negotiations with men like Dr. Roth, Mr. Kasschau, Dr. McDaniel, Dr. Pitzer, and others who were our direct contacts in the negotiations.

Aside from these factors which had to do with the feeling of the place of a reactor and what its potential usefulness might be, there was another important factor which figured prominently in the success of this project. I mention it because several items are suggested which must not be overlooked in other similar projects. This other circumstance to which I refer was partly fortuitous and coincidental but it has been essential to the establishment of an atmosphere in which such a project could flourish. The Engineering School at North Carolina

State College, under a new leadership, with aggressive plans for expansion and development, just before 1949 launched a vigorous campaign to raise the level of instruction and expand the scope of its research activities. This was true in various divisions of the college but was particularly evident in the Engineering School of the College, where the previous activities had been largely at the undergraduate level and the need for advanced instruction had become obvious.

There was a ready response to ideas around which this desire for expansion could develop. When the program in nuclear engineering was suggested, therefore, there was no hesitation or reluctance whatever. The response was enthusiastic and the support of the college administration has continued to be so. This is an exceedingly important factor in any university reactor project. No such program should be undertaken unless the administration is solidly informed about how it means to build a reactor, what the consequences are, and what the problems to be encountered are likely to be in the reactor's construction and operation. Unless the administration and the faculty are solidly in favor of the project, it might be wise not to continue, because so many different components of the university are certain eventually to become involved.

Early in the project positive efforts should be made to bring members from other departments and other divisions into active participation in the project through committee assignments, through advisory councils or in some other way. These participants may not actually render much direct service to the project, but their interest and support will be enlisted. Without this, I think the success of the venture would be jeopardized.

This problem of relationships within the framework of the university is one which comes up in a surprising number of places. It is one which leaders interested in driving ahead and establishing a program might tend to overlook. But it must not be forgotten because it will affect the operation of the project all the way down the line.

Once the decision to build a university reactor has been reached, the next important thing is to assemble an adequate staff to carry the project forward. It is not easy even now to find well-trained experienced people in this field of technical endeavor. In 1949 it was practically impossible to find such men. Yet we were particularly fortunate in assembling into our program a number of qualified and exceedingly able young men to participate in the project. Dr. Murray, one of our standard bearers, is here today. Dr. Menius, another, could not come because of illness. There were three or four other key men in the development of our reactor.

I quite agree with the AEC requirement that as an essential prerequisite to launching a reactor project there be a core of at least one or two competent, well-trained men who can carry the responsibility for the direction of the program. I think perhaps four experienced people would be about the minimum number around which a reactor program could be organized. This number should include at least one good theoretician with a practical bent, and a good instrumentation expert.

The type and design of the reactor to be chosen depend on its intended uses and a number of other criteria relating to the objectives to be achieved in its future operation. Our project has had two major objectives. The first is the training of students in nuclear engineering. I am not sure that this may not prove in the long run to be one of the largest contributions that universities can make. There is a shortage of qualified personnel in this field, and it will continue to exist for a good many years. I think that any university which plans to build a reactor ought to include plans for using it effectively in training students.

Our reactor, up to the present, has been used to a certain extent for training, and in the future will be used in three specific ways for training purposes. First, it will be used as a tool with which specific laboratory experiments will be performed. We have a formal course in reactor theory, and with it an associated reactor laboratory. Here students will perform about 12 experiments using the reactor as they would a piece of equipment in a chemistry laboratory to illustrate to them some features and characteristics of the reactor.

Secondly, a number of students will work around the reactor as part-time assistants on research projects. These are assistants the college normally furnishes the physics department to assist in research projects. Their assignment to reactor projects will provide valuable experience as well as help the departmental research projects.

Thirdly, a number of graduate students will undertake theses involving the use of the reactor or exploring some of the fine points of reactor characteristics. Beyond these direct involvements of the reactor in the training program are several intangible benefits which accrue to the program.

The second major objective of our program was to use the reactor for a variety of research explorations, both basic and applied. It may be, however, that many people are misguided about the value of a reactor in research programs. It can do many things; it can be used as a tool in many types of investigations, but it is by no means a tool which will solve all of the research problems that are to be faced. Some people, who initially are enthusiastic, become somewhat disappointed when they first become aware of its limitations and the difficulties encountered in its use.

On the other hand, the reactor does have many useful potentialities beyond the tremendous amount of its radiation. For example, it may be quite valuable as a catalyst in the research programs to consolidate interest from many different departments on the campus. Frequently, a defect in our instructional programs on the campus may be the tendency of the various departments to isolate themselves while our technology of today and the uses of industry require that people from different disciplines work together. The reactor can serve in many ways to cut across lines between fields of interest and bring people together from different disciplines on problems of mutual interest.

To achieve these two primary objectives in our reactor project—the training of students and its use in research programs—we adopted a number of criteria which have guided the development of the project to its present stage. The first was that, insofar as possible, the reactor would function as a normal component of the instructional and research programs of the school. By normal component, I mean one which would be used as an electronic microscope or a Van de Graaff machine or some other piece of equipment in the school which is used. This result could not be achieved by setting the reactor up with a big fence around it and putting various barriers of mystery, security, and secrecy in people's minds about it, but instead by simply integrating it into a proper place in the instructional and research programs.

This is not entirely possible, because the reactor is unique in some respects. However, in order to achieve this insofar as possible, it was stipulated further that the design, construction and operation would be on an unclassified basis and thus would be free of the encumbrances which inevitably evolve from classified information.

In 1949 this was a goal which did not appear easy; but, as was pointed out earlier in 1950 there did come a large declassification. We were thereby enabled to carry through on this desire in a satisfactory way.

Our next criterion was that we would ask no financial assistance in capital investment from the Atomic Energy Commission. That was not because we have lots of money; we do not. Like any school, we are quite limited. There were two reasons, however, for this criterion. First, we felt that approval of the project would be facilitated, and I am sure it was. We probably would not have approval yet if we had asked for money to build the reactor along with approval of the idea. By eliminating the financial problem from the other parts of the negotiations, the whole project was tremendously expedited and easier in the negotiations. The AEC may have been somewhat astonished that no money was requested, but they accepted it!

Secondly, it appeared that maximum freedom could thereby be granted the college in subsequent operations. This to us seemed a good worthy of attainment.

The third criterion established was that the reactor would have maximum safety and dependability in operation and flexibility in its research usage. We therefore chose a well-established principle in the design and well-proven components in construction. We were not attempting in any way to set forth novel advances in reactor technology. We simply wanted a unit that would work, and in this we were tremendously benefited by such people as Dr. King, who had operated the water boiler at Los Alamos and who always gave us information when we needed it; by people here at the National Laboratory who assisted in answering many questions about details of technical information; and by people at Brookhaven.

The important thing we observed was that at anytime we needed help or any time we asked for it people gave it unhesitatingly.

These criteria led us without any hesitation whatever to the type of design which we chose: the water boiler. The only possible choice at that time was the water boiler, unless we chose to embark on an extensive developmental program which we were not equipped to do.

If we were undertaking the project today, we would probably choose the same type. In the last few months, a number of improvements have been made in some of the auxiliary equipment which make it easier to handle the gases given off by the water boiler. This is the chief objection to its use. Other designs of reactors, of course, have certain advantages too. In the final analysis, a group which intends to build a reactor has to decide which type fits the need of its particular interests, or which will accomplish his particular objectives best.

It is impossible for us to say exactly how much this reactor cost. It was built under the guidance and largely through the direct efforts of the staff of the Physics Department. There are twenty people on the staff. When we launched this project, as I indicated earlier, there followed a major transition in the departmental program. In 1950 there were four students majoring in physics. Four years later we had about 150 majors, including 45 graduate students. The staff in the meantime had been responsible for developing a new training program in nuclear engineering, organizing the courses, and bringing it into a state of equilibrium. At the same time the staff designed the reactor, negotiated the contracts, built the facility and placed it in operation. So it is impossible to say what part of the time went into the actual building of the reactor and what part into teaching and other work in the department.

However, we did spend, aside from staff time, \$125,000 to build the complete reactor with its associated equipment. This included some staff salaries over two full summers for writing reports, design studies and calculations; as well as all the materials and equipment that went into the reactor. It could be done again I think for considerably less than this cost.

The building itself in which the reactor is housed cost \$380,000, and we now have an additional \$120,000 to equip the building—that is, to put in furniture and equipment in the laboratories and for auxiliary equipment around the reactor. The major burden of this project, from the time it was conceived until it was completed, was carried by five key senior staff members and five technicians over a period of about three years. In addition to these ten people, there were a half dozen part-time students and staff members who worked for short periods at various times during the project.

The extensiveness of future operations will depend on the research projects which develop. We have something like the following in mind: Four full-time people will be required to operate the reactor on an 8-hour a day basis, which is what we are planning at the moment. These would include one supervisor who would be responsible for maintaining the reactor in good shape, coordinating the experiments around the reactor, etc. There would be one expert instrumentation supervisor who would be responsible for maintenance and operation of the instruments and two shop electronic technicians to assist in whatever jobs were needed around the reactor. Perhaps a half- or full-time clerical person to keep the records should be added. There would probably be four or five reactor operators who would be graduate students trained to operate the reactor under direction of this supervisory staff. In addition to this minimum group of people responsible for operating the reactor, each major research project would be staffed by its own personnel.

Salaries for the four key members of the operating staff would be about \$20,000. About an equal amount would be needed for supplies. This would not include permanent capital investments or large items of equipment, but just the expendable items needed to operate the reactor and maintain it in good condition. Thus, an annual operation and maintenance budget would total about \$30,000 to \$40,000.

It would be somewhat difficult to make specific recommendations for changes in the present AEC university relationship which would make reactor projects more feasible or more satisfactory. In general, I would say that the outline of policy proposed by Dr. Johnson is quite acceptable from the standpoint of the university.

I certainly agree that there ought to be a Reactor Safeguards Committee or some other appropriate committee to review any reactor going to a university campus. However, the

biggest problem, the biggest danger, in operating a reactor on a college campus is not that it will blow up, but that people will be hazardedously exposed to radiation. The review by the Reactor Safeguards Committee doesn't really ascertain the adequacy of preparations to handle this problem. In fact the whole matter of protection from radiation exposure needs further consideration. Neither the definition of acceptable practices, the standardization of procedures, the safety stipulations in the contract, the specification of tolerance limits, nor the inspection-reviews are at present adequate or satisfactory. In this same general area, the AEC has developed no procedures and has not exercised initiative in suggesting bases of negotiations and relationships between reactor projects and public health officials. Formal relationships are certain to develop, and enlightened leadership could help guide these into effective and cooperative channels.

There may arise a problem of defining what is research, which is permitted, what are development or routine utilization, and which are not. We, of course, have not encountered this problem, but there is a possibility that some difficulty could arise.

The requirement that every research usage of the reactor be reported to the commission, and the possibilities that this in turn might be reported at large, I think, could lead to difficulty—although I have no real expectation that it will. Universities frequently undertake projects for sponsoring companies who do not want the results widely published. But there is a matter of principle involved here, to which I object.

There appear at various places in the reactor contracts incongruent and contradictory attitudes of the AEC toward responsibility or blame in case an accident or injury occurs. Safety features must be scrutinized in advance, and any change must be approved, etc., which seems to leave nothing to the judgement or discretion of the projects directors. Conversely, if an accident occurs the AEC declares in advance that it is not responsible. Despite reviews, approvals and inspections, the impression is given that the AEC would absolve itself of any part of the blame for any undesirable incident that might occur. Actually the AEC could not do this, and I think they have no intention of so doing. It is a joint undertaking and both parties should have and do have a share in the responsibility for safe operation.

Despite these various comments, it is my over-all opinion that the arrangement is a good one and I foresee no major difficulties in the working relationship.

THE UNIVERSITY OF MICHIGAN REACTOR PROJECT

by Henry J. Gomberg*

At the University of Michigan, we were faced with a situation somewhat different from that at North Carolina State College or Pennsylvania State University. Dr. Beck, in presenting the history of the development of his project, indicated a number of years spent at Atomic Energy Commission laboratories. Professor Braezeale went to Penn State after some years at Oak Ridge. When interest at Ann Arbor developed in building a laboratory reactor for research in nuclear energy, we did not have the services of a senior staff member, or even a junior staff member who could claim substantial experience on reactors in the AEC laboratories. Several of our faculty members had been engaged in theoretical aspects of the field and a number of others were consultants in various specific areas, but none of us could claim first-hand knowledge of day-to-day operation of a reactor or much working experience with one.

Nevertheless, we were extremely interested in the field. So, like many other schools, were faced with not only the decision of picking a reactor design, but also with first getting enough information on the field and then evaluating it to decide whether the area was strictly for the annointed, or whether it was going to develop into a general technical and engineering field which would spread beyond the Commission's confines.

We came to the conclusion that the atom was here to stay and that we would like to become better acquainted. We actually made a beginning on this, as some of you may know, through our Phoenix Project, which is the University's war memorial. It started in the late 1940's, not long after the war, with a proposal from one of our alumni that a fitting war memorial would be a university-wide program to study the peace-time implications and applications of atomic energy. We were about ripe for that. The public mind was well indoctrinated to the terror of the atom bomb. Michigan had lost enough men to take the concept of the memorial seriously. The potentialities for peacetime use of atomic energy had been neglected, yet were obviously great. And the need to bring as much of the work as possible from behind the routine security walls of the government laboratories into open university laboratories was most apparent.

So the seed fell on fertile soil. I will make a long story rather short. Since the beginning of the drive and the development of the campaign, about \$7,500,000 was contributed by students, alumni, cooperating corporations, and individuals. This support has enabled us to develop what we think is a broad program.

The program includes work all the way from studies of the Atomic Energy Act itself by people who are not on the government payroll (namely, our own law school), through a public administration study, on through engineering, medicine, biology, geology, and almost anywhere

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else you would care to look for it. In other words, it is an attempt to evaluate what is going to happen to us both technically and socially as a result of the development of what is generally here agreed to be a major new form of controlled energy.

Perhaps the harnessing of electricity was the last time that a major new energy form became available, or perhaps it was the utilization of steam. But historically, every time a major form of energy has become available, there have been rather strong technological and social repercussions. So in a very small but in a very ambitious way, we are trying to help solve everybody's future problems.

We have felt that in order to do this properly we would have to fulfill our functions as a university not only in research but also by entering the field of teaching, to train men in this field. To do both adequately, we would have to set up laboratories, including a nuclear reactor. The reactor, in our case, is not the major laboratory, but is actually a portion requiring some 30 per cent of our total building and expansion activity. Just before we left Ann Arbor, we opened the bids on the Phoenix Memorial Laboratory, which does not include the reactor, but which provides facilities to handle radioactive materials up to several thousand curies, and diversified experimental areas in which the radioactive materials may be used in research.

To help visualize our proposed layout, and to help introduce the swimming pool type reactor, we have some figures which will illustrate what a typical swimming pool type assembly would look like and how it will be integrated into our laboratory and campus (Fig. 1). One of the first things you are going to hear about if you take the problem of the reactor seriously is "exclusion area," or, "Where are you going to put your reactor so, if it blows up or vaporizes, nobody except the people responsible for the catastrophe will be killed?" On the usual university campus, this is just about impossible. A much better approach is the selection of a reactor design whereby a reactor accident leading to the release of most of the fission products is not possible. We believe that the swimming pool reactor can fulfill this requirement.

However, we have also provided what we believe is effective exclusion space. We are in a fortunate position in that the university has found itself, over the last few years, extremely cramped for space on its regular campus in Ann Arbor. So, rather than continuing the practice of buying up buildings and then knocking them down to make room for new buildings, we have gone to an uninhabited area, essentially farm country, and bought some 300 acres. The 300 acres are now called the North Campus, and what you see in Fig. 1 is a projected ten-year building program for the North Campus.

Only one building exists on it now, the Cooley Memorial, which is an engineering research laboratory and with which we will coordinate our work. The Phoenix Laboratory mentioned previously will be here, and we plan to put the reactor at the north end of that building so that the very elaborate—for a university—radiation handling facilities which were planned for the Phoenix building can be usefully coordinated with the reactor. If you go above 10^{13} neutron flux, you get into activation problems which require special facilities for handling intensely radioactive material. As I will discuss later, we plan to go to 10^{13} neutron flux or higher. The other buildings are projected, and Fig. 1 is simply an attempt to show approximately how the new campus will look in ten years.

Our "exclusion space" is obtained as follows: Within 500 feet of the reactor, we would have nothing but research work; very low density population. Within 1500 feet there would be nothing but classrooms, no apartment buildings or anything of that type, so that all the space is easily evacuated; and beyond this radius we lose control. In fact, there is a Veterans Administration hospital outside the 1500 foot circle, putting a logical limit on our planning.

Figure 2 is an airplane view of the site looking at it from the northeast, showing a good part, but not the complete tract that we have available at the present time.

Figure 3 is an overhead view of the tract showing the Cooley Building, the reactor, the Phoenix building, the exclusion circles, and the University Hospital. At the time this picture was taken, the Veterans hospital was just being started. We are well out of the populated area. Meteorologically, we were very fortunate; the university, when it bought the site, was not thinking of us; but the prevailing winds are such that we are in a most favorable location.

We now consider the swimming pool reactor (Fig. 4). This is one view or one possibility of how such a reactor could be put together if the reactor core is never to be moved. In other

Fig. 1—Relation of reactor to other installations.

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Fig. 2— Air view of reactor site.

Fig. 3—Overhead view of reactor site with exclusion circles superimposed.

Fig. 4—Swimming pool reactor with fixed reactor core.

words, this is a fixed installation. The reactor is under about twenty feet of water. A water circulating system is shown since we are planning for a power level of one megawatt.

Here is one of the possible arrangements for the six neutron beam ports. Other features shown are the shielding, the coffins for taking activated material in and out of the beam ports, a two-level arrangement so we can work down at the lower or beamhole level or come in at the top with experiments that will be lowered through the water to the vicinity of the reactor itself. The upper level also serves as a visitors' gallery.

I would like to emphasize one feature of the swimming pool type which has figured very heavily in our going to this design when we had both the swimming pool and the water boiler to choose from: In this type, you have essentially an infinite window. The students can watch the reactor in operation. This means more than seeing Cerenkov radiation. The fact that a reactor is inherently an extremely simple device can best be demonstrated by one in operation, and this is a method of actually demonstrating a reactor in operation under safe conditions.

Figure 5 represents our more advanced thinking, involving technical improvements over the first design. This one is a good deal closer to the Penn State plans, with the same type of core and the same depth of pool. Instead of using square sides, we are now going to the angle idea, which is used at North Carolina State as well, a water circulating system as before, and, like the Oak Ridge swimming pool, a moveable bridge so that the reactor core can be shifted in the tank.

The fact that, in a swimming pool, the reactor core is suspended from a bridge provides certain rather important advantages. You can get the reactor out into another compartment without taking it apart, drain the tank, and do work down at the tank bottom. Also, should you want to open a beam hole after the reactor is shut down, you can back it up enough so that you do not have a very intense beam of gamma rays coming out through the open beam hole.

The heat exchanger and so forth are part of our design because, if you go above 100 kilowatts, the convection cooling will not be adequate. We would have to use forced circulation.

Figure 6 gives some idea of what a fuel element would look like. This was taken from a report when the element in use at the present time on the swimming pool had not yet been declassified. So it shows a different number of plates.

The fuel element is essentially a box with fuel plates in it, the fuel plates consisting of aluminum-uranium alloy with a pure aluminum cladding, so that the exposed surfaces are all pure aluminum. The fuel elements sit vertically. They plug into a board like the peg boards the kids use, and you can make different fuel lattice arrangements.

Figure 7 is an actual photograph of the swimming pool; the fuel elements are in the board, and the various instrument chambers are enclosed in water-tight containers that sit at the various points in the system.

Figure 8 is a typical lattice arrangement. Since this drawing was made, the recommendation has been made and followed that it would be better to use three safety rods and one control rod than just the two indicated. But the number used is quite flexible. For control, a special fuel element is used that has an extra space in it for the control rod to move in and out.

Figure 9 is a photograph showing a beryllium oxide reflector which can be put in place if you have any reason to do that for fuel economy or to demonstrate the effect of the reflector. The reflector does not have to be in one piece. It can be in cans like the fuel elements themselves, and can be placed at strategic points around the lattice. Here is also shown a magnet which ordinarily would support a control rod.

Figure 10 shows a control panel. I won't take time now to indicate what all the controls are. The general idea is not too different from the Los Alamos reactor. You need measuring devices at the various flux levels. You need rod control devices.

In this case the controls are mounted on the moveable bridge. This saves a great deal of complication in the problem of wiring; if the reactor moves and you take the controls with it, you don't have a lot of cable to take care of. On the other hand, if you are bucking for super-control or if you want an air-conditioned control room, it gets to be more difficult to put that on a moveable bridge. So you have to decide which way you want to go.

The problem of the neutron beam ports is apparently one that is still subject to debate. Everybody has his pet design. Figure 11 shows one that we originated and we cannot guarantee

Fig. 5—Proposed University of Michigan swimming pool reactor with movable reactor core.

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Fig. 6— Fuel element.

Fig. 7—Photograph of ORNL swimming pool reactor.

Fig. 8—Reactor grid plate, partially loaded.

Fig. 9 — Grid and BeO reflector.

Fig. 10—Reactor control panel.

Fig. 11—Preliminary beam hole design.

it yet because it has not been built for use. But it is one approach to the problem. This is an aluminum caisson which comes out close to the reactor. Professor Breazeale tells me that it is usually a good idea to put a boral liner in the caisson to cut down the activation of the concrete through which it passes. The concrete tank wall is made of one of several heavy varieties of concrete. The system is so arranged that when the neutron beam port is not in use it can be flooded. The water in this reactor is not only a coolant and a window, but is also the moderator. The removal of any water from the caisson has to be compensated in some way.

When not in use, the beam hole should not be kept dry for many reasons. The beam hole is kept flooded unless it is in actual use. Figure 11 shows one type of beam hole door including a special hinge. It is carefully interlocked so that it is impossible to open the door while the reactor is in operation.

One word now on power level. You have seen the design we have in mind. It is also typical of a number of other designs, all of which are based on the swimming pool core. The reason we went to this one is that we wanted high power, to provide the opportunity for graduate students to work on a thesis in this area of research.

One region certainly in the engineering part of this work—and nuclear engineering is a very important part of our interest—is the problem of new materials which will stand up in the presence of radiation. There is a rule of thumb that to test a material for stability, it is well to test it up to about 10^{19} neutrons. If you have a reactor that is running at about 10^{10} neutron flux, the test would take about 31.5 years. So a reactor that is running at low power immediately excludes the graduate student from this type of study.

On the other hand, if we want to run an experiment of this type and we have 10^{13} neutrons, it takes approximately one-third of a year of actual irradiation time. This is a completely feasible experiment. It is our feeling that this class of problems is a very important one and we do not wish to be excluded, by our equipment, from working in this area.

Incidentally, in the biological field, Dr. Alexander Hollaender has told me that these high flux levels are extremely important for adequate work with bacteria and bacteria phage. So the use of high power is not just for generating steam, but for providing experimental conditions in keeping with our knowledge of the needs in this field.

DESIGN COMPARISON OF UNIVERSITY REACTORS

by J. A. Lane*

As in the case of any new industry, the art of building nuclear reactors is in the process of evolution. Normally, this process occurs in three phases, the first of which involves providing the rudimentary tools which just do the job. The next step is to refine these tools and improve performance. Finally, techniques are introduced which take into consideration economic factors and these result in reduced costs.

Most phases of our reactor development program have not progressed far into this evolutionary cycle. Production reactors, for example, because of extreme dependence on reliability have not and probably will not get beyond the second phase. The same is true for the various mobile reactors, since here again the emphasis is on reliability rather than economics. In the case of research reactors, however, one can afford to be more daring with respect to cutting costs and, for this reason, designs have evolved over the past decade which are economical enough to be well within the range of the average university's pocketbook.

Although the number of nuclear systems which might be used in the design of a research reactor is practically unlimited, experience has shown that some systems are superior from the standpoint of safety, reliability, and cost. These types, which I will describe in more detail later, have the common characteristic of being fueled with enriched uranium and are water cooled. Other types, such as the air-cooled natural uranium piles, appear to be significantly less attractive as a high level source of neutrons for research. The reason for this is mainly their inherently high cost per unit of flux. It is of interest, however, to compare the characteristics of natural uranium research reactors with the types using enriched fuels. The properties of natural uranium research reactors are shown in Table I.

GRAPHITE PILES

The first graphite reactor, the Cp-1, or Stagg Field reactor, was started in November, 1942, and went critical on December 2, 1942. It operated at power levels up to 200 watts for brief periods of time. After a few months, it was dismantled and rebuilt at Argonne as the CP-2. The job required 21 days for completion and the new reactor could be operated at a power level of 2 kw, though no cooling was provided.

The next step in the evolution of graphite reactors was the construction of the X-10 reactor which was started in January, 1943, and reached criticality 11 months later. The initial air

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Table I—Research Reactors Fueled with Natural Uranium

<u>DESIGNATION</u>	<u>DATE</u>	<u>FUEL, TONS</u>	<u>MODERATOR</u>	<u>POWER LEVEL</u>
CP-1	1942	6 U Metal 40 U Oxide	385 tons C	100 watts
CP-2	1943	10 U Metal 42 U Oxide	472 tons C	2 kw
X-10	1943	35 U Metal	620 tons C	3800 kw
CP-3	1944	3 U Metal	6.5 tons D ₂ O	300 kw
NRX*	1947	10 U Metal	17 tons D ₂ O	30,000 kw
BNL*	1950	60 U Metal	700 tons C	28,000 kw

*The amount of fuel and specific power of NRX and BNL reactors have been calculated from published flux and power data.

Table II—Research Reactors Fueled with Enriched Uranium

<u>DESIGNATION</u>	<u>DATE</u>	<u>ENRICHED U-235 FUEL</u>	<u>MODERATOR</u>	<u>POWER LEVEL</u>
<u>HEAVY WATER TYPE</u>				
CP-3 prime	1950	4 kg U + Al	7 tons D ₂ O	300 kw
CP-5	1953	1.2 kg U + Al	6.5 tons D ₂ O	1000 kw
<u>WATER BOILERS</u>				
LOPO	1944	0.5 kg UO ₂ SO ₄	H ₂ O	<1 watt
HYP0	1944	0.8 kg UO ₂ SO ₄	H ₂ O	6 kw
SUPO	1951	0.8 kg UO ₂ SO	H ₂ O	45 kw
NO. CAROLINA	1953	1 kg UO ₂ SO ₄	H ₂ O	10 kw
<u>MTR TYPE</u>				
LITR	1950	3 kg U + Al	H ₂ O	2000 kw
BSF	1951	2.5 kg U + Al	H ₂ O	100 kw
MTR	1952	4 kg U + Al	H ₂ O	30,000 kw
ORR* (scheduled)	1956	2.5 kg U + Al	H ₂ O	5000 kw
<u>HOMOGENEOUS GRAPHITE</u>				
NAA LOW POWER	—	3.2 kg U ₃ O ₈	GRAPHITE	160 kw

*The ORR reactor mentioned here refers to the conceptual design of a reactor for basic research using advanced MTR technology. It does not refer to a specific reactor project.

cooling system was later modified to permit raising the power level from 1000 kw to 3800 kw. The reactor has operated continuously at approximately that power level for about 10 years.

The design of an advanced type graphite reactor for nuclear research at Brookhaven was started in 1946, and this reactor reached criticality in August, 1950. This reactor is designed to operate at 30,000 kw and produce a maximum flux of 6×10^{12} n/cm²/sec. The reactor has run continuously since start-up at power levels close to the maximum, to serve the staff of the laboratory and visiting scientists and engineers in neutron research. It also has become a large producer of radioisotopes.

HEAVY WATER REACTORS

The first natural uranium heavy water reactor CP-3 was completed in May, 1944, by Argonne Laboratory and operated at 300 kw. The core consisted of a cylindrical aluminum tank 6 feet in diameter and about 9 feet high. Aluminum sheathed uranium rods were suspended vertically in the tank. This reactor was kept in service 6 years. In 1950, due to suspected deterioration of the Al sheaths, it was decided to replace them with fresh rods of enriched uranium. Other modifications to the reactor were made and the rebuilt facility called CP-3 prime.

Work on a higher power version of the natural uranium-heavy water system started in Canada in 1944. This reactor (NRX) went critical in 1947 and ultimately reached power levels of 30,000 kw. On December 12, 1952, a sequence of operating errors, coupled with a number of mechanical defects in the safety system, caused a power surge and subsequent melting of some fuel rods and rupture of the reactor core tubes. This reactor is at present being repaired and modified for higher performance.

ENRICHED SYSTEMS

The widespread use of enriched uranium as fuel for research reactors is shown in Table II. Five systems may be described: a) solid fuel-heavy water; b) solid fuel-light water; c) liquid fuel-light water; d) homogeneous graphite; and e) liquid fuel-heavy water. This latter type offers some advantage, but has not yet been used as a research reactor because of outstanding development problems, and is not shown in this table. The pros and cons of these systems will be described later.

PERFORMANCE AND COST OF RESEARCH REACTOR TYPES

A comparison of the performance of various systems measured in terms of the specific power and thermal neutron flux is shown in Table III. The approximate cost of the reactors is also shown, not including fuel costs.* It is evident that not only is the absolute performance improving with time, but also the flux level per unit of construction cost. Plotting this performance index as 10^{12} flux units per "megabuck" against the start-up date indicates a definite upward trend for the majority of systems. This is shown in Figure 1.

BREAKDOWN OF COSTS

Although one can argue that the performance index shown, measured in terms of total dollars spent, is not a fair comparison of the various reactor types since in most cases only a small fraction of the cost went toward cooling (i.e., providing high flux), a breakdown of costs of even the extreme cases indicates that approximately the same fraction of the cost went into cooling. This is shown in Table IV.

*In some cases (HYPO, SUPO) reactor costs have been adjusted to include a reasonable building cost. Actual cost of SUPO was \$200,000 without bldg. (Building costs of LOPO were added.)

Table III—Performance and Cost of Research Reactors

REACTOR	DATE	SPECIFIC POWER kw/ton of fuel	AV. THERMAL NEUTRON FLUX	COST, \$ x 10 ⁶
CP-1	1942	0.002	4×10^6	1.5
CP-2	1943	0.04	1×10^8	2.0
X-10	1943	110	5×10^{11}	5.2
CP-3	1944	100	5×10^{11}	2
HYP0	1944	7,000	1×10^{11}	0.5
NRX	1947	3,000	2×10^{13}	10
CP-3 ¹	1950	68,000	2×10^{12}	2
BNL	1950	470	2×10^{12}	20
LITR	1950	500,000	1×10^{13}	1
SUPO	1951	50,000	1×10^{12}	0.5
BSF	1951	37,000	1×10^{12}	0.25
MTR	1952	7,000,000	2×10^{14}	18
NCSR	1953	9,100	2×10^{11}	0.5
CP-5	1954	910,000	2×10^{13}	3
ORR	1956	1,800,000	5×10^{13}	2.8
NAA	-	45,000	1×10^{12}	1.4

Fig. 1—Performance index of research reactors.

Table IV — Cost Breakdown of ORR, MTR, X-10 Reactor

<u>ITEM</u>	<u>MILLIONS OF DOLLARS</u>		
	<u>ORR</u>	<u>MTR</u>	<u>X-10</u>
SITE	---	2.1	---
REACTOR	1.4	5.9	2.7
BUILDING	0.6	3.5	1.1
WATER SYSTEM	0.4	3.1	---
AIR SYSTEM	0.1	0.3	0.9
POWER PLANT	---	1.0	---
DESIGN, etc.	<u>0.3</u>	<u>2.1</u>	<u>0.5</u>
	2.8	18.0	5.2
FRACTION ASSIGNED TO COOLING SYSTEM	17 %	18%	18%

Fig. 2—Flux of enriched reactors with fixed cooling costs.

Fig. 3—Enriched fuel required for reactors with fixed cooling costs.

I am not aware if this is true of other cases, but it is clear that certain inherent characteristics of the various systems dictate performance rather than the cost of facilities other than the cooling system. For example, the natural U-graphite reactors are of necessity large reactors. In the case of the BNL reactor, the cost of graphite alone amounted to approximately $\$2 \times 10^6$. Fuel, if it were considered, would add another $\$4 \times 10^6$.^{*} This may be compared with costs less than \$100,000^{*} for the fuels used in the enriched systems with no cost for the water moderator. In addition, the large size and high fuel inventory of graphite moderated systems considerably reduce the flux for a given power level.

COMPARISON OF ENRICHED SYSTEMS. (Calculated by M. C. Edlund)

Turning now to enriched fuel water moderated reactors, it is of interest to determine the maximum flux that one can get for a given cost of moderator and cooling system. Four systems may be considered. These are:

1. light water—solid fuel
2. light water solution (homogeneous)
3. heavy water—solid fuel
4. heavy water solution (homogeneous)

If one sets a limit, say \$250,000, to be spent for D₂O and for the heat removal system, the thermal neutron flux for these four systems will vary with the diameter of the reactor core. This variation is shown in Figure 2, which takes into consideration the change in fuel concentration and the amount of moderator for the stated conditions. As a basis for the comparison, the cost of D₂O has been assumed to be \$100/liter. This has been estimated by manufacturers to represent a future free market value for D₂O. The cost of the heat removal system has been taken at \$50/kw heat. In the case of the circulating solution reactors, the external system holdup has been assumed to be 20 liters/MW heat for a closely coupled system. Fuel costs are not included in the comparison, but are approximately the same in all cases of interest.

Figure 2 shows that circulation solution D₂O reactors have a considerable advantage in terms of thermal flux obtainable compared to the other systems. The present development of homogeneous reactors at ORNL may well lead to the use of this system for high neutron flux research. Material requirements are shown in Figure 3.†

SAFETY

The importance of a high degree of safety and reliability in a research reactor is obvious. The water systems shown are characterized by a strong negative temperature coefficient and ability to shut down automatically on loss of coolant. This has been demonstrated experimentally in a number of reactors of this type. The light water-cooled graphite moderated or heavy water moderated reactors do not necessarily possess this feature and, depending on the particular design, may not be inherently as safe as the heterogeneous or homogeneous water reactors.

^{*}\$35 per pound, U-238, \$20 per gram, U-235. Lit. cit. Zinn, W. H., Basic Problems in Central-Station Nuclear Power, *Nucleonics*, Vol. 10, No. 9, September 1952, pp. 8-14.

†The minimum U-235 requirements per unit of flux (10^{12} n's/cm²/sec) are: H₂O, solid fuel—.07 kg/10¹² n's/cm²/sec; H₂O, circ. fuel—.14 kg/10¹² n's/cm²/sec; D₂O, circ. fuel—.40 kg/10¹² n's/cm²/sec; D₂O, solid fuel—1.03 kg/10¹² n's/cm²/sec.

REACTORS OR OTHER NUCLEAR MACHINES

by Arthur H. Snell*

Please consider with me, if you will, the problem presented by Professor Diddle. Professor Diddle is, of course, a fictitious person; he is Chairman of the Physics Department of the equally fictitious East Yaphank University. East Yaphank U at present has no nuclear machines, but the Physics Department wants to start some experimental nuclear physics, and Professor Diddle has appeared asking for advice as to what kind of a machine they should acquire. There seems to be no preconceived determining factor in the choice; that is, there is no betatron man on the staff and nobody who particularly wants a cyclotron or reactor. The feeling in the department is neutral.

I asked Professor Diddle, "How about your Biology Department? Are they interested in some particular machine?"

He said, "Well, they are getting along fine so far as gamma rays are concerned by using a cobalt source, but they would like a source of neutrons. They are much concerned about the purity of their radiation source, and for this reason their inclination is toward a Cockcroft-Walton D-T generator or a cyclotron."

"And your Chemistry Department?" I asked.

"They get most of their isotopes from the AEC," he answered. "If we have a local radioisotope producer, it will be useful mainly for only short-lived materials, and here the choice of the radiochemists leans toward a cyclotron because with it they can make the positron emitters as well as the negatron emitters. The radiation chemists also use a cobalt source and, as a particle machine, they would prefer an electron accelerator."

"And what about your engineering faculty? Are they interested in training reactor engineers?"

"If they were," he replied, "I wouldn't be here with these questions because their choice would settle the matter and we would build a reactor." Then he added as an afterthought, "and besides the students can go to Brookhaven to learn about reactors."

At this point, he sensed a definite stiffening in my attitude and realized that I was from Oak Ridge and that at Oak Ridge we pride ourselves particularly on our reactor training, so he added hastily, "proximity, you know!" I let him get away with that one, but this was the start of increasing personal difficulties between us.

"There is really no environmental factor determining our choice of a machine," Professor Diddle continued, "and we think the choice has to be made on the basis of what can be done in the Physics Department with nuclear machines of the various kinds."

*Arthur H. Snell has been a member of the staff of Oak Ridge National Laboratory and its predecessor, Clinton Laboratories, since 1944 and has been Director of the Physics Division since 1949. Before taking his Oak Ridge post, he was a research instructor in physics and chief of the cyclotron section of the Metallurgical Laboratory at the University of Chicago.

"How much money do you have to spend?" was my next question.

"What does it matter?" he asked.

"Look," I replied crushingly, "a \$20.00 wheel barrow is a much more functional object than a \$20.00 pick-up truck, but if you go to the \$2,000 range, then things are different—the same applies to nuclear machines."

So Doctor Diddle went back to the president of East Yaphank U for further details as to how much money he could count on spending. The president would not let himself be pinned down. It seems that negotiations just then were in a particularly delicate stage... Finally the president said "Prepare your plans for anything in the price range from \$50,000 up to \$1,500,000."

When Doctor Diddle reported this to me he added "but, you know, I have an idea about this cyclotron thing. One of our trustees of the University is on the Board of Directors of the Bethlehem Steel Corporation and maybe we can..." I interrupted him—"There are two ways of financing these things. Either you can do it on a commercial cost basis or you can do it on a scrounge basis. On the commercial cost basis you will certainly pay a lot more money for nuclear machines than you would on the scrounge basis if you can use graduate students for design labor and use whatever help you can get in the obtaining of materials, but the scrounge basis is extremely variable and an uncertain thing to count on, so, in any comparison, let's take the commercial values—off the shelf wrapped in cellophane and usually fixed with a breath-taking price tag."

We agreed that there is no point in cutting things too fine, cost-wise, so we divided the president's price range into four broad bands. We further agreed that the various nuclear machines can be compared only on very general grounds, deciding finally on four bases of comparison. In the first place, we would consider the versatility of the machine as a nuclear research tool. Secondly, we would consider the mechanical reliability, because nobody likes to spend much of his research time fighting the machine. Thirdly, we would ask if certain machines have pedagogical advantages over others, that is, whether one machine more than another would introduce, or, shall we say, force graduate students into a greater variety of experimental techniques. Fourthly, we would rate the machines according to the number of simultaneous experiments which they could support. Then we did some enquiring and looking up of costs, and Mister Diddle drew up Tables 1 to 4. In doing so you will note that he omitted a comparison according to the number of simultaneously supported experiments. I reprimanded him severely for this, but, as it is, we will have to weave this aspect into the discussion of the tables as we go along.

Table 1 shows the approximate situation in the price range below about \$100,000. It is interesting to note in the first line that the classical nuclear machine still remains a useful and versatile object. Not only can it be used to clear up remaining details of nuclear reactions in the lightest elements, but also it can serve as a very powerful source of D-D or D-T neutrons. Furthermore, it can be used in the investigation of stopping powers and charge exchange cross sections for charged ions as they penetrate matter—currently an active field. Pedagogically it rates high because the student comes into contact with vacuum techniques, ion source design, ion focussing and deflection, penetration through thin windows, and the stopping powers of various thick and thin targets. The same considerations apply to the small electrostatic generator, the difference being merely that one trades intensity of current for extra voltage. The betatron is the commercial article which has been available in this country, and the linear accelerator is the English Mullard machine which can accelerate powerful pulses of electrons to the indicated energy, and can thereby be made to supply short pulses of photoneutrons. The reactor in this price range would probably be an uncooled affair which could supply some neutron activations of moderate intensity and support a rather limited amount of slow neutron physics. Any of the electrical machines could be placed in a vacant corner room in the main physics building at East Yaphank, but neither Mister Diddle nor I felt comfortable about placing the reactor in a classroom building because of the possibility of a blunder which would let the reactor run away. There is not much to choose between the machines of Table 1 with regard to the number of simultaneously supportable experiments.

Table 1 — Nuclear Machines: \$50,000-\$100,000 Price Range

MACHINE	"RATING"	SPECIAL BUILDING?	VERSATILITY RATING	PEDAGOGICAL RATING	PERFORMANCE DEPENDABILITY RATING
TRANSFORMER-RECTIFIER "COCKCROFT-WALTON"	SEVERAL ma AT 600 Kev	NO	A	A	B
ELECTROSTATIC GENERATOR	1.5 TO 2 mv ELECTRONS OR + IONS	NO	A	A	B
CYCLOTRON	18-in. 3 Mev H ⁺ OR D ⁺	NO	B	A	B
BETATRON	25 Mev	NO	C	B	B+
LINEAR ACCELERATOR	12 Mev ELECTRONS	NO	C	B	B
REACTOR	1 kw CONTINUOUS 10 kw FLASH 10 ¹⁰ -10 ¹¹ SLOW FLUX	YES	C	B	A

Table 2 — Nuclear Machines: \$100,000-\$300,000 Price Range

MACHINE	"RATING"	SPECIAL BUILDING?	VERSATILITY RATING	PEDAGOGICAL RATING	PERFORMANCE RATING
ELECTROSTATIC GENERATOR	3 mv POSITIVE IONS	NO	A	A	B
CYCLOTRON	6 Mev H ⁺ OR D ⁺	MARGINAL	A	A	B
BETATRON OR SYNCHROTRON	75 Mev ELECTRONS	YES	B	B+	B
REACTOR	10 ¹² SLOW FLUX (Swimming Pool)	YES	B	B	A
LINEAR ACCELERATOR	INSUFFICIENT EXPERIENCE				

Table 3 — Nuclear Machines: \$300,000-\$750,000 Price Range

MACHINE	"RATING"	SPECIAL BUILDING?	VERSATILITY RATING	PEDAGOGICAL RATING	PERFORMANCE RATING
ELECTROSTATIC GENERATOR	5-6 mv	VERT: YES HOR: MARGINAL	A	A	B
CYCLOTRON	40-in. 10 Mev D ⁺ 15 Mev H ⁺	PREFERABLE	B	A	B
SYNCHROTRON	200 Mev ELECTRONS	YES	B	B	B
REACTOR	10 ¹² SLOW FLUX (water boiler)	YES	B ⁺	B	A
LINEAR ACCELERATOR	INSUFFICIENT EXPERIENCE				

Table 4 — Nuclear Machines: \$750,000-\$1,500,000 Price Range

MACHINE	"RATING"	SPECIAL BUILDING?	VERSATILITY RATING	PEDAGOGICAL RATING	PERFORMANCE RATING
ELECTROSTATIC GENERATOR	9 mv	YES	A	A	B
CYCLOTRON	60-in. 20 Mev H ⁺ OR D ⁺	YES	A	A	B
SYNCHROTRON	350 Mev ELECTRONS	YES	B	B	B
REACTOR	10 ¹³ SLOW FLUX LITR OR NAA DESIGN	YES	A	B	A
LINEAR ACCELERATOR	INSUFFICIENT EXPERIENCE				
STRONG-FOCUSING ELECTRON OR PROTON SYNCHROTRON	INSUFFICIENT EXPERIENCE				

In Table 2 we go to the next higher priced range and the machines become more powerful. In accordance with practice in this country, the electrostatic generator has displaced the Cockcroft-Walton machine, although it might have been wise to keep the Phillips transformer-rectifier set in the picture. The reactor is still rated below the positive ion accelerators because of its limitation to neutron physics. It will, however, be a highly reliable machine, and perhaps can support more than one experiment at a time. Shielding requirements begin to demand that these machines be placed in special buildings.

In the \$500,000 price range, Table 3, the electrostatic generator retains the high ratings for versatility and pedagogy for the reasons indicated in the discussion of Table 1. The cyclotron is given a slightly lower versatility rating because experience has shown that the electrostatic generators have given a greater wealth of accurate and detailed nuclear information than have cyclotrons. Both Diddle and I could point to brilliant exceptions to this, but we agreed that it was generally true. The cyclotron, however, might have been up-rated slightly because at this size it becomes an important and unique source of the positron-emitting radioactive isotopes. The reactor is, of course, still limited to neutron physics, but in this range it can be expected to stand in a shield of its own with several beam holes, and can support a number of simultaneous experiments. Electron accelerators are limited to photonuclear reactions, and as such have been given a lower versatility rating throughout.

In the last table we come to the highest price range, and here we have guessed at 9 million volts for the electrostatic generator because the most advanced machines of this kind are nearing that energy. The post-war cyclotrons that were on the market were priced in the neighborhood of \$1,000,000 for a 60" job. The linear accelerator situation is pretty unclear. The several in this country that are under construction or in operation have involved rather serious development costs, and at the same time they have not yet proved themselves research-wise to the extent of the other machines. The strong-focussing machines are, of course, even less well known. I had some argument with Diddle about the versatility rating of the reactor in the 10^{13} slow flux range. Diddle was plugging for a high rating and I still favored the charged particle accelerators.

"Coulomb excitation!" I screamed, "accelerate fancy ions!"

"Look here, bud," he said (you see, we had achieved pretty familiar terms with one another since our little tiff about the omission of data from the tables) "when I get up into the 10^{13} flux range with my reactor, I can set up spectrometers and get into the neutron diffraction business, which means a unique approach to solid state physics and to magnetic structure. I am no longer afraid of being in the shadow of the bigger reactors at the national laboratories. Does this not counterbalance the charged particle business that you have been harping on so much in arguing for the positive ion machine?"

I had to admit that it did. On these grounds we rated the reactor as equally versatile to the charged particle accelerators. It is still a more reliable machine and can definitely support many more experiments at one time.

In summarizing our conclusions, I would say that if one is considering a reactor for physical research, it pays very much to go to the high flux range. If one cannot afford this kind of a tool, then some of the well-known positive ion accelerators become very strong competitors. On the other hand, the high flux reactor can support a number of people for their lifetime in research in induced radioactivity, solid state physics (mainly through neutron diffraction), and in neutron physics. In these conclusions, I may say that August* and I were in complete agreement.

*That was his first name.

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III. RESEARCH WITH A REACTOR

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RESEARCH WITH A LOW-POWER REACTOR

by L. D. P. King*

Although I have been removed from direct university work for some time, I did have contact with graduate and research work at M.I.T., Wisconsin, and Purdue, before going to Los Alamos. We at Los Alamos feel that we have a distinct university atmosphere and spirit in our research program. Although much of our work is of a classified nature, there is a good deal of effort on fundamental research which is declassifiable. During my ten years with the Los Alamos Scientific Laboratory, I have spent considerable time on the development of a small homogeneous reactor known as the "water boiler," and on the research work carried out with its facilities.

A small reactor, it seems to me, furnishes the best single research tool available for a university at the present time. A reactor is certainly more reliable, simpler to operate, and probably less costly than, for example, a cyclotron or Van de Graaff generator.

The chief virtue of a reactor, however, is its great versatility. It is not only a tool for the use of a physics department, but will be highly advantageous in research carried out in such fields as chemistry, engineering, biology, medicine, and agriculture.

The up and coming field of nuclear power, furthermore, requires the training in reactor technology of many engineers, physicists, and chemists. This work has been well initiated here at Oak Ridge in the Reactor Training School. A university, which has the facilities of a reactor available, can greatly assist in such fundamental training, and, at the same time, carry out a research program which could make substantial contributions to the field of nuclear power development.

In general, the suitability of a reactor for research work depends on having a high neutron flux which can be made available at numerous points. A high flux does not necessarily mean a large high-power reactor if enriched uranium is used. The neutron flux in the 1 ft diameter core of the water boiler, for example, is comparable to that of some of the large graphite natural uranium piles, the cores and powers of which may be almost a thousand times larger.

A small research reactor will probably fall in a power range somewhere under several hundred kilowatts. The outside appearance, such as the size and shape of the shield, will not differ very widely from one reactor to another unless it has been made for some specific purpose. The core structure, on the other hand, can differ substantially, depending on whether the active material is dissolved in a solution or is in the form of solid fuel elements.

*L. D. P. King is a Group Leader in the Director's Office, Los Alamos Scientific Laboratory. A member of the Laboratory staff since 1943, Dr. King is an authority on research with a water boiler reactor. Before going to Los Alamos, he was on the staff of Purdue University, where he carried out research for the Office of Scientific Research and Development.

An essential requirement for a reactor installation is plenty of available space in all possible directions. Unlike many other large machines which have single beams and directions for experimentation, a small reactor will have numerous such facilities.

Space is needed for a twofold purpose: (1) to reduce background radiations produced by scattered neutrons; and (2) to provide adequate floor area for the bulky equipment which may be needed. This is especially true if the equipment requires additional shielding.

Numerous port facilities should exist so that a number of experiments can be done simultaneously; also, the equipment for experiments requiring long running times or accurate alignment does not have to be disturbed until the experiment is completed.

I would next like to give you a very brief description of the small homogeneous reactor known as the water boiler, which is located at the Los Alamos Scientific Laboratory. This reactor was the outgrowth of the first enriched uranium criticality studies. It has been in operation since 1944, with the exception of a few periods during which modifications were made to improve its performance as a research tool.

I want to point out some of the constructional features which have been found advantageous and those which could be improved in best serving a broad research program.

The space around the water boiler and the rectangular shape of the shield, shown in Fig. 1, are not ideal, since the reactor was fitted into the back of an existing building in 1944, when there was a premium on time and little thought was given to the possibility of using this reactor for more than a couple of years. A multisided shield, in the shape of an octagon, for example, would provide a better shield geometry than a rectangle, by optimizing the available surface for experimental facilities. Long beam paths are, however, available in four directions with facilities to minimize wall scattering.

Figure 2 is a general exterior view of the reactor. The multiple ports in the south thermal column can be seen, as well as the superstructure housing the rod mechanism.

A small reactor with neutron fluxes in the 10^{12} - 10^{13} neutrons/cm²/sec range will require a shield 4' to 6' thick, depending on its composition. Special concrete rich in iron and containing some boron is probably the most efficient shield material which can be easily cast into any desired shape. Such special materials are more costly than ordinary concrete, but the saving in floor space and the increase in external beam intensities due to shorter path length may offset the cost.

The water boiler is of the solution or homogeneous type. There seem to be some advantages for this kind of reactor if there exists an active and interested chemistry group. Several types of experiments, as I will point out later, can be carried out with less elaborate equipment and the reactivity of the solution can be maintained without the necessity of handling and replacing fabricated highly radioactive fuel elements.

Figure 3 shows a north-south vertical section through the reactor. The water boiler core consists of a 1 ft diameter thin-walled stainless steel sphere containing a uranyl nitrate and water solution enriched in U²³⁵. There is sufficient U²³⁵ to maintain a chain reaction and some excess to take care of losses in neutron multiplication due to the negative temperature coefficient of the solution and the requirements of special experiments. The over-all uranium concentration has normally been held at about 880 grams of 88 per cent enriched U²³⁵.

The reactor core is surrounded by special high purity graphite which is in the form of 1, 2 or 4 ft long stringers with a $4\frac{1}{4}$ in. $\times$ $4\frac{1}{4}$ in. cross section. The graphite is easily machinable so that a good fit around the sphere, for example, is easy to obtain. A $4\frac{1}{2}$ ft cube of the graphite which immediately surrounds the sphere is called a reflector, since it reduces the amount of U²³⁵ required to maintain a chain reaction by reflecting some of the escaped neutrons back into the solution. Due to the low absorption cross section of the graphite, a large space is available, within which high neutron intensities can be maintained for sample irradiation.

On two sides of the reflector, additional graphite has been provided for special experiments requiring only slow neutrons. The neutrons are slowed down to thermal energies by making many elastic collisions with the graphite atoms. Because of this property, these regions are usually called thermal columns. An $8\frac{1}{2}$ in. thick bismuth shield which is transparent to neutrons prevents gamma radiation from the reactor core from reaching these graphite volumes. This permits working in these regions with the reactor, and therefore the neutrons,

Fig. 1—Plan view of reactor and control room.

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AECU-2900

Fig. 2—General exterior view of Los Alamos Water Boiler.

Blocks marked "R" are removable.

Fig. 3 — North-south vertical section of water boiler (SUPO Model).

shut off. The thousands of curies of residual gamma radiation remaining in the solution will die off only very slowly.

The general type of shield of the water boiler can be seen in the east-west section illustrated in Fig. 4. The shield consists of $\frac{1}{2}$ in. of boron plus paraffin to remove the slow neutrons, 2 in. of steel to help degrade fast neutrons, 4 in. of lead to reduce the hard gamma-ray leakage, and 5 ft of ordinary concrete to reduce all the remaining radiation to tolerance values.

A desirable feature is to carry irradiation ports in as close to the reactor core as possible, since there are always some experiments requiring the maximum flux levels. To this end two holes run completely through the reactor; one known as the "glory hole" actually passes as a re-entrant tube through the core itself. This type of port permits access to the highest flux and also makes possible some experiments which may require an extremely short irradiation time. This facility was made use of in an experiment to determine the half-lives of the shortest delay neutrons and gamma-rays by shooting samples at high known velocities through the reactor.

The horizontal section through the reflector and north thermal column, Fig. 5, illustrates the type of shielding used to minimize all gamma radiation in the thermal columns. The $8\frac{1}{2}$ in. thick bismuth shadow shield, as mentioned before, prevents the direct reactor gamma radiation from entering the column, while the boron shields absorb the slow leakage neutrons with a minimum of low energy secondary radiation. The separation of the gamma-rays from the neutrons has been found to be essential, for example, in determining the effects of neutron dosage on animals. I will mention this experiment later.

For some experiments large ports are required. In the thermal column shown, a 16 in. $\times$ 12 $\frac{3}{4}$ in. $\times$ 4 ft deep cavity can be made available easily and quickly. This has been used for large equipment or for cases where the residual capture gamma-rays produced by the graphite of the thermal column need to be still further reduced by the use of an additional internal bismuth shield. Direct pile radiation from the normal reactor has only about one neutron per four or five gamma-rays. In this column, values of 77 neutrons/gamma-ray have been obtained.

Three 20 ft long stainless steel tubes wound as a set of nesting helical coils dissipate up to 50 kilowatts of heat with 3 gallons of water per minute. Figure 6 illustrates the coil geometry prior to welding on the lower hemisphere. The main reactivity control is provided by two motor-driven boron rods moving vertically into the sphere in re-entrant thimbles. These can be seen in the figure. Three additional hand-controlled cadmium rods are tangent to the sphere and can be used for special experiments where quick changes in reactivity are desired. An external view of the sphere, external rod sheaths and piping, is shown in Fig. 7 with only the lower reflector layers in position. Figure 8 illustrates the graphite reflector at the half-way point of its construction.

When running at powers over a few watts some of the water in the solution is decomposed into hydrogen and oxygen. These gases can be recombined and returned to the reactor by means of a small circulating system and catalytic recombiner. A schematic drawing of the components of the recombination system is shown in Fig. 9. If uranyl nitrate is used as a solution, a small amount of nitrogen must be released because of some decomposition of the nitrate. These gases which also contain volatile fission products have been advantageously used for studying certain rare isotopes occurring as fission fragments.

The control equipment is quite simple compared with most other large research tools. Figure 10 is a view of the control panels. A brief description of the main components of the panels may be helpful. The rod control chassis, neutron level meters, and safety circuits are immediately in front of the operator. Neutron levels can be read from 0.01 watt to 50 kilowatts, since they are proportional to power measurements. Accurate power levels are essential for some precision experiments. An automatic pilot will maintain power levels to better than 0.1 per cent. The reactor is automatically shut down because of a variety of causes if all components are not working perfectly. A series of trouble lights is used to locate the fault quickly. A neutron and gamma-ray monitor serves to indicate that radiation levels are satisfactory in the reactor room. The reliability and simplicity of the required running mechanism

Concrete ---
 Steel ---
 Lead ---
 Boron Plastic ---
 Graphite ---
 Boron Carbide ---
 Borax Paraffin ---

Recombiner Assem.

Fig. 4—East-west vertical section of water boiler (SUPO Model).

Fig. 5—Horizontal cut through central plane, north and center.

Fig. 6—Coils for dissipating heat.

Fig. 7—External view of sphere and piping.

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Fig. 8—Graphite reflector construction at half-way point.

Fig. 9—Recombiner assembly (schematic).

Fig. 10—Reactor control panels.

are such that operating times are normally better than 90 per cent of the available running time. The reactor has run 120,000 kilowatt-hours since March of 1951, when the power level was increased and the gas recombination system installed.

Let me now give a few illustrations of the many experiments which have been done on this small reactor, without going into any great detail. A few figures will help illustrate the types of measurements made on the reactor itself, as well as the size of some of the equipment used. I will mention experiments in reactor technology, physics, chemistry, and biology, since these have received the main emphasis at Los Alamos.

The first group of experiments was done to study the characteristics of the reactor as such. They are also very useful in giving personnel experience with radiation, and illustrate the methods used for detecting and counting neutrons and gamma-rays.

An approach to critical measurements made on the reactor is shown in Fig. 11. The reciprocal of the counting rates, measured on foils or counters, is plotted against the grams of U^{235} in the solution. A small radium beryllium source is placed near the center of the sphere. The counting rates, when the sphere is filled with water, serve to normalize the readings to one. As one adds uranium, the counting rates increase and give a measure of the multiplication.

The curves indicate that one can predict considerably ahead of time what the critical mass of an assembly is going to be. The shape of the curves is dependent on the position of the source and detectors. The upper concave downward curve in the slide was made with manganese foils placed too close to the source, so that it essentially masked the multiplication and gave the wrong initial slope for extrapolation; the curve does come down eventually.

Detectors placed at the proper distance from the centrally located source—in this case near the third harmonic—give the two nearly straight lines shown in the figure. The concave upward curves were produced by detectors placed at various points external to the sphere; these measure neutron leakage. The types of detectors used were fission chambers, and indium, gold, and manganese foils.

Control rod calibration curves are shown in Fig. 12. These particular curves are for the cadmium rods used in an earlier reactor model of the water boiler. The S shape of the calibration is usual, and is due to the decrease in relative effectiveness of the rod when it is near its "in" or "out" position. The short, nearly linear, portion of maximum effectiveness occurs as the end of the rod is moving tangentially to the sphere. The ordinates are expressed in microreactivity units which one must multiply by 10^{-6} to convert to K. The abscissa is grams of U^{235} equivalent.

The control rods shown are made of strips of cadmium about $2\frac{1}{2}$ in. wide by 24 in. long. The cadmium is sandwiched between strips of aluminum. The shim rod was a cylinder of cadmium about $\frac{1}{2}$ in. in diameter and 24 in. long. As can be seen on the figure, this rod was considerably less effective than the other two rods.

The internal boron rods which are used on the present reactor in addition to the above mentioned cadmium strip rods were calibrated and shown to be about three times as effective as the external cadmium rods.

The criticality behavior, shown in Fig. 13, is another interesting feature of a reactor which can be studied. This curve is a plot of the reactor period for different amounts of excess reactivity. The excess K was produced by step changes in one of the calibrated rods. The first term of the equation is due to prompt neutrons and the other terms represent the contribution from the delayed neutrons. The constants shown were determined for an earlier model of the water boiler using beryllium oxide as a reflector rather than the graphite used in the present SUPO model.

If the reactor, for example, is on a 100 second period, it means that there is an excess K of about 0.08 per cent. This might be produced by a change in rod position. If one produces larger and larger changes in the reactivity, the delay neutrons become less and less important, as indicated by the flattening of the curve. Near the point of inflection where the period is about 0.4 second, the excess K is equal to the total effectiveness of the delayed neutrons. For still shorter periods than this, the prompt neutrons begin to take over.

On the present model of the water boiler, such studies were carried out to about 0.3 second. This required a rapid removal of the rods and observations of the reactor power rise

Fig. 11—Approach to critical measurements.

Fig. 12—Control rod calibration curves.

Fig. 13—Criticality behavior.

over numerous periods. The initial transient phenomenon is permitted to die out in order to obtain a true exponential rise.

A study of the temperature coefficient is shown in Fig. 14. Here grams of U^{235} equivalent are plotted against the solution temperature. If one heats the solution of a homogeneous reactor, one finds that the reactivity goes down, i.e., there is an apparent loss of uranium. The curve indicates that when the reactor is running at low power, the gram equivalent uranium loss is about 0.72 per degree centigrade temperature rise. In other words, there is quite a large negative temperature coefficient of reactivity which helps stabilize this type of reactor.

As the power level is increased, one observes that the slope increases or the apparent uranium loss is larger. This increase is due to the fact that the true temperature coefficient, produced by the expansion of the water and uranium, has an additional effect coming in, caused by the formation of bubbles. At a 20 kilowatt power level, one has an equivalent loss in reactivity of about 1 gram of uranium for every degree rise in temperature. This indicates that a water boiler type of reactor requires a substantially larger amount of uranium to operate at the higher powers and temperatures than would be indicated by a cold critical measurement. The normal top operating temperature of the water boiler is about 85 degrees centigrade.

Flux distributions, shown in Figs. 15a, 15b and 15c, show another interesting feature of a reactor. These measurements were made with a U^{235} fission chamber and indium or gold foils. The first figure of this group (15a) shows how fast the thermal neutron intensity falls off in the north thermal column. A vertical cut through this column was shown in an earlier figure. Bismuth, as I mentioned earlier, takes out gamma-rays but behaves more like a window for neutrons, because of its very small absorption cross section. This is shown very nicely in the plateau region of the curve where there is almost no neutron drop-off in passing through the bismuth region. Beyond the bismuth, the curve goes through a long graphite section where the slope gives a drop-off of approximately a factor of "e" for every foot of length. This type of neutron attenuation occurs in a good quality 5 ft square thermal column. The drop-off depends on the cross section of the column and the decrease will be faster if these dimensions are made appreciably smaller. The decrease in flux intensity is quite rapid at the end of the column because of the boron-absorbing shield which prevents neutrons from being reflected back.

The second figure (15b) on flux distributions is a similar type of curve taken in the "glory hole," i.e., the transverse hole through the sphere. The ordinate is relative and has been normalized to read "1" at the reactor center. The abscissa is in centimeters from the sphere center. Since the sphere has a diameter of 1 ft, the 15 centimeter point represents the outer edge of the sphere.

The Cd/Au/Cd curve is for relatively fast neutrons since the cadmium prevents the gold from receiving thermal neutrons; it drops off quite rapidly beyond the sphere surface. On the other hand, the thermal neutrons, which were measured by cadmium difference with gold foils in one case, and also a somewhat different distribution with a U^{235} fission chamber, show a less rapid fall-off. This is a typical effect if one uses a good moderator outside of the reactor core for slowing down neutrons. You will note that the thermal neutrons actually have a higher intensity in the graphite than at the sphere surface.

Another property of the neutron distributions, known as the cadmium ratio, is shown in Fig. 15c. There are various cadmium ratios depending on the type of detector used. The values shown in the figure were obtained with indium foils. The results tell you what the relative numbers of slow and fast neutrons are. This is a sort of a measure of the effectiveness of a thermal column in slowing down neutrons. The curve shows that in the reactor core the ratio is about 3.5; this means that there are 3.5 times as many thermal neutrons of 0.025 volt energy than exist in the indium resonance region with an energy of about 1.4 volts.

Farther out in the column, the cadmium ratio increases rapidly until at the outer end the ratio is 10,000. Here only a very small fraction of a per cent of fast neutrons are left. For some experiments one wants only slow neutrons; however, we have rarely used ratios as high as this since experimenters are usually satisfied if, say, only a half of a per cent of fast neutrons remain.

Neutron energy distributions using a chopper for slow neutrons and photographic plates for very fast neutrons have also been made.

Fig. 14—Study of temperature coefficient.

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Fig. 15a—Neutron flux distribution in north thermal column.

Fig. 15b—Neutron distribution in transverse hole through sphere.

Fig. 15c — Cadmium ratio of neutron distributions.

A series of shielding studies was performed in the large cavity produced by the removal of one of the thermal columns. Large sections of shielding materials could then be studied for their effectiveness in removing reactor radiations.

The largest series of experiments has been devoted to fundamental research in the field of physics. This is partly because of the fact that the reactor was run by a group in the Physics Division. I will mention only a few of the experiments which have been performed.

Quite a large series was done in the study of the fission process. Two experiments, for instance, measured the energy distribution of the neutrons coming out from fission by observing the proton recoils. A special ionization chamber was used for detection of the fast neutrons, and a hydrogen cloud chamber for measuring the slower neutrons. The source used for these experiments is called a neutron converter. When a series of U^{235} discs placed in the "glory hole" is looked at from the outside, one sees essentially a source of fission spectrum neutrons, with some slow neutrons superimposed. This was used with the recoil chamber.

To minimize the effect of any slow neutron leakage, an external fission source was used with the cloud chamber; it was a piece of U^{235} placed in an external beam. This converted all the slow neutrons coming out of one of the thermal columns into fission spectrum neutrons.

As I mentioned earlier in another experiment, observation of the number and energy of neutrons and gamma-rays appearing after fission was done by shooting samples through the "glory hole" at high velocities and determining the length of time in the reactor and the time it took to get to the detector. In this way, one can also measure the radioactivity produced by very short irradiation times.

A search was made for triple fission, using a large special triple coincidence chamber which was placed directly in the cavity of the thermal column. The results of this experiment indicated that the fission process gives off only two—and, very rarely, three—large particles.

The determination of the total energy of fission was made by placing a calorimeter with an internal sample of U^{235} directly into the thermal column. This illustrates the need of large cavities for some experiments.

A measurement was made of the velocity distribution of the fission fragments by measuring the time of flight of the fragments. These last two experiments were done in order to clear up a discrepancy between the calorimetric and the ionization chamber fission fragment energy measurements.

Figure 16 is a view of the equipment used in this experiment. The large drift tube can be seen which is placed at right angles to a beam of neutrons emerging from the north thermal column of the water boiler. Measurements of the velocities of the fission fragments were made by observing their time of flight in the long evacuated drift tube shown. One fragment traveled a 1 centimeter distance to the nearer detector and the other about 350 centimeters to the more remote detector.

Figure 17, showing the counting apparatus used for the velocity measurements, illustrates the appreciable floor area frequently required for electronic equipment. These are typical racks of equipment. The rack on the extreme right contains two ten-channel discriminators used to count 20 delay channels simultaneously.

A large number of neutron cross section measurements can be made effectively with the pile. I will illustrate a couple. Figure 18 is a view of the setup that was used to measure the total cross section of He^3 for slow neutrons. In this case the energy was varied by a filtration technique. The absolute values are obtained by comparison with a known boron sample. The technique here is to have a beam come out of the south thermal column of the reactor, and to place a series of graphite blocks of different thicknesses in the beam ahead of the sample. The graphite has the property of scattering out the fast end of the Maxwell distribution and letting the slower tail go on through. The thickness or the length of the graphite, therefore, change the neutron energy spectrum.

The spectrum, it is true, is complicated. However, in an experiment like this where one compares an unknown with a known absorber, it was fairly straightforward. As shown in the figure three quartz containers could be inserted into the beam. One container is a blank, the second container has a known amount of boron in it, and the third one a known amount of He^3 . By quick one or two minute exchanges of these, using first the blank, then the boron,

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Fig. 16—Equipment used to study velocity distribution of fission fragments.

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Fig. 17—Counting apparatus used for velocity measurements,

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Fig. 18—Apparatus used to measure total cross section of He^3 for slow neutrons.

and then the He^3 , the transmission can be obtained and the total cross section calculated. A boron counter is placed at the far end and the whole equipment is shielded by a cadmium box.

The large equipment for an experiment which is still in progress is shown in Fig. 19. Here the total fast neutron cross sections are being measured in the 3-12 mev energy region. As I mentioned earlier, very effective beams of fission spectrum neutrons can be obtained by a U^{235} disc converter placed in the "glory hole." The equipment shown is mounted on a movable cart. The sample holder can be seen mounted on the west face of the reactor covering the opening from the "glory hole." The large ionization chamber is pressurized with an argon filling. Radiators containing hydrogen or deuterium in the form of polyethylene are used to produce recoils from the incident neutrons. Collimation permits counting only particles emerging within 10 degrees of the incident beam. The energies of the recoil particles are determined by their pulse height in the parallel plate ionization chamber. Here again multi-channel discriminators are used so that one can count a large range of pulse heights at the same time. The change in the number of neutrons in a given energy range with and without a sample in the beam serves to determine the average total neutron cross section in that energy range.

Figure 20 illustrates the size of the equipment. Here is a case where an experiment interferes with others due to the large backgrounds which are produced when a strong neutron beam strikes an external target. This difficulty was solved in this case by surrounding the entire equipment with an effective neutron shield. The 1 ft cubical steel shield boxes shown were filled with a boron paraffin mixture.

The shield does not interfere with the experiment itself, since one is working only with high energy neutrons. Very few fast neutrons which suffer collisions can remain in the million volt region. All slow neutrons resulting from multiple scattering cannot, however, leak out of the shield and produce objectionable room backgrounds.

Another group of experiments that has been carried out is the study of nuclear excitation levels and decay schemes. Samples are activated in the reactor, and then the radiations are studied with a crystal spectrometer for coarse resolution and with a thin lens beta ray spectrograph for finer resolution. If one works, for instance, with short-lived material, it is essential that one has a reactor close at hand.

Most of the experiments carried out by the chemistry group have not required a lot of equipment at the reactor. At the most, a few counting circuits and special comparison chambers were inserted into the thermal column. For the most part, samples are made radioactive by placing them in a high flux region of the reactor. Half-life measurements are generally considered to be the chief characteristic of radioactive isotopes. Isotopes with the same element that happen to have similar half-lives can be distinguished by the types and energies of the radiations emitted. Frequently materials with rather short half-lives are required, and it is then essential that a reactor is close at hand.

The chemical experiments making use of the reactor usually fall into one of the following categories: (1) Radioactive tracers are used to follow the progress and test the completeness of the chemical separation procedure. (2) Quantitative analysis is made for a component of a mixture by using known numbers of molecules tagged by radioactivity. (3) Activation analysis is used; it is a powerful technique where known samples are activated by neutrons and the chemical constituents identified and assayed by analysis of the resulting decay curves. (4) The detection and quantitative determination of extremely small samples or impurities can be made by studying their disintegration products. In the case of fissionable materials, this can be done in a comparison chamber which is itself placed in the thermal column. Samples as small as a thousandth of a microgram have been determined by this method.

A small thermal reactor can conveniently supply two types of neutrons for sample irradiation. Essentially pure thermal neutrons can be obtained in the thermal column, or fast fission spectrum neutrons can be obtained by placing the sample in a container made of U^{235} , which, as I mentioned for the sources, will convert any existing slow neutrons into fission spectrum neutrons.

Chemical experiments well-suited for a small homogeneous reactor make use of the partial fission product separation produced in the reactor itself. Samples of gaseous products

Fig. 19—Set-up for measuring total fast neutron cross section.

Fig. 20—Size of equipment required for neutron cross section experiment.

can be obtained directly from the gas circulating system. Particular isotopes can be emphasized by making use of their half-lives: that is, by taking a sample from the exhaust line close to or far from the reactor. Another gaseous separation technique is to pass the gases through a long tube along the axis of which is a negatively-charged wire. The various gases will deposit their solid radioactive daughters on the wire in a manner proportional to their half-lives.

Small amounts of reactor solution itself furnish excellent sources of isotopes. Here certain products can be emphasized by the previous running history of the reactor. Numerous decay scheme studies have been obtained of either rare isotopes or very short-lived ones by the use of the reactor solution itself.

The reactor application to biology and medicine can be illustrated by an experiment which was done to determine the biological effectiveness of thermal neutrons. Figure 21 is a schematic illustration of the reactor geometry used. About 15 mice are placed in a graphite cage which is placed in the middle of the thermal column. This column, as I already mentioned, has a high neutron-to-gamma ratio because of the use of a bismuth and boron shield shown in the figure. If one wants to reduce the gamma-rays still lower, one places an additional bismuth shield immediately around the cage. This shield reduces the 5 mev capture gamma-rays produced by the graphite of the column when it is subjected to neutrons. These are essentially the only remaining gamma-rays in this column and their removal permits the determination of the effect of thermal neutrons alone on the mice.

For hard gamma-ray measurements, which would be the 5 mev gammas produced by the graphite, a lithium shield is placed around the graphite cage. The lithium removes the thermal neutrons without disturbing the high energy gamma-rays existing in the column and without adding additional radiation.

Figure 22 shows the geometry using the lithium shield. The whole unit of cage and mice slides into the thermal column, and then the lithium can be replaced by bismuth for the other measurement. Figure 23 illustrates the experimental setup in position. An air tube supplies air to the mice. The horizontal strips on the graphite blocks are used to hold up the blocks so that a large cavity can be opened in the thermal column if desired.

The close analogy between slow neutrons and 250 kev X-rays can be seen in Fig. 24. The dose in roentgens is plotted against the mortality rate in per cent. The dots are the thermal column neutrons. You see that the effectiveness of neutrons and of these low energy gamma-ray appears to be similar as shown by the shape of the curves.

An interesting result is shown in Fig. 25, where the dosage in roentgens is plotted against median survival time in days. You notice the plateau region. The gut of the animal appears to be critically damaged by radiation exposure above 600 r for slow neutrons and about 1000 r for the gamma-rays. Any additional radiation up to about 10,000 r shows little effect on the curve. That is, they will die in about three days whether you give them 1000 or 10,000 r.

Dosages above this point show a new radiation sensitive factor indicated by a drop in the curve. This is due to the damage of the central nervous system of the animal.

Large cavities in the reactor are advantageous for the biologist also, since he either wants to put in many small animals such as mice to get statistics, or one like a monkey to get a closer analogy to man. There are many other applications of radioactive materials obtainable with a small reactor that have not been mentioned, since they have not been used extensively at Los Alamos.

The use of such materials for plant mutation studies, sterilization, thyroid and cancer treatment, and so forth, is well known.

Fig. 21—The north thermal column schematic.

Fig. 22—Geometry of lithium shield.

Fig. 23—Experimental set-up in position.

Fig. 24—Analogy between slow neutrons and x-rays.

Fig. 25—Dosage in roentgens plotted against median survival time.
 —Mice, γ and x-rays (composite curve). ---Mice, slow neutrons.

REFERENCES

1. LA-1301 (AECD-3287), Technical Information Service, Oak Ridge, "The Los Alamos Homogeneous Reactor, Supo Model."
2. Rev. Sci. Instr. 22, 489 (1951), "An Enriched Homogeneous Nuclear Reactor."
3. Nucleonics 11, 25 (1953), "Gas Recombination System for a Homogeneous Reactor."
4. Phys. Rev. 87, 1033 (1952), "A Study of the Spectrum of the Neutrons of Low Energy from the Fission of U^{235} ."
5. Phys. Rev. 87, 1037 (1952), "Energy Spectrum from Thermal Fission of U^{235} ."
6. Phys. Rev. 78, 533 (1950), "Symmetrical Tripartition of U^{235} by Thermal Neutrons."
7. LADC-1063, "Preliminary Measurements with a Fission Calorimeter," R. B. Leachman and Collins.
8. Phys. Rev. 92, 1091 (1953), "Velocity Distribution of Slowed Fission Fragments."
9. AECD-3605, "Interpretations of the Velocity Distributions of Slowed Fission Fragments," R. W. Schmitt and R. B. Leachman.
10. Phys. Rev. 75, 1366 (1949), "The Total Cross Section of the He^3 Nucleus for Slow Neutrons."
11. Phys. Rev., (Fall of 1954), "Average Neutron Total Cross Sections in the 3-12 Mev Region," Norris Nereson and S. Darden.
12. Nucleonics 12, 48 (1954), "The Biological Effectiveness of Thermal Neutrons on Mice—I."
13. Nucleonics 12, No. 4 (1954), "The Biological Effectiveness of Thermal Neutrons on Mice—II."

CHEMICAL RESEARCH

by E. H. Taylor*

The following discussion is intended to present from a chemist's point of view some of the considerations bearing on whether to build a university research reactor.

Most of the chemical work foreseeable with such a reactor falls into four fields: radiation chemistry, nuclear chemistry (including hot atom chemistry), production of tracers for chemical use, and neutron activation analysis. It will be assumed that two classes of reactor performance are under consideration: one with a flux of about 5×10^{11} n/cm²/sec, the other with a flux of 5×10^{13} .

In considering reactors as radiation sources for radiation chemistry the first consideration is whether the dose rate is sufficient to produce measurable chemical effects. Table I lists dose rates from several different sources, as well as typical amounts of chemical change brought about by the smaller of the two Co⁶⁰ sources listed. In a number of systems of interest in radiation chemistry one can measure the species produced to a precision of $\pm 10\%$ at a concentration of about one micromole per liter. This is true for ferric ion produced in the ferrous sulfate dosimeter, for hydrogen peroxide produced in water and aqueous solutions, and for gaseous hydrogen (and other gases) determined by micro-gas analysis. The sensitivity of analysis is generally less in studies of organic materials in which the products of radiation have to be separated physically from the reactants, and unless their nature provides a specifically sensitive analytical method the separated products have to be analyzed by conventional organic methods. The possibilities naturally are extremely varied, but for example, work is presently being conducted at this laboratory in which products of very low yield are being sought in aqueous organic solutions, and the work is progressing satisfactorily using irradiations of about a day by a 1000-curie Co⁶⁰ source.

So far as intensity goes, then, the more convenient Co⁶⁰ sources produce adequate amounts of chemical changes for most radiation chemical studies. Further, if one is interested for some reason in extremely high dose rates, one would prefer electrons from a Van de Graaff generator to either of the reactors specified in Table I. A possible exception to this statement will be noted below in connection with ionization density of various sources.

The second consideration about possible sources for radiation chemistry is the local

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Table I—Dose Rate to Water of Various Radiation Sources

Source	Radiation	Dose Rate	
		r/min.	cal/g H ₂ O, min.
Reactor, graphite, ~ 5×10^{11}	Gamma	1.2×10^4	0.03
	Neutron	-	0.05
Reactor, heterogeneous, H ₂ O moderated, ~ 5×10^{13}	Gamma	-	8
	Neutron	-	2
Co ⁶⁰ , 300 curies	Gamma	4×10^3	0.01
Co ⁶⁰ , 1000 curies	Gamma	1.5×10^4	0.04
Van de Graaff, 2 Mev	Electrons	1×10^9	2800
	X-rays	1.5×10^5	-
X-Ray Machine, 50 Kv peak	X-rays	1×10^6	-

Chemical Effects from Co⁶⁰ Source (300 curie)

4×10^3 r/min is equivalent to 3 micromoles/liter, min or to 3×10^{-5} cm³ gas
STP/cm³ H₂O, min for G = 1 atom reacted/100 ev.

ionization density produced in the sample—that is, the number of ionizations per unit length of track. Since the chemical effects of a particular kind of radiation depend upon the local ionization density, it is desirable for simplicity of interpretation to have radiation of simple quality—that is, to have only a very small range of local ionization density in any one experiment. As a corollary, one would like to have available radiations of different simple qualities so that the effect of local ionization density can be varied from experiment to experiment. Table II indicates the range of values of ion density available from a variety of radiations.

A reactor is not a desirable source from this point of view, because the radiation is always a mixture, as indicated in Table I. It contains gamma rays producing low ionization density and fast neutrons which eject protons of relatively high ionization density from hydrogenous samples. The existence of these types of radiation increases the difficulty of interpretation of experiments performed in a reactor. Nor is it possible in general to alter the quality of radiation obtainable from a reactor. The range of ionization densities obtainable in a reactor, which can be seen from Table II, can be bracketed by radiations obtainable in relatively pure quality from other sources.

There are two cases in which reactor radiations are probably superior to other radiations for particular purposes in radiation chemistry. In the first place, if one wants the very highest local ionization density obtainable (without using fission fragments themselves), one can obtain this by using solutions containing B^{10} or Li^6 . Upon irradiation with slow neutrons these nuclei give rise to heavy charged particles giving very high local intensity of ionization. In the second place, if one is interested in a homogeneous distribution of very intense radiation through a fairly large sample, the same expedient serves very well. Since a solution containing even these nuclei is relatively transparent to neutrons, the ionizing events occur quite uniformly throughout reasonably large volumes of solution, and this sort of high-intensity, uniformly distributed dose is not obtainable from other sources such as protons or electrons from accelerators.

An inconvenience of reactors as sources for radiation chemistry is that the sample containers, and sometimes the samples themselves, become quite radioactive by neutron capture and this requires either fairly elaborate precautions in handling or rather long times for radioactive cooling before analysis. It requires also the use of fused silica rather than pyrex for containers, and this, although not prohibitive, is an added experimental difficulty.

The field of nuclear chemistry is probably the one which has led to most of the interest by chemists in nuclear reactors. The most obvious criterion for the usefulness of a university research reactor for this purpose is probably the half-life of the species of interest. If a radioactive species has a half-life longer than perhaps two days it is probably more convenient to buy it through the Atomic Energy Commission, while if its half-life is shorter it would probably be preferable to be able to produce it locally at will. The number of nuclei having half-lives shorter than two days is probably about two-thirds of those known, based on those known in 1947. Since probably more of the unknown or less well characterized radioisotopes lie in the short half-life region, one can probably conclude that somewhat more than two-thirds of the species likely to be of interest will have half-lives short enough to make a local reactor desirable.

Purely for convenience in classification, the field of hot atom chemistry in this discussion is included with nuclear chemistry. The very high neutron flux obtainable from a reactor makes it the most desirable source for such experiments, although it is of course well known that a great deal of interesting work was done in this field before the first nuclear chain reaction was demonstrated, using such neutron sources as radium-beryllium. Some work can even be done by buying some of the longer lived fission products which are part of a chain, at least one further member of which is still radioactive and can thus be identified after the initial hot atom reaction.

Tracer production, the third field under consideration, might have been included with nuclear chemistry, but is here considered separately because of the rather broader class of people interested in it. Almost all scientific departments of a university have occasion to use radioactive tracers, and for that reason may be interested in a university research reactor.

Table II—Absorption of Ionizing Radiations

Radiation	Energy Mev	Range in Water microns	Ion density ions/micron
Alpha	1	5	5210
Alpha	5	35	1300
Proton	1	23	400
Proton	5	355	100
Electron	1	3600	~1
Gamma	1	~100,000 (half-thickness)	-
	Kev		
Electron	1	0.05	230
Electron	10	2.5	30
Electron	100	141	5

The most obvious criterion in this case is also the half-life. Table III is a partial list of elements for which long-lived, reactor-produced radioisotopes are not available. If a radioactive tracer for one of these elements were needed, one would have to prepare it in a nearby reactor (or in some cases with an accelerator). There are clearly some elements of chemical and biological interest included in this list.

One advantage, from a tracer standpoint, of having a reactor at hand is that one probably would make very much more use of tracers than if each one had to be justified, ordered, and delivered in advance of the intended research. One of the fields in which this laboratory has benefitted greatly by living with a reactor over the last ten years is that of comparative inorganic chemistry. The use of radioactive tracers for analysis in such experiments as distribution between solvents has made it possible to run through practically the whole periodic table in studies of a particular property or a particular type of equilibrium in a relatively short time. Such a program using conventional analytical methods might have been a lifetime's work.

The fourth category is neutron activation analysis. Again, this could have been included with nuclear chemistry, but will appeal to a much wider variety of scientists and engineers. The Oak Ridge National Laboratory is currently developing a program of service analysis by this method for outside customers, and Table IV indicates the sorts of analyses that are potentially available. The advantages of neutron activation analysis are the very great sensitivity available for many elements, the good specificity because of the possibility of measuring both the half-life and the energy of the radioactive decay, and finally the relative freedom from contamination during most of the analytical manipulations.

The criterion for deciding whether to buy such analyses from a laboratory owning a reactor or to use this as justification for building one at one's own university is largely a matter of cost. Currently these analyses cost something like \$40.00 per element per sample, which is not tremendously out of line with usual costs of commercial analyses. However, there will likely be many cases in which a great many analyses will be wanted—say in connection with a biological experiment, and in such a case it would obviously be very desirable to have a reactor at hand.

There are a few general considerations about the desirability of a university research reactor which arise from our ten years experience with such a reactor at Oak Ridge National Laboratory. From the point of view of a chemist, a reactor project has to be relatively large in order for it to have the advantages to him which have been described above. The reactor must be essentially a service device with an operating crew for it to appeal very largely to a chemist. When he wants a tracer he wants to be able to put a sample immediately in the reactor and have it irradiated while he does something else, rather than having to get together a party of chemists to go up to the reactor, repair some instruments or controls that are not operating, and stand by personally until the irradiation is finished.

A corollary of this is that a reactor is probably rather negative from an educational point of view, pretty much as any such major device is likely to be for a chemist interested in its uses rather than its construction and operation.

A secondary advantage to a chemistry department in having a reactor on a university campus is that the supporting services in other fields would probably be greatly increased. In particular, this is likely to be true of instrumental facilities, particularly for radioactive measurements including both the instruments themselves and people to keep them in order.

Table III—Elements Without Long-Lived, Reactor-Produced Tracers

Element	Longest-Lived n, γ -Produced Radioisotope	Approximate Half-life
Aluminum	Al ²⁸	2 min.
Bromine	Br ⁸²	34 hr.
Copper	Cu ⁶⁴	13 hr.
Dysprosium	Dy ¹⁶⁵	2 hr.
Fluorine	F ¹⁸ (n, 2n)	2 hr.
Gallium	Ga ⁷²	14 hr.
Holmium	Ho ¹⁶⁶	28 hr.
Magnesium	Mg ²⁷	10 min.
Potassium	K ⁴²	12 hr.
Silicon	Si ³¹	3 hr.

Table IV—Elements Without Long-Lived, Reactor-Produced Tracers

Elements	Sensitivity of Detection* (grams)
Bismuth, Calcium, Iron, Sulfur, Silicon	10 ⁻⁶
Cerium, Chromium, Mercury, Molybdenum, Neodymium, Platinum, Ruthenium, Silver, Strontium, Tellurium, Thallium, Tin, Zirconium	10 ⁻⁷
Barium, Cadmium, Cesium, Chlorine, Cobalt, Erbium, Gadolinium, Germanium, Hafnium, Nickel, Osmium, Phos- phorus, Potassium, Rubidium, Selenium, Yttrium, Zinc	10 ⁻⁸
Aluminum, Antimony, Arsenic, Bromine, Copper, Gallium, Gold, Iodine, Lanthanum, Palladium, Scandium, Sodium, Praesodymium, Tantalum, Terbium, Thulium, Tungsten, Vanadium, Ytterbium	10 ⁻⁹
Holmium, Indium, Iridium, Lutetium, Manganese, Rhenium, Samarium	10 ⁻¹⁰
Europium, Dysprosium	10 ⁻¹¹

*The amount of an element that would produce sufficient activity to be measured after the element has been exposed to a predetermined neutron flux for a given period of irradiation.

RADIATION EFFECTS IN SOLIDS

by D. S. Billington*

There are so many ways that a reactor can contribute to solid state research that it seems entirely reasonable to me that a university might consider building a research reactor for the sole purpose of doing solid state research. The university that has a solid state program underway can augment this in many ways through the use of a research reactor, while those universities contemplating the inauguration of a solid state research program would find it very convenient and economical to build a solid state program around a research reactor. I would like to mention three important ways that a research reactor can contribute to solid state research.

The most important way that a research reactor contributes to solid state research is through the economical production of large quantities of radioactive isotopes. The use of radioactive isotopes for research purposes is well documented and new research techniques and uses are being reported with increasing frequency as research proceeds; many of these uses are directly applicable to solid state research. The value of radioactive isotopes lies in the fact that one can "tag" atoms and thereby follow the course of reactions that take place in the solid state. For example, the measurement of self-diffusion coefficients in a solid is a unique application of the tracer technique.

The second important way in which a research reactor contributes to solid state research is by means of neutron diffraction techniques. This topic has already been discussed very ably by Dr. C. G. Shull in an earlier talk. I would like to point out that some of the most important solid state research in the world today is being done by neutron diffraction. The ability to determine structures that formerly were impossible to determine by other techniques and the fact that one is able to deduce certain magnetic characteristics of solids by neutron techniques are altering our concepts of solids in many important ways. Drs. Shull and Wollan have pioneered this work in a brilliant fashion and have inspired others at this laboratory and elsewhere to adopt this technique for the study of the solid state.

The third way that a research reactor contributes to solid state research is by neutron bombardment. Since this field is less well known, I should like to discuss it in some detail. In a reactor, one has many sources of high intensity, high energy neutrons. When one subjects solids to bombardment by these high energy neutrons, one learns that many property changes have been induced in these solids. It is my belief that neutron bombardment techniques may in time become as valuable for solid state research as the techniques previously mentioned. My reason for saying this is that it has become apparent over the past few years that defects play an

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important role in determining many of the properties of a solid and that many solid state reactions can take place only because of the presence of defects in the lattice of a solid. Since neutron bombardment is a technique for introducing certain defects into a solid in a novel fashion, it does seem that the potentialities of a bombardment technique for use in solid state studies are most promising. Unfortunately, this technique will develop somewhat more slowly than the other methods for two reasons: (1) There is a lack of complete understanding regarding the role of defects in the absence of neutron bombardment. (2) The best methods of exploiting neutron bombardments as a tool are not well understood. In spite of these limitations the neutron bombardment technique is proving to be a most interesting and profitable field of research.

I should like to illustrate the type of property change that can be induced in various solids by neutron bombardment. These experiments have been carried out in the Oak Ridge graphite reactor by members of the Solid State Division and I am grateful to them for their help in preparing this talk.

Figure 1 illustrates the changes that can be induced in the conductivity of an n-type germanium crystal as a function of neutron irradiation. It can be seen that the conductivity has been reduced by a factor of five after a relatively short irradiation period—of the order of 1000–10,000 seconds in the Oak Ridge graphite reactor. The reduction in conductivity indicates that the neutron bombardment is introducing defects that act as traps for the conduction electrons.

Figure 2 illustrates the effect of bombardment on another semiconductor, silicon. In this example two types of silicon have been bombarded: n-type, which conducts by electrons and p-type, which conducts by holes. Here again the drastic change in conductivity after short bombardment periods is very pronounced.

Figure 3 illustrates the effect of neutron bombardment on the mechanical properties of pure copper single crystals. The solid curve is the un-irradiated control sample, while the other curves are of copper samples which have had varying amounts of fast neutron bombardment. Note that the resolved shear stress (the stress at which the copper begins to deform plastically) increases with increasing amount of neutron irradiation. However, once the irradiated metal begins to flow, its behavior quickly begins to resemble that of the un-irradiated copper.

Figure 4 is a replot of the data of Fig. 3. In Fig. 4, the critical shear stress is plotted against fast neutron bombardment. It should be noted that the critical shear stress increases from 0.3 Kg/mm² to 2.5 Kg/mm². The general shape of this curve leads to the speculation that the effect of neutron bombardment is similar to what happens to copper when one adds zinc to the copper to form brass.

The upper curve of Fig. 5 is the same as the curve in Fig. 4, while the lower curve shows what happens when zinc is added to copper. It is readily apparent that a relatively short bombardment has increased the critical shear stress to higher values than can be obtained by adding up to 30 atomic per cent zinc. The conclusion to be drawn from these curves is that neutron bombardment acts in a manner indicating that the copper is alloying with another metal. In this case, the assumption is made that the copper is being alloyed with interstitials.

Some studies have been made on the order-disorder alloy, copper-gold (Cu₃Au). If one heat treats this alloy to obtain the so-called "ordered" structure, the gold atoms occupy the corners and the copper atoms occupy the faces of a face centered cubic lattice. This structure has a resistivity of approximately 4.7 micro-ohm centimeters. If, on the other hand, one heat treats the alloy in such a way as to obtain the "disordered" structure, then the copper and gold atoms occupy random positions in the lattice. The resistivity in this case is 11.4 micro-ohm-centimeters.

If suitable samples of this alloy are subjected to neutron irradiation at room temperature and the resistivity measured after removal from the reactor, it is found that the resistivity of the disordered sample is not affected; however, the ordered samples show an increase in resistivity proportional to the amount of neutron irradiation received. This indicates that the neutron bombardment is stirring up the atoms and thus disordering the ordered samples, while the disordered samples remain unchanged because of the already random array of atoms.

Fig. 1—N-type Ge. Conductivity vs bombardment.

Fig. 2—Conductivity vs fast-neutron bombardment for silicon.

Fig. 3—Stress-strain curves of neutron irradiated copper single crystals. — No irradiation; ---- 1.4×10^{17} nvt; -.- 6×10^{17} ; -- 1.1×10^{18} ; --- 5×10^{18} ; -.-.- 2×10^{19} .

Fig. 4—Effect of neutron irradiation on the critical shear stress of copper.

Fig. 5—Effect of neutron irradiation on the mechanical properties of pure copper single crystals. ○, Effect of neutron irradiation on the critical shear stress of copper; ●, effect of adding zinc on the critical shear stress of copper.

Fig. 6—Change of electrical resistivity vs time of Cu_3Au sample 15A.

Figure 6 shows another experiment done with a sample of copper gold. To begin with, this sample was prepared to obtain a disordered structure and was then held at a temperature of 150°C for several weeks, during which time there was approximately a 1 per cent lowering in the resistivity, indicating that at this temperature ordering proceeds at a very slow rate. While being held at this temperature, the sample was inserted into the reactor. It can be seen that an immediate drastic reduction in the resistivity takes place, indicating that the sample is being "ordered" through neutron bombardment. It is postulated that the excess number of vacancies introduced as a result of bombardment has increased the rate of diffusion of the copper and gold atoms to such an extent that ordering begins to take place rapidly.

Figure 7 compares effects obtained in a copper beryllium alloy with the effects obtained in a series of unsaturated solid solution alloys of copper. The change in hardness and electrical resistivity is readily apparent. It is apparent that something different than the ordinary hardening is happening in the case of copper-beryllium. This alloy containing 2½ weight per cent of beryllium in copper is known as a precipitation hardening alloy. The solubility of the beryllium in copper increases with increasing temperatures. One can prepare a supersaturated solution by quenching the alloy in cold water from an elevated temperature. This state is stable at room temperature, but if one reheats at 200-300°C, then the excess beryllium begins to precipitate out with consequent increase in strength of the alloy. If one irradiates a sample of this alloy in the supersaturated condition, one obtains results as shown on this figure. Thus one is led to wonder if it is possible to induce precipitation by neutron bombardment. We were led to consider this problem several years ago and, as a matter of fact, are still wondering whether true precipitation is being induced. That is, we cannot prove in an unambiguous manner that precipitation hardening is caused by neutron bombardment. However, there is a great deal of circumstantial evidence indicating that precipitation is being induced.

Figure 8 shows what happens when a control sample and an irradiated sample of copper beryllium are heat treated subsequently to irradiation. The upper curve with the solid circles is the irradiated sample and shows the increased resistance due to irradiation. When these samples are heat treated simultaneously, it is observed that most of the radiation induced resistance is lost, with the two curves eventually merging.

Figure 9 is a similar plot, except in this case the upper curve with the solid circles is a sample heat treated at 125°C prior to irradiation. The analogy with the previous figure is very strong and one concludes that irradiation is similar to low temperature precipitation hardening.

The decrease of resistance in the 125°C sample is due to the resolution of precipitate nuclei as a result of raising the temperature to 325°C. Thus it could be said that neutron bombardment is equivalent to aging at 125°C, even though the alloy has been irradiated at room temperature.

I think that the examples cited in the case of copper gold and in the case of copper beryllium illustrate that it is possible to alter by means of fast neutron bombardment the time temperature relationships existing in diffusion-controlled reactions.

Let us now consider some non-metals. Figure 10 shows pictures of a wide variety of plastics subjected to neutron irradiation in the Oak Ridge graphite reactor. The numbers under each sample indicate the relative exposure to neutrons. The first sample from the left in each set of three has had no irradiation; the second sample from 0.02 to 2.9×10^{19} ; and the third from $2.9 - 13 \times 10^{19}$ (nvt). It can be seen that the plastics vary widely in their resistance to irradiation, some being relatively unaffected while others are essentially disintegrated.

Studying the effect of organic solids can be a fascinating field of study because of the large number of structures and properties that can be observed.

Figure 11 shows a stress strain curve for samples of vinyl chloride acetate which have received varying degrees of bombardment. Note that the non-irradiated sample has a high breaking strength with a relatively low plasticity. Small amounts of irradiation have lowered the tensile strength while greatly increasing the plasticity. Excessive amounts of bombardment will lower both properties.

Figure 12 illustrates the behavior of Teflon (poly tetrafluoroethylene). It shows that the plasticity and strength are both drastically reduced by neutron bombardment. Thus, the plastic which is so resistant in the absence of radiation falls rapidly in an atmosphere of neutrons.

Fig. 7—Comparison of irradiation effects in Cu-Be and unsaturated Cu solid solution exposure 1.5×10^{18} nvt.

Fig. 8—Effect of neutron irradiation on subsequent aging of copper-beryllium. Aging temperature, 325°C; ○, standard; ●, exposed to 1.8×10^{18} nvt.

Fig. 9— Effect of low temperature aging of Cu-Be on subsequent aging at a higher temperature. Aging temperature, 325°C; 2% Be by weight; ○, standard solution annealed prior to aging; ●, solution annealed and aged 122 hr at 125°C prior to aging.

0 0.48 2.9
Asbestos-fabric Bakelite

0 0.62 2.9
Asbestos-fiber Bakelite

0 11
Haveg 41

0 0.61 8.6
Linen-fabric Bakelite

0 0.13 8.6
Micarta

0 2.9 9.2
Catalin

0 1.5 6.0
CR-39

0 13
Plaskon Allkyd

0 0.73 7.2
Selectron 5038

0 1.3 13
Amphenol Polystyrene

0 2.4 13
Styron 411 C

0 1.7 13
Polatron

0 0.021 0.68
Saran B-115

0 0.0053 1.3
Vinylite (Vinyl Chloride Acetate)

Fig. 10—Plastics subjected to neutron radiation.

Fig. 11 — Stress-strain curves for pile irradiated vinyl chloride acetate.

Fig. 12 — Stress-strain curves for pile irradiated teflon (polytetrafluoroethylene).

Figure 13 is a picture of a single crystal of quartz which has been bombarded very extensively. It apparently is unchanged except for a slight pinkish tinge. However, if one makes certain quantitative observations, one learns that a great deal has happened to the quartz. For example, Fig. 14 shows the density change as a function of bombardment. At 1.8×10^{20} nvt, the crystal has suffered a 14 per cent decrease in density. If one makes further observations, looking at the X-ray diffraction patterns of powdered quartz irradiated simultaneously, one sees that the structure has become amorphous; subsequent annealing studies reveal that the α - β transformation at 575°C has been lost completely.

I believe the above examples are sufficient to show that many properties of a wide variety of solids can be altered in a very pronounced fashion by fast neutron bombardment. Furthermore, these effects can be introduced at low fluxes $10^{11} - 10^{12}$ such as are obtained in the Oak Ridge graphite reactor.

Let me discuss the way in which these property changes are introduced by neutron bombardment.

When a high velocity neutron collides with an atom of copper, it will by a "billiard ball" type of collision, transfer enough momentum to the struck-on atom to displace it from its equilibrium position in the lattice; in fact, if we consider a neutron of approximately 1 mev energy, it will, on the average, transfer 30,000 electron volts to the knocked-on atom. Since it requires only 25-30 electron volts to displace an atom, there is a tremendous excess of energy transferred. This excess energy will, in turn, be used by the struck-on atom in displacing other atoms from their equilibrium positions, which in turn displace others. Thus a cascade of displaced atoms is set up for each collision that the fast neutron makes. When an atom is displaced from its position it leaves a "vacancy" behind, and when the atom comes to rest it will be in an interstitial position unless it comes to rest in a pre-existing vacancy.

In the early part of the range of the struck atom it is traveling with such high velocity that most of its energy is lost by ionization and electronic excitation. It is near the end of the range that most of the collisions occur, resulting in vacancies and interstitials. A certain amount of the energy dissipated comes about through lattice vibrations set up in the wake of the moving atom. These enhanced lattice vibrations are designated as "thermal spikes." Various estimates have been made of their extent. Most of the estimates agree that for each spike approximately 5-10,000 atoms are involved and that they are heated up to approximately 1000°A for 10^{-10} to 10^{-11} seconds.

The incident neutron will eventually reach equilibrium with its environment as a result of successive collisions; if it is still in the mass of copper it will be captured by a copper nucleus. Subsequent radioactive decay will cause the formation of a zinc atom. Thus an impurity atom has been introduced. This is a minor effect in most cases, e.g., one impurity atom per neutron, thousands of vacancies and interstitials per neutron.

To summarize, we have shown five ways in which the properties can be changed by neutron bombardment:

1. vacancy
2. interstitial
3. thermal spike
4. impurity atom (alloying) - minor effect
5. ionization and electronic excitation.

We have shown by means of the figures how the more important of these effect the properties of solids. For example:

1. Vacancies probably increase diffusion rates on a micro scale.
2. Interstitial atoms act as very effective alloying elements.
3. Thermal spikes can cause disordering.
4. Ionization can break chemical bonds.

It is possible to use other nuclear machines to do similar experiments. Protons, deuterons, alpha particles, etc., from accelerators will, in general, give similar effects, since after the first collision in any case the disrupting mechanism is the knocked-on atom. It is not feasible to use accelerators as a source of neutrons for this type of experiment because the experimental area is too small, i.e., neutrons essentially originate as a point source (1 cm^2).

Fig. 13—Single crystal of quartz after neutron bombardment.

Fig. 14—Density change of quartz as a function of neutron bombardment.

Let us compare the research reactor with other nuclear machines as a means of introducing the above mentioned defects into a solid with particular emphasis on utilization of the reactor as a university tool for solid state research.

The principal advantages of an accelerator are as follows:

1. Less induced radioactivity, thus making sample manipulation after irradiation simpler (accelerator induced activities can not be ignored, however).
2. Monoenergetic radiation—can be of value in threshold studies that are not possible in a reactor with a spectrum of neutron energies.
3. High beam currents—corresponding to much higher fluxes than can be obtained in a research reactor.

The advantages of a research reactor are:

1. One is certain that he is obtaining volume effects because of the much greater range of the neutron in the solid. The range of a charged particle, say 20 mev deuterons, is probably less than ten one-thousands of an inch (0.010") in copper.
2. Large numbers of experiments can be performed simultaneously. This feature lends itself particularly well to university research as compared to the one-at-a-time experiments with other nuclear machines.
3. Experimental area in a reactor is large, permitting use of large samples if necessary.
4. Temperature control is easy to build into a reactor experiment and one does not worry about heating of the gross sample caused by the bombarding neutrons. The absorption of high energy into a thin foil poses a very difficult problem in accelerator experiments. The ultra high energy machines have a good range, but one must still face the competition from the other experimental groups.
5. One can easily induce damage using thermal neutrons by employing fissionable material. For example: $\text{Li}^6 + n \rightarrow \text{He} + \text{H}^3$. The recoiling He + H^3 give accelerated displacement effects.
6. One has a ready source of gamma rays either from the reactor or by irradiating cobalt, for use outside the reactor.

It has been the experience at Oak Ridge that a nuclear research reactor is an inexpensive, convenient, versatile tool for use as an instrument for solid state research. Not only does it contribute in conventional fields, but offers the opportunity to work in an important new field in solid state, i.e., radiation effects.

The reactor is suitable for university faculty research and for student instruction, as well. There is sufficient space to allow many groups to work simultaneously and still not interfere with physics, chemistry, biology, and other groups that may wish to use the reactor at the same time.

We wish to wholeheartedly recommend that universities consider most seriously the acquisition of a university research reactor.

We have found it possible to do a wide variety of solid state experiments in many types of reactors. There are advantages and disadvantages in any type. We believe, however, that the "swimming pool" type is perhaps the most versatile for radiation effects research.

REFERENCES

Selected references relating to work on the motion of charged particles through matter but with no attention to effects on the solid:

- "The Penetration of atomic particles through matter by Neils Bohr." Royal Danish Academy XVIII, 8, 1948
- S. C. Lind, Chemical Effects of Alpha Particles & Electrons. 1928 (Chem. Catalog Co.)
- Mott & Massey, Theory of Atomic Collisions (Oxford Univ. Press 1934)
- Burton and Rollefson (Prentice Hall, N. Y., 1939)
- Mott & Guernsey, Electronic Processes in Ionic crystals

Reviews and Theoretical Studies

- M. Burton, J. Phys. Colloid Chem. 51, 611 (1947)
F. Seitz & A. O. Allen, Irradiation Physics Notes, 1946
F. Seitz, Trans. Fara. Soc. #5, 271 (1949)
J. C. Slater, J. Appl. Phys. 22, 237-256 (1951) Review
G. J. Dienes, Vol II, Am. Rev. Nuclear Service (1952)

Typical Experimental Studies (Meant to be typical only, not complete.)

Chemical:

- A. O. Allen - MDDC-962 (1947)
A. O. Allen - J. A. Ghormley, J. Chem. Phys. 15, 208 (1947)
M. Burton - Radiation Chem. - Am. Rev. of Phys. Chem. (Am. Rev., Inc.) 1950 pp 113-132

Semi-Conductors:

- R. E. Davis, W. E. Johnson, K. Lark-Horovitz and S. Siegel, Phys. Rev. 74, 1255 (1948)
J. H. Crawford, Jr. & K. Lark-Horovitz, Phys. Rev. 78, 815 (1950)
J. W. Cleland, J. H. Crawford, Jr., K. Lark-Horovitz, J. C. Pigg, and F. W. Young, Phys. Rev. 83, 312 (1951), Phys. Rev. 84, 961 (1951)
Semi-conducting Materials (Butterworth Publications, 1951)
M. C. Wittels, Phys. Rev. 89, 656 (1953)

Metals:

- Billington and Siegel - Met. Progress 58, 847 (1952)
G. T. Murray & W. E. Taylor - Bull. Am. Phys. Soc. 27, (1952)
T. H. Blewitt & R. R. Coltman - Phys. Rev. 85, 384 (1952)
T. H. Blewitt, R. R. Coltman, & F. A. Sherrill - Bull. Am. Phys. Soc. 26, #2, 13 (1951)
S. Siegel, Phys. Rev. 75, 1823 (1949)
A. B. Martin, Bull. Am. Phys. Soc. 25, 21 (1950)

Ionic Crystals:

- Pringsheim et al., Phys. Rev. 78, 293 (1950); J. Chem. Phys. 18, 887, 1564 (1950); 19, 574 (1951)
D. Westervelt, Bull. Am. Phys. Soc. 27, #2, 10 (1952)
A. O. Allen & J. Ghormley, J. Chem. Phys. 15, 208 (1947)
R. L. Sproull, R. S. Caswell, C. M. Nelson - Bull. Am. Phys. Soc. 28, #1, p35, Cambridge 1952
R. Berman, P. G. Klemers, F. E. Simon, T. M. Fry - Nature, 166, 864 (1950)

Glasses:

- G. S. Monk - ANL-4536 (1950)
R. H. Kernohan & G. McCammon - Bull. Am. Phys. Soc. 27, 1952

Plastics:

- O. Sisman and C. D. Bopp - ORNL-298 (1951)
W. L. Davidson & G. I. Geib, J. Appl. Phys. 19, 427 (1948)
M. Dale - NP-3237 - pp 120-148 (1950)

SOME BIOMEDICAL USES OF REACTORS

by C. S. Shoup*

Although the atomic energy establishments, certain research institutes, and various colleges and universities interested in radiobiology here and abroad are actively engaged in basic studies on radiation effects, other institutions with new interests should not hesitate in entering this promising field. The establishment of nuclear engineering in a university could be an added stimulus to such interests. Nuclear reactors built at university centers and designed for power levels suitable to radiochemical or metallurgical research might well be adapted, or, better yet, anticipated in design, as contributors to an institution's biological or medical research program.

In considering biomedical usage of reactors, it is appropriate to remind an audience predominating in physical scientists that the biologist is faced with the study of radiation effects in a very complex and continually-changing medium. This medium, living matter, has been under organized scientific observation since the time of Aristotle (384-322 B. C.). It is almost impossible to convey an idea of the complexity of living material. We know that the effective site of action of radiations is the cell. We know too that the profundity of effect essentially depends on the gross number of cells that are changed if they are somatic cells, or a single one if that important changed cell enters into reproductive processes as germ plasm.

Chemically, we know the cell as a multiplicity of organization containing from 30 to 90 per cent water, with cations like potassium, sodium, calcium, and iron with carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus, in extremely varied proportions as the fats, carbohydrates, proteins, pigments, hormones, vitamins, and enzymes, together with trace elements. These are the life-making constituents. The normal functioning of the cell depends on a chemical balance between all these with a complex dynamic equilibrium of synthesis and disruption. Similarly, a constancy of structure and replication of structure seems required if normal storage, synthesis, and cell-reproduction are to continue. The vital functions associated with the cell, and, in turn, with the organism as a whole, are those of metabolism, growth, reproduction, absorption, assimilation, excretion, respiration, and oxidation. All are incompletely-understood processes that vary with the physiological state of the cell and organism, and all may be altered through absorption of radiant energy.

Recognizing this extreme variability and complexity of living matter, plant or animal, I believe it is clear that in quantitative biology today, the details of radiation effects are probably best studied by use of sources yielding particular radiations of a narrower energy range than would be afforded by the nuclear reactor. Calculations for the ionization and energy absorption

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required to produce disruption of chemical bonds, for causing breaks and aberrations in chromosomes within the cell nucleus, or for interference with enzyme action, may be best arrived at through use of ionizing radiations or neutrons as nearly monochromatic as possible. Such employment of monochromatic ranges of radiations would tend to minimize the introduction of yet another set of variables into already complex biological experimentation. Possibly in most cases the relative biological effectiveness of specific radiations on individual cell processes can be best studied through utilization of radiochemical sources or accelerator reactions yielding specific energies.

The fact remains, however, that the principal external radiation hazards to man may be expected from mixed radiations. For this reason, and because the nuclear reactor may become more generally available as a radiation source, it is fitting and proper that full biological use should be made, where practical, of neutrons and gamma radiation from reactor operations. Possibly there are many new kinds of biological experimentation that may be accomplished with the reactor if neutron exposure can be in a flux of 10^9 or 10^{10} n/cm²/sec. or more, or where gamma beams may be segregated yielding dose rates comparable with the commonly-used radioisotope sources. The likelihood of improved biological uses of reactors is being enhanced today through improvements in instrumentation and in dosimetry.

Here in Oak Ridge at the graphite reactor of the Oak Ridge National Laboratory (known then as the "Clinton Pile"), some of the earliest pile-radiation studies were made on biological materials. These studies during Manhattan Project days,^{1,2} were among the first to show the extent of additivity of fast neutrons and gamma rays in causing death and to show strain differences in laboratory animals when exposed to whole-body irradiations. Although gamma contamination of neutron dose was incompletely known, the experiments demonstrated a general threshold for acute lethal action by fast neutrons and brought out differences in total dose required for killing in acute lethal exposures and chronic repeated doses down to what was probably about 3.0 r.e.p. per day. In the same experiments the relative biological effectiveness (RBE) for pile radiations is given values compared with gamma rays for both acute and delayed lethal effects on mice. The relative values for the RBE arrived at in the early experiments are not far different, so far as immediate effects are concerned, from our more modern estimates.³

Reactor irradiations of biological materials present a complicated picture of effects due to liberation in tissues by fast neutrons of recoil protons of various energies. If a considerable flux of slow neutrons is also present, these may induce capture reactions augmenting the damaging ionization. The additional ionization is due to gamma radiation, electrons, or additional protons emitted from the predominant hydrogen and nitrogen of tissues when new nuclei are produced with excess energies. A considerable gamma contaminant accompanying the total neutron dose may also be a contributant to the overall biological effect. Because of the logical desire to evaluate individually the biological action of the several radiations of the nuclear fission spectrum, it is of interest that some special efforts have been made to isolate the radiation components in certain biological experiments with reactors.

At the Argonne National Laboratory, a special type of fast-neutron exposure chamber with an appropriate absorbing shield for the gamma contaminant has been prepared, and in such fashion that it may be attached to the opening of the thermal column of a reactor. Slow-neutron capture in a uranium converter produces a fast neutron dose of 150 to 275 r.e.p. in 90 minutes. The dose is delivered to animals in the shielded biological chamber when the reactor is operated at 150-190 KW. For study of the possible additive effect of gamma irradiation, cobalt-60 sources may be admitted to the biological chamber to permit administration of up to 15 r per minute.⁴ Current studies in this facility have demonstrated an LD/50 of 205 r.e.p. for fast neutrons in a strain of Carworth Farms mice.⁵

In the above-mentioned exposure chamber at Argonne, it has been shown that neutrons are much more effective than gamma rays in causation of cataracts in mice, probably with an RBE greater than 10. With attention to this same biological effect, Christenberry and Furth⁶ exposed mice in the thermal column of the Oak Ridge graphite reactor and concluded that slow neutrons induce lens opacities sooner and in a higher percentage of animals and in smaller doses (on the basis of LD/50) than equivalent quantities of X-rays. It is worth noting that in the Oak Ridge experiments, the slow neutron flux of 0.9×10^9 n/cm²/sec. was accompanied by 4 to

Fig. 1—Biological Thermal Neutron Exposure Chamber as used at the Oak Ridge National Laboratory. (Alan D. Conger, 1950.)
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Fig. 2 — Gamma-Neutron Radiation Chamber for Biological Studies at the Argonne National Laboratory. (H. H. Vogel, Jr., R. A. Blomgren, and N. J. G. Bohlin, 1953.) Reproduced by permission of the editors of NUCLEONICS.

8 r/min. of high-energy gamma radiation. Results from both kinds of reactor experiments have tended to confirm the sensitivity of mice to induction of radiation cataract.

It may be stated further that the Argonne experiments have been directed toward comparison of the mortality pattern of mice resulting from separate fast neutron and gamma irradiation, and mixtures of the two. To date it appears that although acute gamma irradiation between 750 and 1100 r (LD/50 about 925 r) produces a peak mortality 13-14 days following exposure, a dose of fast neutrons in the 205 r.e.p. LD/50 range causes the mortality peak to back up to only 5 or 6 days post-irradiation, with an RBE of 4.4 for survival as compared with the gamma-ray effectiveness.⁷

As one can imagine, the biological exposure chamber in use at Argonne is by no means confined to survival studies and cataract research alone. Work in progress also includes studies of tumor induction in laboratory animals and effects on sensitive organs such as the thymus and spleen, and on chemical protection against both gamma and neutron exposures. The incidence of chromosome aberration in Drosophila, cytogenetic changes in the Orthoptera, bacterial growth and resistance, and germination of food plants are all under study.

Quite recently, English investigators⁸ have reported on male fertility studies of mice wherein the animals were exposed in a cage atop a reactor thermal column, with the floor of the cage made of uranium to provide a uranium converter. By this means, a fast neutron total dose of 70 r.e.p. was found to produce a fifty per cent reduction in fertility in the animals when delivered as a weekly dose of 8.3 r.e.p. An accumulated dose of 100 r.e.p. halved the testis weight. It was found, somewhat surprisingly, that the female mice were less sensitive than the males, and an accumulation of 140 r.e.p. by the females over a period of 17 weeks did not seem to alter their reproductive ability. The doses that had a striking testicular effect on the males did not appear to cause growth or weight changes, nor haematological changes in them, over a period of 35 weeks of observation.

At Oak Ridge, Giles and Conger⁹ and Giles, Beatty, and Riley¹⁰ compared effects of fast fission neutrons of between 1.0 and 4.0 mev from a reactor, with higher-energy cyclotron neutrons in production of chromosomal interchanges in the microspores of Tradescantia. The results obtained gave added evidence for a linear increase of interchange frequency with dose as a one-hit phenomenon, and showed that the lower-energy neutrons from the reactor have greater efficiency in producing these types of chromosome changes because of the greater ionization density along the path in the cell of the slower particle. In some of the few studies of fungi made with a reactor, Markert¹¹ at Oak Ridge exposed species of Glomerella to fast neutron doses ranging from an estimated 27,670 to 133,000 r.e.p. in order to compare mutagenic effects with those obtained from X-rays and from ultraviolet radiations. Qualitative differences and the relative proportions of mutations did not seem to change with the kinds of radiation used in this instance. Additional reactor exposures of fungi seem to be of promise, and some work on species other than Glomerella is in progress at the Oak Ridge National Laboratory at the present time.

As a turn in another direction in use of reactors for biological purposes, and in a field that has had rather common application for possible production of new varieties or for somatic mutation studies, investigators from the Nebraska Agricultural Experiment Station studied the susceptibilities of maize pollen and seed to thermal neutrons. These susceptibilities were compared with X-irradiation effectiveness on subsequent seedling development.¹² The plant material was exposed to thermal neutrons for short periods up to 8 minutes in a flux of $7 \times 10^{10} \text{ n/cm}^2/\text{sec}$. Results obtained on seeds caused reduced plant height, delayed lethality, modification of leaf size and shape, and some structural and physiological anomalies of the leaves. Increasing the duration of pollen exposure led to an eventual reduced plant height and a diminished maximal stand. On analysis of the data obtained, it was concluded that on the basis of X-ray comparisons, thermal neutrons were from 6 to 12 times as effective on maize seeds than on the pollen in producing a smaller plant.

At the Los Alamos Scientific Laboratory, a series of animal experiments have been based on exposures to thermal neutrons from a homogeneous reactor. In the course of evaluating the effectiveness of thermal neutron dose delivered to such small laboratory animals as mice, the Los Alamos biologists have shown that in their reactor studies at least three factors must be taken into consideration in dosimetry: (a) the gamma contamination of low RBE from slow neu-

tron capture in graphite; (b) the animal itself as a weak gamma source; and (c) the "sink" effect or shielding of animals for each other when closely adjacent.¹³ The RBE for mortality in laboratory mice was found in the Los Alamos experiments to be of rather low order at 1.7 compared with X-rays. This value is the same for thermal neutrons from the same facility when studied with regard to effectiveness in inhibition of mitosis in the ear epithelium of the mouse¹⁴ where it is possible to cause a mitotic delay up to 4.25 hours following a 45-r.e.m. dose.

Again at Oak Ridge, in a most ingenuous experiment, Conger and Giles¹⁵ utilized an exposure chamber shielded by bismuth and placed in the middle of the thermal column of the graphite reactor. They discovered that 99 per cent of the effect of thermal neutrons in causing chromosome breakage in *Tradescantia* could be accounted for by capture reactions in hydrogen, nitrogen, and the naturally-occurring boron of the plant material. The later two elements, on the basis of analysis, accounted for 78 per cent of the r.e.p. dose. Reaction of a neutron with a N^{14} nucleus results in emission of a proton, but the highly-ionizing alpha particle results from the boron reaction. The important role of the boron trace element is because of its high capture cross-section together with the fact that the heavily-ionizing particle produced loses all its energy within the tissue. Giles and Conger were able to show that thermal neutrons were about 11 times as effective as X-rays when measured in r.e.p. Confirmation of the boron effect in the plant tissue was later demonstrated by Conger with use of boron-enriched plants,¹⁶ a development of suggestions made as early as 1940 in relation to the therapeutic implications of neutron capture.^{17,18}

Tissue enrichment by neutron-capturing isotopes, with view of producing a means for neutron capture therapy of the human patient with pile radiations, has now been explored by Drs. Farr and Sweet and their collaborators.¹⁹⁻²¹ They have made calculations of radiation dose to be expected if boron will accumulate in intact brain tumor, and at the Brookhaven National Laboratory have conducted exploratory experiments. Using the Brookhaven air-cooled graphite reactor, patients with certain types of brain tumors have been treated through exposure to the gamma-shielded neutron beam. Some patients have been given more than one treatment following boron administration, and the temporary amelioration of clinical symptoms has suggested that a retardation of tumor growth occurred. The results have been encouraging enough to warrant a further extensive exploration of the neutron capture therapy principle with high-cross-section isotopes other than boron and with continuing use of the reactor as a radiation source.

Turning again to whether a reactor may be used as a gamma source, it does appear that pile radiations may be shielded so as to provide predominantly a gamma field. It is worth mentioning that when North Carolina State College began its project on peanut seed irradiation under direction of Dr. W. C. Gregory, consideration was given toward wholesale gamma irradiation of the seed in a cadmium container as an in-pile experiment. As it turned out, however, the work proceeded as a variation and population study on plants from seeds exposed to X-rays. A few experiments at the pile were made under Manhattan Project studies, with small laboratory animals exposed in a cadmium box with boron-carbide shielding. Probably our improved knowledge of shielding and dosimetry can lead to new applications of reactor gamma rays.

It is my hope that the above recitation of biomedical studies indicates the nuclear reactor to be useful as a biotest instrument. The studies cited are but a few selected examples of biological uses of reactors, and are in the ranges of uses mentioned by Beck²² and by Fox²³ in their reviews of research uses of reactors. In addition to the above, there are the obvious uses of the reactor for activation of radiation sources and for the production of short-lived isotopes of interest to the biologist. It would seem, in addition, that use might be extended to new experiments on production of varieties of economically-important plants,²⁴ or on changes in plant or animal populations as an effect of total radiation. Some organisms, notably the invertebrates, have scarcely been touched with respect to study of the effects of radiation. It is true that some cell types have been used of special adaptation to radiobiology, such as the grasshopper neuroblast and the egg of *Arbacia*, and the whole animal in the instance of *Drosophila*, *Habrobracon*, and some of the economically-important insects. Perhaps interesting experiments could be performed on organisms bearing widely variable amounts of water or total fat in the protoplasm or on those with unusual metallic content, as in the case of the crustacea and mollusca. Among

the poikilothermal vertebrates, some species have been examined with respect to growth or cell reproduction under the influence of radiation, or with respect to change in endocrine function. However, generally, we have inadequate information on the radiobiology of cold-blooded vertebrates compared with what we have for the homiotherms. Some plants, notably those bearing normal high levels of manganese, or lithium or silicon, might afford interesting experiments. It is possible that new information could be obtained through examination of the growth of microorganisms in a radiation field. And, most important of all, the reactor might be used to explore the problem of comparative effects of single total dose and fractionated dose more extensively on more species of organisms, especially with the view of determining the nature of delayed or latent effects. Planning and design for biological usage, begun early during the contemplations that will lead to the establishment of a nuclear reactor, may pay dividends in knowledge and new techniques for using the reactor as a biological tool.

DISCUSSION

QUESTION: This question concerns the unit of dosage used. How do they get the equivalence of the neutron dosage to the roentgen as it is understood generally?

MR. SHOUP: In a good many of these experiments this was done partly by foil activation.

QUESTION: That will tell you how many neutrons were incident per square centimeter.

MR. SHOUP: In some of the plant experiments, estimations of the dose in r.e.p. were made on the basis of the composition of the tissue and the expected particle-producing reactions occurring. In some experiments the n-units could be multiplied by a factor for RBE in a range somewhere between 2 and 3, say 2.5, to obtain an estimate of r.e.p.

A. M. WEINBERG: We at Oak Ridge National Laboratory have been particularly sensitive to the fact that neutron dosimetry, especially for biological purposes, is in a somewhat nebulous state. Mr. Hearst and Mr. Ritchie of Oak Ridge National Laboratory have developed a special neutron dosimeter which actually measures the energy disposition by measuring it in a system which has about the same water content as protoplasm. We now believe that neutron dosimetry is fast becoming almost as accurate as gamma ray dosimetry.

MR. SHOUP: I would like to mention that the Laboratory people are working on these problems with close attention to current developments by Failla and Rossi in New York, who are also preparing and have prepared various types of tissue equivalent chambers. The various groups that are working together, and especially the Oak Ridge investigators, should shortly place neutron dosimetry in a situation where all energy ranges may be measured.

LITERATURE CITED

1. Zirkle, R. E., J. R. Raper, E. F. Riley, and G. E. Stapleton. 1945. Additivity of Fast Neutrons and Gamma Rays in their Acute Lethal Action on Mice. (AEC-2328. Decl.) Jour. Amer. Chem. Soc. 71: 2245-2246, (1949).
2. Henshaw, Paul S., E. F. Riley, and G. E. Stapleton. 1946. The Biologic Effects of Pile Radiations. MCCR-259. pp. 1-26.
3. Mitchell, J. S. 1952. Tolerance Levels for Fast and Thermal Neutrons, in "Biological Hazards of Atomic Energy," ed. by Haddow. Oxford Univ. Press. pp. 113-121.
4. Vogel, Howard H., Jr., R. A. Blomgren, and N. J. G. Bohlin. 1953. Gamma-Neutron Radiation Chamber for Radiobiological Studies. Nucleonics. 11 (3): 29-31. Mar.
5. Vogel, Howard H., Jr. 1952. Progress Report. Appearance and Progression of Cataract Formation following Irradiation with Fast Neutrons. ANL-49-48. Uncl. pp. 24-26.
6. Christenberry, K. W., and J. Furth. 1951. Induction of Cataracts in Mice by Slow Neutrons and X-Rays. Proceedings Soc. for Expl. Biol. & Med. 77: 559-560.
7. Argonne National Laboratory. 1953. Progress Report, Biology and Medicine. ANL-5129. Uncl. p. 8. Oct.
8. Neary, G. J., J. Munson, and R. H. Mole. 1953. Effects of Daily Irradiation by Fast Neutrons on Male Fertility. Nature. 171: 256.

9. Giles, N. H., and Alan D. Conger. 1950. Chromosomal Interchanges Induced in Tradescantia Microspores by Fast Neutrons from Uranium Fission. Jour. Cellular & Comp. Physiol. 35 (Suppl. 1.): 83-88. June.
10. Giles, N. H., Alvin V. Beatty, and Herbert P. Riley. 1952. The Effect of Oxygen on the Production by Fast Neutrons of Chromosomal Aberrations in Tradescantia Chromosomes. Genetics. 37: 641-649. Nov.
11. Markert, Clement L. 1952. Radiation-Induced Nutritional and Morphological Mutants of Glomerella. Genetics. 37: 339-352.
12. Schmidt, J. W., and E. F. Frolik. 1951. Comparative Effects of Thermal Neutron Irradiation of Maize Pollen and Maize Seed on subsequent Seedling Growth. Jour. of Heredity. 42 (4): 173-177. July-Aug.
13. Brennan, J. T., Payne S. Harris, Robert E. Carter, and Wright H. Langham. 1954. The Biological Effectiveness of Thermal Neutrons on Mice. Nucleonics. 12 (2): 48-56. Feb. (Part I.), 12 (4): 31-35. Apr. (Part II).
14. Storer, John B. 1952. The Biological Effectiveness of Thermal Neutrons in inhibiting Mitosis in Mice. University of California, Los Alamos Scientific Laboratory. LA-1400. Uncl. pp. 1-25.
15. Conger, Alan D., and Norman H. Giles. 1950. The Cytogenetic Effect of Slow Neutrons. Genetics. 35: 397-419. July.
16. Conger, Alan D. 1953. The Effect of Boron Enrichment on Slow-Neutron Irradiated Tissues. Genetics. 38: 128-133. Mar.
17. Kruger, P. G. 1940. Some Biological Effects of Nuclear Disintegration Products on Neoplastic Tissue. Proc. Natl. Acad. Sci. 26: 181-192.
18. Zahl, P. A., F. S. Cooper, and John R. Dunning. 1940. Some in vivo effects of localized Nuclear Disintegration Products on a transplantable Mouse Sarcoma. Proc. Natl. Acad. Sci. 26: 589-598.
19. Sweet, William H., and M. Javid. 1952. The Possible Use of Neutron-Capturing Isotopes such as Boron¹⁰ in the Treatment of Neoplasms. I. Intracranial Tumors. Jour. Neurosurgery. 9: 200-209. Mar.
20. Javid, M., G. L. Brownell, and William H. Sweet. 1952. The Possible Use of Neutron-Capturing Isotopes such as Boron¹⁰ in the Treatment of Neoplasms. II. Computation of the Radiation Energies and Estimates of Effects in Normal and Neoplastic Brain. Jour. Clinical Investigation. 31 (6): 604-610. June.
21. Farr, Lee E., William H. Sweet, et. al. 1954. Neutron Capture Therapy with Boron in the Treatment of Glioblastoma Multiforme. Amer. Jour. Roent. & Nuclear Medicine. 71 (2): 279-293. Feb.
22. Beck, Clifford K. 1951. Uses and Limitations of a Low-Power Reactor. Nucleonics. 9 (5): 18-27. Nev.
23. Fox, Marvin. 1953. Use of a Reactor for Research. Nucleonics. 11 (6): 46-48. June.
24. Tolbert, N. Edward, and Paul B. Pearson. 1952. Atomic Energy and the Plant Sciences. Adv. in Agronomy. 4: 279-303.

NEUTRON DIFFRACTION WITH A RESEARCH REACTOR

by C. G. Shull*

One of the unique types of experimentation that has become possible with the availability of intense neutron currents from reactors is that of the neutron diffraction technique. I would like briefly in the next few moments to describe this technique in very general fashion, and then to proceed to two simple examples of the types of problems which are being worked upon at the present time.

Figure 1 shows a schematic diagram of a typical neutron diffraction spectrometer. One is interested in taking a neutron beam from a reactor and scattering this neutron beam from substances with the idea of determining something about the physical state of the scattering substance. A reactor is shown with a hole passing through the shield of the reactor. A neutron beam emanates through this hole and strikes a monochromating crystal at B in the figure. The radiation from a reactor is of heterogeneous character; that is, one obtains neutrons of all speeds or velocities, and it is necessary for most of the scattering experiments that one is interested in performing to monochromate this beam.

This is done by placing a single crystal, a suitable monochromating substance—in this case it is shown as a lead crystal—in the path of this beam; one thereby obtains from this monochromating crystal a monochromatic beam of neutrons by simple Bragg reflection from the crystal planes within this single crystal. This monochromatic beam passes through or is scattered from a scattering specimen. Then the whole experiment resolves about a determination of the scattered intensity as a function of the scattering angle produced by the scattering substance upon this monochromatic neutron beam.

In the figure are shown some typical neutron current densities. At the center of the reactor, in the figure, a typical current density would be of the order of magnitude of 10^{12} neutrons per square centimeter per second. This is the flux figure that you have heard quoted with respect to many of the reactors which you are considering. By the time one collimates such a beam from such a central isotropic neutron flux, there is a large solid angle factor which reduces the neutron current down to a neutron current density of the order of 10^7 neutrons per square centimeter per second, so that this is the actual current density which is available at position B for scattering or for monochromitization by the monochromating crystal. Upon monochromitization, there is a further reduction in intensity.

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Fig. 1—Schematic diagram of a typical neutron diffraction spectrometer.

One picks out a slice of the continuous spectrum which is incident upon the monochromator and this further reduces the intensity available at the scattering sample (position C) to 10^5 neutrons per square centimeter per second.

For the usual types of scattering samples encountered, the actual intensity in the diffraction pattern is further reduced by a sizeable factor to a level of 10 neutrons per square centimeter per second. This is the signal intensity. This is low, but it is a good deal higher than the usual background intensity encountered in equipment of this type. This background may be of the order of a tenth of a neutron per square centimeter per second, so that the signal intensity is approximately a hundred times the background intensity.

The next figure (Fig. 2) shows a photograph of two of these typical units. These are two spectrometers which are mounted at the X-10 pile here on the Oak Ridge site. The principal reactor shield is in the background and a neutron beam comes out through that shield with a cross-sectional area of perhaps one square inch, and is incident upon a monochromating crystal which cannot be seen since it is enclosed within a secondary shield, the black box in the figure. The monochromatic beam comes out through an opening in this black box and passes on to a scattering specimen which is mounted upon a simple spectrometer unit.

The detection of the scattered currents is accomplished with a typical neutron counter shown within its movable shield work. This whole counter assembly rotates about the axis of the spectrometer, thereby following the intensities of scattering as produced by the scattering sample.

There are two units here, a second one in the background. There is also shown a variety of electronic instrumentation, voltage suppliers, amplifiers, scaling circuits, and recording equipment associated with such spectrometers. Some of this is shown in the background. Such spectrometers must, of necessity, be custom-built, as there is no commercial source of supply of equipment of this type. The cost of manufacture or construction of a typical unit is between \$20,000 and \$35,000, depending upon the complexity of the particular instrument that you are building and the degree of flexibility which you have designed into the instrument. This compares not unfavorably with equivalent pieces of x-ray equipment which may also run in the vicinity of \$15,000 or \$20,000 as purchased from a commercial vendor.

The next figure (Fig. 3) shows a further photograph of another instrument. This particular instrument was built by General Electric Company research scientists and installed at the Brookhaven reactor. It has been running there now for some twelve months. This unit is similar to the units that I have just described: A monochromating housing is shown with a monochromating crystal back inside the housing. The monochromatic beam passes over the spectrometer axis, and the scattered intensity is detected and recorded with characteristic neutron equipment.

There are some 13 of these units in operation at the present time, and in Fig. 4 I show the distribution of such of the spectrometers that I happen to know of as a function of the central flux of the reactors to which they are attached. Here is a plot of the number of spectrometers as a function of the log of the central flux, covering the range of 10^{11} to 10^{14} . As you see, most of the units are operating in the region between 10^{12} and 10^{13} . Please do not be misled by this. This is not an optimum flux region for equipment of this type. There is no optimum flux; the more the better. The more flexibility you have in types of experimentation with higher fluxes, the better. The apparent maximum exists because most of the reactors which are available for work of this type operate in this flux region. You may be puzzled if you study Fig. 4. I plotted one point here with an ordinate value of 1.5 spectrometers. I wasn't sure whether there were one or two units in operation with reactors in this flux region, so I split the difference and plotted this as 1.5.

The next figure (Fig. 5), leads me into a discussion of a typical application of equipment of this type. I would like to discuss for a moment the ferroelectric properties of this substance, potassium-hydrogen-phosphate. If you study the dielectric properties of this material as a function of temperature, you find that at high temperatures it is what is called a paraelectric, and then at low temperatures it takes on a permanent electric polarization of its own. There is a curie point, and this curie point is located at 121 degrees absolute. Below this temperature there are permanent electric dipoles that are set up within the crystal, and this has very

Fig. 2—Photograph of two neutron diffraction spectrometers located at the X-10 pile in Oak Ridge.

Fig. 3 — Photograph of neutron diffraction spectrometer constructed by General Electric Company personnel and installed at Brookhaven National Laboratory.

Fig. 4—Distribution of neutron diffraction spectrometers.

Fig. 5—Some physical and structural properties of potassium dihydrogen phosphate.

useful applications and is associated with very understandable properties of the material. So the electric polarization takes on a high value at low temperatures and is very much smaller at high temperatures.

The structure of this material had been studied many years ago by x-ray techniques, and the x-ray people had established the structural symmetry of the lattice and had determined the potassium, the phosphorus, and the oxygen positions within the lattice. I show in Fig. 5 a portion of this crystallographic structure, which shows the symmetry or the relative positions of the oxygen atoms within the lattice. The oxygen atoms form a tetrahedron, with four oxygens at the corners of the tetrahedron. The rest of the lattice then consists of further tetrahedra which are tied onto this central one.

In the middle, or somewhere within this tetrahedron, is the phosphorous ion; and the x-ray people have established where that is. They have also established where the potassium ions are in the lattice. There was nothing unusual about the positions of the potassium, the phosphorous and the oxygen ions that would account for this sort of ferroelectric behavior. It was proposed by Slater that the ferroelectric behavior would be connected with the hydrogen atom positions in the crystal. He proposed a very nice model some twelve or thirteen years ago. It was suspected that there was a hydrogen atom existing along each of the oxygen bonds connecting adjacent tetrahedra, but the x-ray people could not tell where on this bond the hydrogen atom was located.

In Slater's proposed model, he envisaged at temperatures below the curie point that the hydrogen atoms existing along the two upper bonds were displaced towards the oxygen ions of the central tetrahedron. On the other hand, Slater postulated that the two hydrogens on the two bottom bonds were displaced away from the central oxygen ions. We have two top oxygen bonds and two bottom oxygen bonds. The two hydrogens on the bottom were displaced over to the other fellows away from the central position, whereas the top fellows were pulled in. This tended to produce, with a little bit of argument, an electric dipole in this assembly, since symmetry has been lost in the charged distribution within the group.

On the other hand, at high temperatures Slater's model proposed that the hydrogen atoms were not located at specific positions along the oxygen bonds; consequently, I show (in Fig. 5, lower right) alternate positions for the hydrogen atoms.

The important point of the Slater picture was the repositioning or ordering of the hydrogen atoms at the low temperature as contrasted with the high temperature structure.

It remained then for the neutron people to look for this effect since they could see the hydrogen atoms a lot more easily than the x-ray people could. Figure 6 shows why they could do this. Here are relative scattering amplitudes for x-rays for the four different types of atoms in this material, and you see that the hydrogen scattering amplitude for x-rays is very much smaller than the others. Intensity-wise these differences have to be squared so that the relative scattering power of the hydrogen atom to a potassium atom—which is expressed here by a factor of 20 in the scattering amplitudes—is only one in 400 for the x-ray case.

So you essentially do not see these when you take an x-ray pattern of the lattice. On the other hand, the neutron scattering amplitudes are very comparable, as you see, and one is in a position actually to go through a complete crystallographic determination of the hydrogen position; that has been done. The neutron people have looked at this material at high temperatures and at low temperatures, and the x-ray people have refined their measurements within the last year or so.

Levy and Peterson at Oak Ridge, Pepinsky and Frazer at Brookhaven, and Bacon at Harwell, have all directed the neutron technique to an understanding of this problem. What they have found is shown in Fig. 7. There, sure enough, is this hydrogen ordering at the lower temperatures. The hydrogens at the top part of this tetrahedron do move toward the central oxygen positions, and the fellows on the bottom move away. This was just what the Slater picture had proposed.

On the other hand, there were other interesting aspects; it may very well turn out that these other aspects are the important ones in the successful understanding of the problem. It was established that the phosphorous ions had moved downward from their high temperature positions. In contrast, the potassium ions shown in the figure had moved upward; the phosphorus moves down and the potassium moves up.

	X-RAYS	NEUTRONS
K	4.4	0.35
P	3.5	0.54
O	1.8	0.58
H	0.23	0.38

Fig. 6—Relative x-ray and neutron scattering amplitudes for some ions.

Fig. 7—Crystallographic structure of potassium dihydrogen phosphate at low temperature as seen by neutron and x-ray diffraction.

It appears now that this is the important thing relative to the production of the electric moment and not the actual repositioning or reshuffling of the hydrogen atoms. Before you could establish where the hydrogens were in the lattice, you were always suspicious that they were the fellows that were responsible for everything. Now that you have gotten hold of them, further experimental measurements have shown that the repositioning of the other ions is probably the more important contributing factor.

My second illustration concerns the electronic configuration in the uranium atoms. Figure 8 shows what I mean. In the atom, of course, there is a nucleus and then there are various electronic shells surrounding the nucleus. In the case of the transuranic elements—uranium and higher—it has been uncertain whether the outer electrons are falling into a 5f configuration or shell or into 6d shell. The chemical evidence has become increasingly in favor of a 5f type of configuration rather than a 6d. The thing about this problem is that the two shells differ materially in their effective or average radius. The 5f shell is the smaller radius shell than is the 6d.

There are associated with uranium atoms magnetic moments which are produced by the electrons within either the 5f or the 6d shell. Since the neutron has a magnetic moment, it is capable of interacting with these electronic moments; and furthermore, it is capable of permitting the determination of just what the average radius of this shell might be, because of the existence of magnetic form factors. This determines the angular distribution of the intensity of magnetic scattering of a neutron beam by such a magnetic moment, whether it is the 5f shell or the 6d shell. The two form factors differ materially with respect to the scattering angle of observation.

Some observations have become available recently, so that we are in position to determine or select a characteristic type of behavior. Figure 9 illustrates the data here. This is uranium deuteride, a substance which becomes ferromagnetic at low temperatures, a very interesting thing in itself. It is the only uranium compound I know of which shows actual ferromagnetic behavior. At low temperatures, down at 150 degrees absolute Kelvin, it becomes ferromagnetic. Here are neutron diffraction data expressed in intensity, neutrons per minute, as a function of the scattering angle—one pattern at low temperature, another at room temperature.

There are differences appearing in the two patterns. These differences are characteristic of the extra ferromagnetic scattering that sets in at low temperature. The difference exists at the (210) and (211) reflection positions. There are increases in intensity by factors of 3 or 4 in these reflections. From these absolute intensities, one can hope to determine or distinguish between the two alternative suggestions; namely, that the magnetic electrons are within either the 5f shell or the 6d shell.

Figure 10 shows this quantitative comparison of the observed absolute intensities in these reflections, and the calculated values for the two possibilities. If the configuration exists in the 6d orbit, we should have observed the absolute intensities calculated for this orbit, whereas if it is in a 5f orbit, the other set of intensities would have been observed.

You see that the intensities observed agree more favorably with the 5f than with the 6d calculations. There is a factor of 100 in the difference in intensity between the observed and the calculated values for the 6d configuration. These are just two examples of the sort of problems that one can tackle with the neutron diffraction technique. There are many others which I won't have time to discuss but which are apparent to you by analogy to the topics which I have mentioned.

DISCUSSION

QUESTION: You showed a 10^5 attenuation of neutrons between the surface from which you were taking them and the outer end of your beam hole tube. Of what diameter and what kind of a length of beam hole tube is this typical?

MR. SHULL: I think this was calculated using an opening at a distance of 16 to 18 feet, which is the characteristic distance between the center of the X-10 pile and the useful position outside the pile. It depends entirely upon the degree of collimation; for the usual collimation which is encountered, this is the factor of 10^5 . If the reactor is smaller and you can position

Fig. 8—Possible electronic structure existing in a uranium atom and its magnetic form factor implications.

Fig. 9—Neutron diffraction patterns taken for UD_3 at low and high temperatures.

ABSOLUTE INTENSITIES OF
UD₃ MAGNETIC REFLECTIONS

	(210)	(211)
Observed	.019	.016
Calculated		
6d orbit	.00018	.00027
5f orbit	.027	.013
	(10 ⁻²⁴ cm ² /U atom)	

Fig. 10—Comparison between observed and
calculated magnetic intensities for UD₃.

your apparatus closer to the central flux producing region, then for a given size opening the reduction factor is less. For the same collimation, for the same angular divergence in the beam, it would be the same, though.

QUESTION: If you have an MTR type of reactor where the flux is actually higher in the reflector region, isn't this still further to your advantage?

MR. SHULL: This is certainly further to your advantage. You should look at a scattering substance which is at the highest thermal flux position.

QUESTION: What kind of space would you recommend beyond the surface of your pile to accommodate the equipment that you use in this neutron diffraction? How many feet?

MR. SHULL: A minimum might be 8 or 9 feet, preferably about 15 feet, linear dimension out from the reactor shield. One needs side-wise space around the beam hole, side-wise extension of perhaps three feet on either side. An area of perhaps 6 feet wide and 12 feet long would be, in my opinion, rather good.

QUESTION: What is the chemical evidence for the 5f configuration?

MR. SHULL: The chemists, I think, are getting closer and closer to being more unanimous that it is a 5f configuration just because of chemical reasoning. The chemical properties of these materials follow the rare earth chemistry in which one is filling up the 4f shell so that by analogy there, this should follow. It hasn't been unanimous, however.

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**IV. ROUND TABLE DISCUSSION:
SOME RESEARCH REACTOR PROJECTS**

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PENNSYLVANIA STATE UNIVERSITY REACTOR PROJECT

by W. M. Breazeale*

Last summer Pennsylvania State University submitted a proposal to the Atomic Energy Commission covering the construction of a reactor research facility at the School's expense, provided the Commission would agree to allocate sufficient uranium to fuel the reactor.

Recently advice has been received from the General Manager that the required amount of uranium enriched to 90 per cent will be allocated if the school will follow "health, safety, and security measures" required by the Commission. The School is going ahead with the construction of the building and fabrication of the reactor. We expect that the electronic safety and control equipment will be purchased from some outside supplier and the rest of the reactor fabricated in the school shop. This latter work, the reactor fabrication, is about half completed now.

The design is similar to that of the bulk shielding facility here at Oak Ridge. This design has been well publicized in an article in "Nucleonics."[†] Mr. Gomberg of the University of Michigan, is going to give you some more details about it. If you take the tour tomorrow, you will see it in person. So I won't spend any time discussing the technical details of this particular reactor. Instead, I will go on to some more general comments.

Our school is proceeding with the fabrication of the reactor itself essentially because last summer we were not able to obtain it from commercial sources at what we considered a reasonable price. The only firm quotation received last summer for the reactor and controls alone was about as large as our entire budget for the reactor, pool, building, utilities, and landscaping. This was after the educational discount. A study of the particular proposal we received last summer revealed that it contained a very substantial sum for the development, and also that the design specified a number of components that appeared to us to be unnecessarily complicated and expensive.

We define a research reactor as one built solely to supply neutrons. Penn State is building its reactor for research and instructional purposes, and not for the purpose of any reactor development. The most important instructional use that we will seek will be the training of graduate students in techniques involving the use of neutrons. And as is normal, this will be in connection with their thesis work.

From investigations of techniques which we believe will attract the students' interest, it appears that a maximum neutron flux of the order of 10^{12} or 10^{13} neutrons/sq cm/sec. will be satisfactory for everything except perhaps a few radiation damage studies. With higher fluxes

*W. M. Breazeale is Professor of Electrical Engineering at Pennsylvania State University. He was intimately associated with the development of the Oak Ridge National Laboratory swimming pool reactor while a member of the staff there. Prior to going to Oak Ridge, he was professor of electrical engineering at the University of Virginia.

[†]Vol. 10, No. 11, Nov. 1952, pp. 56-60.

than this the samples frequently become so radioactive that the handling problem is quite difficult. Corresponding to fluxes of 10^{12} or 10^{13} , a reactor using enriched uranium operates at power levels between 100 kilowatts and 1 megawatt.

A research reactor designed for operation at power levels up to a megawatt really need not be a complicated device. Certainly it is not as complicated as a Van de Graaff generator operated at medium voltages. Everyone knows it is possible to purchase a medium voltage Van de Graaff for between \$60,000 and \$150,000. It seems to us that very shortly it should be possible to buy a reactor and controls of the type under discussion here, for essentially the same amount, exclusive, of course, of the uranium. If this is to be accomplished, it will take considerable intelligent cooperation on the part of the customer as well as the supplier.

Every research reactor today that I know about carries a heavy design charge, and I feel this charge should not be necessary much longer. The customer must be willing to accept standard parts and standard designs for items like the active lattice, control rods, operating mechanism, safety circuits, cooling equipment, and such things. When one buys a Van de Graaff—to get back to the Van de Graaff generator—from the High Voltage Engineering Corporation, for instance, he doesn't ask the manufacturer to start a complete design from scratch. He takes what the manufacturer has. I think the time is rapidly coming, if it isn't here now, when we should have the same condition as far as the supply of research reactors is concerned.

Someone will point out to me that the Van de Graaff manufacturers do not have to wrestle with an advisory committee on Van de Graaff safeguards; but even so, I do not think their advantage is so overpowering.

The supplier, too, must do his share. He should make an honest attempt to supply simple and inexpensive equipment. If gravity is adequate for the safety rod operation, then he should be satisfied with gravity and not try to sell the customer an expensive hydraulic system for this purpose, as one firm tried to do to us.

What about the future for the research reactor business? We would say that two steps still remain if these reactors are to make significant contribution to technical progress in this country. First we need more people trained in techniques of using neutrons. Schools like North Carolina State College, the University of Michigan, Penn State, and others are now preparing to do this. Secondly, as I have said before, industry must put itself in a position to supply small reactors, those up to perhaps a megawatt, at reasonable cost. Along with this, it would please us to see industry supplying the equipment to use the neutrons again at a reasonable cost.

To get back to the Penn State program: Besides graduate work, which includes such things as neutron diffraction work, solid state physics experiments, radioactivation analysis, and so forth, we expect that our undergraduate students in reactor physics and reactor engineering will carry out some experiments in reactor kinetics, determinations of flux distributions, and such. We will doubtless make some very short-life isotopes for relevant work and perhaps do radiations for some of the local industries.

One important part of our program will be an attempt to determine in what way neutrons are useful to the State's industries. However, we very definitely will not irradiate breakfast cereals to make them more crunchy or to add to their vitamin content.

To answer the question about approvals, as far as normal approvals for our proposal are concerned, the information we have from the Commission is essentially that which Dr. Johnson gave you this morning. Our schedule calls for completion of the building by the end of the summer; the installation of equipment by Christmas; completion of tests on the reactor itself some time next spring; and thereafter the opening of the facility to anyone on the staff of the University who wishes to perform an experiment and needs neutrons to do it. This, incidentally, allows us about the right amount of time for initial training of our staff and for the selection of new staff members.

THE UNIVERSITY OF UTAH REACTOR PROJECT. I

by Lyle B. Borst*

The University of Utah is a have-not university. It is not to be confused with one of these rich Eastern schools. Our objectives in building a reactor are to provide a general purpose facility for research throughout the university. We have designed a unit based on three criteria: minimum cost, maximum safety, and optimum flux.

Under the heading of minimum cost, we have an old barracks building which we feel will be adequate to house the reactor and at least to keep the rain out. We propose to use a water reflector around the soup vessel, which will be a modified Los Alamos water boiler, and will dispense with mechanical control devices. Our reflector control will be performed by means of a simple pump. We pump the water up; we dump the water to shut the reactor down.

We have been working with two industrial firms, the H. K. Ferguson Company and the Babcock & Wilcox Company, who have each submitted fixed price bids for the construction of the reactor, exclusive of instrumentation. These two bids are of less than \$100,000 each. A third company declined to bid, feeling that the cost would be too high.

The question of safety is one which any responsible person has to take extremely seriously. A university is not quite the same as the Oak Ridge National Laboratory or the Brookhaven National Laboratory, where one would have a \$100,000 operating budget. We must work with graduate students or with hired technicians. We propose to carefully regulate the rate at which the reflector can be added and construct the reactor so that we cannot exceed a certain Delta K or reactivity.

We propose to use hermetically sealed systems for the soup, for the reflector and for the water cooling system. The only open system will be the ventilation system, which will be connected to a stack. We propose to discharge from this stack radioargon at accepted tolerance levels or below. So we require no meteorological dilution.

Because of the local seismic situation, we will have seismograph control. We will probably have three seismographs spotted in three directions, which are the principal directions of faults, at distances of a mile to two miles in order to get intelligence to the reactor so that the dump valves which dump the reflector will be in the open position when the earth shock reaches the installation. For standby power we cannot rely on electrical power, of course; we propose to use hydraulic power, which is available at our reactor site from a reservoir up a canyon at a good deal higher elevation. The lines are not connected with the city water system and none

*Lyle B. Borst has been Professor of Physics at the University of Utah since 1951. Dr. Borst was one of the early physicists to work on the atomic energy program and was a member of the University of Chicago group which initiated the Metallurgical Laboratory project. He came to Oak Ridge in 1943, remaining until 1946, when he became director of Brookhaven National Laboratory's reactor project.

of them cross any of the known earthquake faults. So we have built as simple, as economical, and as safe a system as we can.

What can we get out of it? We hope to get a power level of about 100 KW, possibly higher, provided our early measurements run well, which presumably should give us a flux of something like $3 \text{ or } 4 \times 10^{12}$ neutrons per square centimeter.

THE UNIVERSITY OF UTAH REACTOR PROJECT. II

by B. A. Mong*

Dr. Borst has already given you the basic features of the water reflector controlled reactor. We have one figure showing the reactor and reflector vessel. From Fig. 1 we can get information as to the over-all size and construction features of the reactor.

The core consists of a cylindrical stainless steel vessel 12 inches in diameter and $\frac{1}{16}$ -in. thickness with a hemispherical bottom. Uranyl sulphate fuel solution in light water is located in the lower section of the container to a height of about 15 inches. The heat generated in the fuel solution by fission is removed by light water flowing through a series of stainless steel hairpin-shaped tubes $\frac{1}{4}$ inch in diameter and 40 mills or less in thickness. The portion of the tubes above the fuel solution is enlarged to $\frac{1}{2}$ inch in diameter, for the following reasons:

1. The primary condenser surface is increased for a given height.
2. The enlarged tubes act as a partial top reflector.
3. The enlarged tubes act as a quencher in case the level of the fuel solution should rise into this area.

The core is encased in an additional container 24 inches in diameter and $\frac{1}{16}$ inch in thickness, providing the space for a 6 inch thickness of light water reflector which is almost equivalent to an infinite water reflector. As Dr. Borst has mentioned, the raising and lowering of the reflector will be the primary means of control. Water is supplied to the reflector from a dump tank by means of a constant volume pump that can be set for any rate of delivery up to a maximum so as not to exceed predetermined minimum period for the reactor. Water is removed from the reflector by means of two automatic drain valves allowing the water to flow back to the dump tank.

Beneath the reflector container is a partial thermal column consisting of a three-foot cube of graphite blocks with one through, and two half-way experimental ports.

Surrounding the reflector container is a $\frac{1}{4}$ -inch air gap followed by a 3-inch thick steel thermal shield, outside of which is the concrete shield. The shield, which is hexagonal in shape, and not shown on the slide, will consist of a mixture of iron ore and concrete. Through the shield, at core level, are six experimental ports, two of which will extend through the reflector to the core.

A flow of helium will be introduced immediately above the fuel solution in the core container to dilute the dissociated oxygen and hydrogen, formed in the fuel solution by fission, to below explosive level. From this point, the mixture of gas and water vapor passes up through

*B. A. Mong directs nuclear design in the Structural Design Section, Atomic Energy Division, Babcock and Wilcox. He is a specialist in stress analysis and with D. K. Davies stress analyzed the Brookhaven National Laboratory reactor in 1949-50. He also was concerned with the analysis of MTR thermal plates under a consulting contract with Blaw-Knox. Mr. Mong attended the 1952-53 session of the Oak Ridge School of Reactor Technology.

Fig. 1 — Reactor and reflector vessel.

a series of baffles in the primary condenser to a demister or entrainment separator, then to a sealed gas pump, and to a catalytic recombiner where the oxygen and hydrogen are recombined to water vapor. At this point the gas and water vapor pass through a secondary condenser, to remove the heat of recombination, before returning to the reactor container. Attached to the closed gas circuit is a variable volume pressure regulator to maintain the pressure in the gas circuit to slightly below atmospheric; therefore, any leakage will be into the circuit rather than out to the surrounding atmosphere. In order to withdraw the gaseous fission products and to reduce the volume of gas in the circuit, at periodic intervals, the following off-gas system will be used:

1. The mixture of gas and water vapor will be drawn from the circuit.
2. Cooled to at least room temperature.
3. Passed through a platinized alumina dryer.
4. Passed through a charcoal bed which has been cooled to a very low temperature.
5. At this point, the gaseous fission products will be absorbed on the charcoal while the excess helium will pass through the bed and into the stack.
6. The charcoal bed is then heated, driving the fission product gases to disposable storage bottles.

In order to maintain the interior of the shield at a slightly negative pressure and to remove gamma heating, air is drawn from outside of the reactor building through a conduit in the shield, through the $\frac{1}{4}$ -inch annulus between the gamma shield and reflector container, and then to the stack. Since the volume of air in the vicinity of high neutron flux is less than a cubic foot, the activity at the stack should be negligible.

The reactor primary coolant circuit is also a closed loop. The primary cooling water passes, in succession, through the hairpin tubes in the reactor container, a finned air-water heat exchanger, a surge tank, a pump, a secondary condenser, and then back to the reactor cooling tubes. Heat is removed from the heat exchanger by means of blowers discharging the heat up the stack.

There are two additional safety features which have been incorporated in the design. One is a secondary shut down system consisting of a trip mechanism inserting boron shot through a small beam port at the top of the reactor directly to the core. The second is an automatic damper which will close in case of fire stopping the flow of air into the reactor. Since the room pressure will be lower than that within the reactor shield, the heat from the fire will not be drawn into the reactor.

VANDERBILT UNIVERSITY REACTOR PROJECT

by M. D. Peterson*

The proposed nuclear reactor at Vanderbilt University is really just an extension of the existing nuclear facilities there. Vanderbilt has rather well developed programs in the chemistry and physics departments, in electrical engineering, and in the medical school. The Thayer Veterans' Hospital in Nashville also has a large radioisotope research laboratory, under Dr. George Meneeley, and Meharry Hospital has Dr. Paul Hahn, one of the pioneers in nuclear medical work. The therapeutic use of radioisotopes in these and other hospitals in Nashville is extensive.

In connection with these programs, we are now using radioisotopes, x-ray machines, radiation from cobalt-60 and from used MTR fuel elements at Arco, and small Ra-Be neutron sources. We are obtaining a Cockcroft-Walton accelerator on which assembly will start this summer. The next stage we feel will be a nuclear reactor.

We can't afford much increase in staff for the purpose of designing or building or operating a nuclear reactor. To us it is a teaching and research tool like the other radiation sources. We therefore seek the simplest, safest, and most flexible and well-tested reactor we can buy, since so many people will want to use it for so many different types of work.

We have settled on a swimming pool type of reactor. It has many advantages for our purposes, especially since we shall have a large activity in chemical operations in which collimated beams are not necessary. We anticipate having a pretty good sized pool in which we can move the reactor to various stations for various types of operation, leaving equipment set-ups in place and moving the reactor over to another station for a different experiment.

We will have some simple beam holes in the pool wall and a removable membrane in the middle, so that either half of the pool can be drained and modified, for maximum flexibility.

We enjoy the cooperation of the W. F. and John Barnes Company in the mechanical design, and of the ORNL staff and alumni in discussing any changes that may seem appropriate in our attempt to make it as flexible and as inexpensive, and as nearly standard a unit as possible.

*M. D. Peterson is Professor and Head of the Department of Chemistry at Vanderbilt University. Before taking this post, he was Director of the Technical Division of Oak Ridge National Laboratory. He is a member of the Board of Directors of the Oak Ridge Institute of Nuclear Studies.

COLUMBIA UNIVERSITY REACTOR PROJECT

by Charles F. Bonilla*

I have been much impressed by the advanced state of the many reactor projects that have been described here. We can not claim as much tangible progress. On the other hand, our feelings on the subject of a university reactor may be of interest to the representatives of other universities in a position similar to ours.

We have not yet moved in the direction of procuring a reactor because no funds specifically designated for this purpose have so far become available. Today, private universities find it difficult to provide a fund of the necessary size from general income.

It happens that we have good nuclear research equipment in the Physics and Chemistry Departments, and are near Brookhaven National Laboratory. This decreases the pressure for a reactor from those departments. On the other hand, we have a large number of "Q" cleared faculty members—I estimate some 25 in the Engineering School—with interests in nuclear reactors. Thus, a reactor certainly would be more valuable to us than one of the other types of instruments described by Dr. Snell. Incidentally, we have so far decided against awarding a nuclear engineering degree, but a student of any engineering curriculum can obtain an M.S. or a doctorate with emphasis on nuclear engineering by selecting electives and a research problem in this field.

We first became actively interested in a reactor in 1950. At that time we visited the swimming pool reactor in Oak Ridge and subsequently the General Electric thermal test reactor; and we followed the North Carolina releases with interest. We felt that our needs fell mainly in three categories: (a) pedagogical, which would probably include New York City groups as well as our own students—visibility, versatility, and variability would be desirable; (b) reasonably high fluxes, so that radiation tests would not take too long; (c) enough space to house reasonable-sized test assemblies.

Beam production in the reactor did not seem to be as much in demand because of the other equipment at the university. Thus we made a preliminary tentative selection of the swimming pool type. However, we will not freeze on details, nor even definitely on the type of reactor until funds become available. We also haven't decided whether the reactor should be the main responsibility of a specialized faculty member with assistants, or should be supervised by a staff committee and an operator; whether the engineering should be turned over to an industrial concern, and other such policy matters. However, we have reached several conclusions.

*Charles F. Bonilla is Professor of Chemical Engineering at Columbia University and a consultant to many industrial and government research laboratories. Prior to joining the Columbia staff in 1948, Dr. Bonilla was professor of chemical engineering and head of the department at Johns Hopkins University. He has taken part in industrial and technical missions to other nations.

(a) Nuclear power will soon be an important employer of engineers. This was first indicated clearly, we feel, by the publication of the estimate which put the known fissile fuel reserves at over 20 times the known fossil fuel reserves, on a heat basis. Against this, however, we have noted in the last year or so a fall-off in student interest in nuclear courses. This may be due to an approaching saturation of the need by graduated engineers working in New York.

(b) A reactor is definitely too expensive and represents too much hard work and faculty time to be sought merely for advertising purposes.

(c) The main interest of engineers should be in power (rather than research) reactor design, development, and operation.

(d) Before selecting a reactor type and design, one should obtain in advance the full characteristics of each possible type of reactor; a vote of interested staff members should probably be taken.

We made an effort in the last direction by listing 20 key experiments and 8 research fields that we felt a swimming pool reactor could handle. This list was passed out to several people interested in other types of reactors, for comparison. Their replies, or lack of replies, bolstered our preliminary conclusion that the swimming pool type fitted our needs best.

Our final selection of reactor type will probably be made from as precise an evaluation as possible, based on the information then available, of the following considerations for each type and size:

(a) What experiments can be carried out to show reactor operational characteristics, and how conveniently and accurately?

(b) What types of research experiments of importance can be carried out in reactors (such as cross sections, radiation damage, and shielding), and how conveniently and accurately?

(c) How is the type suited for instruction in the development, design, and operation of specific reactors suitable for power production?

THE UNIVERSITY OF CALIFORNIA REACTOR PROJECT

by M. A. Greenfield*

Unlike poor Dr. Diddle, who seems to be taking quite a beating today, we at UCLA think we know why we want to have a reactor. I would like to say that I am representing just the Medical Center of the University, which is part of a major university campus. Our interest in reactors arose initially from the expectation that they would be useful tools in connection with experimental investigations of cancer by way of neutron capture therapy by isotopes differentially located in lesions rather than in healthy tissue. The interest in this particular possibility of attack on an important problem was stimulated by the early work by Kruger of Illinois back in 1940, by Zahl and others at Columbia, more recently by the work of Farr and his co-workers at Brookhaven, and by Sweet and others at Massachusetts General Hospital.

As a result of this interest, we began several years ago to work on the design of what you might call a medical reactor with a research program that would be an integral part of the Radiology Department at the Medical Center. For reasons of safety, economy, and the nature of the uses contemplated, a graphite moderated solution type of reactor—in other words, a water boiler—is now being studied.

In addition to the use already mentioned, the reactor should be operated for radiobiological research and for the production of short-lived radioisotopes not now available on the West Coast. It is hoped that there also would be additional facilities such as removable stringers, a glory hole, and a pneumatic tube to accommodate the needs of other campus departments such as chemistry, biology, physics, agriculture, and so forth, all of whom, I might add, have indicated a desire to use such a facility.

A novel feature of this reactor would be the extensive use of external beams of neutrons and gamma rays. This poses a special problem for the design of the reactor and its radiation facilities, as well as for the building in which the reactor is located. Special attention is being given to the design of a thermal neutron beam that will have very little gamma ray or fast neutron contamination present. This is an important requirement in connection with the use of such a beam by a therapy team. Prior to the use of the reactor as a therapy agent for humans, there will have to be an extensive animal research program, as well as the development of suitable instrumentation for measuring radiation dosages in tissue. All of this is still in the planning stage, but we have high hopes for the future. We hope that other reactor groups will interest themselves to whatever extent possible in some of these very difficult medical research problems.

*M. A. Greenfield is Associate Professor and Radiation Physicist, Department of Radiology, School of Medicine, University of California at Los Angeles. Before taking his present post in 1948, Dr. Greenfield was a research physicist with the Atomic Energy Research Department at North American Aviation, Inc. During the war years he was a research physicist with the Bureau of Ships.

U. S. NAVAL RESEARCH LABORATORY REACTOR PROJECT

by T. A. Bergstralh*

For some time the Naval Research Laboratory has been considering the addition of a reactor to its research facilities in nuclear physics. In this consideration, the research program as it has developed in its proposal stage has cut across practically the program of the entire laboratory in the same manner that has been indicated by other speakers. Interest developed, of course, in the chemistry division, in solid state work; and actually, at the present time, six of the twelve divisions of the laboratory are interested in the development of such a facility.

We have therefore carried forward our studies to the point of having a nearly completed design which we are prepared to put into the construction stage soon. Our requirements have led us to the choice of the swimming pool type reactor; and with the help of a few figures I will attempt to describe our version of that reactor as it seems to meet the needs of the program at the Naval Research Laboratory.

Figure 1 gives an artist's concept of the proposed installation at the Naval Research Laboratory; the reactor is expected to be put into an existing building—actually in a wing of a large warehouse building. This wing is 200 feet in length and 60 feet in width, and permits a large traveling crane to be operated down the entire length of the wing. The swimming pool is above ground; it is 26 feet wide and 40 feet long. The core is suspended, as in the Oak Ridge bulk shielding facility, from a moveable bridge and can be moved and operated along the central line of the pool. It will be operated at a depth of about 16 feet of water and at a power level of about 100 kilowatts.

At one end of the pool is a solid shield with beam ports, a thermal column, and exposure port facilities which we can see in greater detail in one of the other figures. The entire facility as contemplated includes control from a remote position where the control operator can view operations at the floor or beam floor level and at the working level for the pool.

In addition to that, other rooms and facilities properly ventilated and air conditioned will be provided for the control of experiments which are going on, or for the preparation of other experiments.

Figure 2 is a drawing of just the reactor itself, and again the pool is shown in this portion of the figure. From a so-called instrument bridge one conception of an instrument is suspended with which it would then be possible to traverse the pool, of course, in the other direction to make measurements behind large shielding mock-ups or other large experimental installations.

* T. A. Bergstralh is Head of the Reactors Branch, Radiation Division, Naval Research Laboratory. He has been associated with the nuclear weapons research program of the Laboratory since 1950, and prior to that time was for four years on the staff of the Rocket Sonde Research Branch of NRL, engaged primarily on cosmic ray studies. He was an electronic officer in the Navy during the war, leaving a teaching post at the University of Minnesota for service.

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Fig. 1—Proposed NRL reactor installation.

Fig. 2 — Reactor, pool and hot laboratory.

Fig. 3 — Core, reflector, and main shield.

Fig. 4—Main shield details.

The forward end or main shield of the reactor is somewhat hidden here by the balconies from which extend the working levels that permit us to work over the reactor core in its main shield position.

At the other end of the pool we have a so-called "hot laboratory," through which access can be obtained from the working floor or from the pool through some water hatches. So, in addition to providing a research facility for the reactor itself, we have in the same unit a provision for handling highly radioactive materials, not necessarily derived from the reactor but which may be part of the program.

Figure 3 is a drawing of the main shield and the core, a standard swimming pool core, with controls and counters in position. Immediately surrounding the core in position on three sides is graphite about one foot thick. We have then a lead gamma ray shield, and the usual varieties of concrete in the amount of $5\frac{1}{2}$ feet beyond the lead. In that shield extending in four directions are exposure tubes, beam ports as we call them. They will be fitted with concentric plugs so that beam ports of various sizes can be opened.

One of the beam ports is at the present time designed as rectangular to permit the opening of a fairly large cavity in close to the core, in addition to which in one direction is the thermal column consisting of the graphite blocks as described in earlier talks. This also will be capable of having a fairly large cavity opened into it for various types of experimentation.

The core then can be moved either into or out of this position, depending upon the particular experiments underway. As Dr. Gomberg just pointed out, one of the advantages we have seen in this is the ability to move the core away in order to work on the beam ports without worrying about the residual gamma ray radiation.

Figure 4 is a cross-section of the main shield which is the primary deviation from the bulk shielding facility at this point, and brings out the four beam ports in four directions; the thermal column is in the forward direction, and one of the beam ports is designed to be quite large. The peculiar structure here is due to a combination of concrete and lead in order to keep the shielding the equivalent of the 13 feet of water at the juncture point where we bring the pool down to the small shield. That is done because the type of concrete and shield have of course been chosen to keep the beam ports as short as possible and to enhance the fluxes at the beam port exit.

On the first floor of the reactor facility, we have in one direction a rather long path, about 100 feet, for time of flight measurements or other measurements. This leads directly off the thermal column portion of the main shield.

In this particular set-up we are proposing to control access to the building by asking all visitors to come in from one end and then permit access out on the floor where the beam ports are to be controlled by the operator, who will have a full view of that floor. This is for safety considerations, of course.

Since the tank itself is over 20 feet high, there are obviously possibilities for a two-floor level facility in this installation.

That describes very briefly the contemplated facility at the Naval Research Laboratory and is another example of the installation of the swimming pool reactor. The power is contemplated to be 100 kilowatts.

WRIGHT-PATTERSON AIR FORCE BASE REACTOR PROJECT

by P. J. Sykes, Jr.*

One of the advantages of speaking toward the end of this program is that additional figures are unnecessary with the paper, since those used earlier by H. J. Gomberg have covered the almost identical schematic concepts that we have had in mind to meet requirements for Air Force engineering test purposes.

As you may know, the Air Force sponsors most of its required research and development; that is, it goes "outside" to obtain most of this work on a contract basis. However, there is a volume of urgent development and test work in nuclear engineering which is rapidly increasing. It is therefore entirely possible that at some Air Force installations in the not-too-distant future, if it is found feasible cost-wise and if other policy considerations permit, appropriate nuclear reactor facilities may be built to undertake some of this work internally.

Our thinking along the engineering test reactor line to date has centered around the pool-type reactor. For a number of reasons we feel this type to be the most suitable for our purposes. We feel that it is simpler to handle this system because of its solid fuel elements. There is then not as much of a problem of gas effluents, and no delicate handling of highly radioactive fuel liquids is involved. The water shield feature, in particular, appeals to us as it has to the Naval Research Laboratory, because it enables one to undertake bulk shielding studies quite effectively.

The major technical areas of interest to the Air Force at this time which require the use of a nuclear engineering test reactor may be grouped in seven categories.

First of all, there is a growing need for radiation damage testing, that is, for investigating the effects of nuclear radiation—gamma and fast neutron—on materials, components and systems employed in and with nuclear propulsion systems, nuclear powered aircraft, nuclear powered missiles. Reactor facilities are necessary for the determination of radiation-induced changes in electrical and thermal conductivity, heat capacity, viscosity, material strength, corrosion phenomena, and other general chemical and physical properties of materials. Over past decades, millions of dollars of your government's money have been spent to determine properties of materials for aircraft use. We must face the possibility in the near future—in fact most of us believe it to be a really strong probability—that these materials will have to withstand a new environment in the form of high intensity gamma and neutron radiations. Therefore

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our interests are increasing in the direction of determining what we of the Air Force can expect materials to stand in this respect, and how much we can depend on them under these new conditions.

The second area is closely related to the first. It concerns materials development: determination and selection of the materials best suited to various specific applications in nuclear engineering and in nuclear-powered aircraft and/or missiles.

Third, there is the basic area of nuclear properties of matter: accurate measurement of neutron absorption and scattering cross-sections, neutron capture-induced gamma-ray spectra and radiation-attenuative properties of many elements, compounds and alloys for which these values are not yet known with sufficient precision to allow effective structural and shielding design, engineering and improvement. A small amount of this type of work is being done at present, utilizing Van de Graaff generator equipment, at Wright Air Development Center. Such basic studies also attract the interest of competent scientific personnel and attract them to Air Force employment—personnel to whom we can readily turn for consultant and developmental work on engineering applications of nuclear physics.

Aircraft shield design and engineering is the fourth category of major interest. It is necessary to determine experimentally such matters as optimum material composition, component geometry, structure and duct design, etc., which yield minimum-weight and highest performance aircraft reactor and crew shields for various possible reactor and engine configurations.

Fifth, we list reactor instrumentation and control development, a field in which much work needs to be done—experimental engineering tests and development studies for nuclear detection, instrumentation and control components, and systems for use with airborne power reactors and engines.

Sixth, radioisotope applications in general are facilitated and stimulated by use of a reactor for radioisotope production, particularly for those of such short half-lives as to be otherwise unobtainable. Planned uses of such radioisotopes include their employment as sources and tracers in autoradiography, non-destructive testing, quality control and physical-chemical process studies of corrosion, diffusion, fluid flow, and so forth. L. D. P. King of Los Alamos Scientific Laboratory mentioned radioactivation analysis, a method of measuring extremely small chemical concentrations down to the part-per-billion range. This is a new and powerful analytical technique, possible only with a reactor of significant flux.

Finally, and perhaps most important of all, a reactor will provide for professional development, on-the-job training at the development center, in order to equip technical personnel for assignments in the nuclear engineering program as it unfolds, or to more fully utilize existing skills and knowledge of our experienced personnel by extension of their activities and competence in the new and growing nuclear engineering field.

As yet, no final program has been formally approved. Our activity to date has been largely confined to planning and to preparation—preparation for the day which is coming when research reactors will be quite common and considered as a standard item of development and test equipment, and no more out of the ordinary than a Van de Graaff generator or a spectroscopy or an induction furnace.

SOME EUROPEAN REACTOR PROJECTS

by Alvin M. Weinberg*

To a visitor from the U. S. atomic energy project a visit to the European atomic energy centers is a little like moving backward to the early years of the Metallurgical Project before a chain reaction had been achieved and before the fervor of those early days had died down. For the most striking characteristic of the European effort, noted independently by several of the nine U. S. delegates to the Oslo Heavy Water Reactor Conference, is its enthusiasm. There is a kind of contagious enthusiasm exemplified, say, by Dr. Gunnar Randers, Scientific Director of JENER and organizer of the conference, which I sensed in much of the conversation about exponential experiments, about heavy water, about uranium fuel elements at the Engineers Club in Oslo where the conference was held.

The enthusiasm stems not only from the novelty of nuclear energy in Europe; it stems from the fact that nuclear energy is a more urgent economic possibility in Europe than it is here. Over and over in my conversations with nuclear people from Europe, Asia, and South America I was told how fossil fuel reserves are dwindling. In Belgium, for example, coal at the pit head is several times as expensive as it is in our country; in England the seams are running thin; in Switzerland there is a negligible amount of coal; and so it goes. The U. S. view—that nuclear power has a hard road ahead before it becomes economical—is somehow considered a little irrelevant in Europe, since in some cases nuclear energy is assumed to be the only available energy source in not so many years.

The technical direction of the European enterprises is rather uniquely determined by the non-existence of facilities for enriching uranium and by the preoccupation with power rather than with weapons. The problem is simply to extract useful power as cheaply as possible from natural uranium; for nuclear reasons this makes heavy water a practically unique choice for moderator. The European effort has nothing like the bewildering number of possibilities that make it so hard to determine a proper approach here in the United States. A power reactor designer in Europe doesn't have to worry about heterogeneous or homogeneous; fast, intermediate, or slow; graphite, beryllium, D_2O , or H_2O ; U^{235} or Pu; or any of the other combinations which are available to us because of our tremendous nuclear production facilities. His way lies along the development of heavy water, heterogeneous reactors with natural uranium for fuel.

The Oslo conference was concerned primarily with what can be done using only heavy water and natural uranium. The power producing possibilities along this line already have been

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described in the open literature by the Commonwealth Edison-Public Service industrial power study group; several of us Americans were embarrassed by the obvious fact that the Europeans seemed to be much more familiar with this report, not to mention American declassified literature generally, than we were.

Throughout the conference there was much discussion, and good-natured grumbling, about the cost of heavy water. Several of the countries, notably West Germany, have begun studies aimed at producing heavy water more cheaply than the \$90 per pound at which it is now being sold by Norway. I think it entirely likely that as the years go by heavy water will be established as a fairly important article of international commerce.

Of course we Americans, as well as our British and Canadian colleagues, were in the somewhat awkward position of often knowing more than we were allowed to say. The U. S. Atomic Energy Commission had declassified performance information on the Materials Testing Reactor, a film about the Homogeneous Reactor Experiment, and data on the new Argonne research reactor especially for presentation at the Oslo meeting. As a result, the American delegation contributed at least as much to the general discussion, even within security limitations, as any other group. This apparently left little impression on a columnist for the Paris Communist newspaper *L'Humanite* who wrote: "The Americans at the conference took everything in and gave nothing in return."

At the conference there were representatives from 19 different European, Asian, and American countries. There were no participants from the U.S.S.R. or its satellites. Among the most interesting were the four Yugoslav delegates, Drs. Dedijer, Peterlin, Popovic, and Ristich, who were very friendly and were surprisingly familiar with the declassified literature. Dr. Dedijer, a Princeton graduate whose brother is described as the Harry Hopkins of Yugoslavia, told me an atomic energy research laboratory has been established near Belgrade. It is being used not only for nuclear energy research but also as a general national laboratory for Yugoslavia—a sort of focal point for the scientific enlightenment of the entire country. From people at the conference who had visited the establishment I got the impression that nothing was being spared to make the laboratory as excellent as Yugoslavia could afford.

Dr. K. Wirtz was the only delegate from West Germany. He told us that plans are being made there to design a 1500 kw isotope-producing and research graphite-moderated, natural uranium reactor very much like the one at Oak Ridge. They hope to be able to construct such a reactor when they receive permission to go ahead from the occupying authorities.

I was struck by the presence at the conference of delegates from such countries as Israel, Spain, and Italy, none of which I imagine could, at least at present, afford a major nuclear energy research effort. On asking one of the Israelis about this, he said that his country's attitude is one of wait and see; that if a practical nuclear power plant should be developed they would like to be in a position to exploit the development. I suppose to some degree this thinking underlies much of the planning on the part of all the European countries with respect to the United States. They hope to take advantage of American developments once they are declassified.

The conference lasted only three days—fortunately for us Americans who were not quite up to the rigor of nightly Norwegian banquets. It ended with a plea by Odd Dahl of the Norwegian project for the Europeans to merge their separate resources in carrying out at least some of the terrible expensive heavy nuclear technological research; and with a suggestion by Dr. Randers for the organization of an international society for nuclear technology somewhat along the lines of the International Union of Pure and Applied Sciences. The first suggestion was conceded generally to be a sensible one, but in view of the many political differences, it seemed unlikely that very much would come of it immediately. No dissent was heard on the proposal for a union, and the delegates were asked to maintain liaison with Dr. Randers who agreed to act as organizer. In both discussions the Americans, British, and Canadians, who I suppose felt a little like outsiders, maintained for the most part a discreet silence.

After the Oslo conference ended I visited the atomic energy establishments in Sweden, Belgium, Switzerland, France, and England. Everywhere I went I was received with utmost hospitality, and while I spent no more than two days at any one establishment, what I found was certainly impressive.

NORWAY AND HOLLAND

My first visit was to the Joint Norwegian-Dutch Nuclear Energy Research Establishment (JENER) which is located at an old German airbase about 20 miles from Oslo. The reactor, a 200 kw heavy water-moderated and cooled machine much like the Argonne CP-3, has been running satisfactorily for over a year; and the Laboratory, which in many ways reminded me of the wartime Argonne Laboratory in Palos Park in Chicago, is doing work in neutron diffraction, neutron spectroscopy, and general reactor physics. The Laboratory has visiting investigators from several other European countries, as well as from the U.S. A. W. MacReynolds of Brookhaven is doing unclassified work there.

The Norwegians are planning to build a 25,000 kilowatt high-pressure, heavy water, power-producing reactor. As described by Dahl, the reactor is to be contained in a spherical pressure vessel and will operate at sufficient temperature to produce about 5 mw of electricity. The time schedule for this reactor is somewhat indefinite.

SWEDEN

The Swedish establishment is in northwest Stockholm on the campus of the Royal Institute of Technology. A 250 kw heavy water reactor, situated at the bottom of a 90-foot shaft sunk in solid granite, is expected to go critical for the first time about June 1954. The workmanship on the reactor seemed to me superb; this is not surprising for even casual visitors to Sweden are inevitably impressed with the expertness shown in everyday devices, such as bathroom fixtures or hotel elevators. The Swedes seemed to take the matter of putting the reactor at the bottom of an artificial cave very much in stride since a fair share of their important industry is already underground.

The Swedes, like everyone else in Europe, are vigorously developing their indigenous uranium raw materials. They are working particularly hard on devising schemes for extracting uranium from the low-grade Swedish shales.

SWITZERLAND

I was not surprised to find that Switzerland, with its well developed conventional heavy equipment industry, is pursuing nuclear power very seriously. The proposed Swiss heavy water reactor, which Professor Paul Scherrer, head of the Swiss group, announced in Oslo had just been approved, is the most advanced type now under way in Continental Europe. It is much like the Canadian NRX reactor except that the coolant is heavy instead of light water. An essential part of the reactor is to be space for performing material and component engineering testing in the power production range of temperatures. It was my impression that in Switzerland, perhaps more than in the other countries, the atomic energy work is very much a partnership between government and those heavy power equipment manufacturers who would ultimately be expected to take over the industry. Thus, the chief engineer on the Swiss project, Dr. Lalive, is from Brown-Boveri, the Swiss power equipment firm.

BELGIUM

As the source of a sizable portion of the free world's uranium supply, Belgium has received special technical assistance from the U. S. and the U. K. in the field of atomic energy. Presumably this special relationship will continue, and even grow, in the future. For example, a group of ten Belgian scientists spent several months at Argonne in 1952 studying certain declassified aspects of reactor design and operation. I therefore already had some familiarity with the Belgian plans when I visited Brussels.

The Belgians are actively planning a 2000 kw graphite-natural uranium reactor, again much like the Oak Ridge graphite or the British BEPO reactor. They have the necessary resources, and their people are individually of the highest technical excellence; I was told,

however, that the number of physical scientists in Belgium is so small that staffing of the atomic energy project might prove to be difficult. Of course this observation applies to most of the other small countries which I visited.

FRANCE

Of the continental western countries, France of course has the most highly organized and elaborate nuclear energy setup. There are two laboratories; the old one at Fort Chatillón on the rim of Paris, and a magnificent brand new one at Saclay, about 20 miles from Paris. There are two reactors in France—a low-power heavy water machine at Chatillón which has recently been modified to operate at about 125 kw; and, at Saclay, a much more ambitious nitrogen-cooled, heavy water-moderated reactor which is designed to operate at 1000 kw. The Saclay reactor is a daring engineering feat; it seeks to solve the formidable problem of recirculating N_2 at moderately high pressure in a system which, because of the slight radioactivity in the N_2 , must be essentially leakproof. The reactor ran successfully for a short time early this year; it is now undergoing some modifications in order to eliminate excessive vibration which occurred during the shakedown run, and it is expected to be back in operation soon. I was particularly impressed with the fact that everything in the reactor and circulating machinery, except the heavy water, is made in France.

The French project is now led by Francis Perrin, a well-known theoretical physicist. On all sides I was told what a remarkable job Professor Perrin has done. Certainly the management of the French project is extremely capable and dedicated, and I would expect their efforts to be very successful.

ENGLAND

A good deal has already been written in the United States about the British project, including an article by H. W. B. Skinner in the June 1953 issue of *The Bulletin of the Atomic Scientists*. The Harwell establishment is in many ways suggestive of the Oak Ridge or Argonne National Laboratory. However, since in Britain the production division has its own engineering laboratories, Harwell is not usually called on to carry pilot planting or engineering design as far as the U. S. laboratories often do. Incidentally, Harwell is the only nuclear energy laboratory I have seen anywhere which has a fully licensed bar. This I learned is a holdover of the days when the old Harwell air base included an RAF officers club.

The British reactor program is concerned mainly with the large CO_2 -cooled plutonium plus power reactor now being constructed under the general direction of Sir Christopher Hinton. This reactor will produce about 50 mw of electricity. As far as I could tell there is little concern about whether the electricity would be produced economically, or even whether the high-pressure gas cooling represents a valid long-term developmental direction. In both these respects the British attitude toward their first power producer is much like the U. S. attitude toward our newly announced nuclear electricity plant.

The British possess plutonium, and they have a uranium enriching diffusion plant. Consequently the possible development directions which are available to them are practically as varied as those which are available to us. Thus, the British are planning to investigate fast breeders; they have already done extensive work in liquid sodium technology, and they hope to build an advanced research reactor, possibly like the new Argonne research reactor or like the Oak Ridge LITR. And in Britain, as much as anywhere, there seems to me to be a sense of urgency about nuclear power development which originates from the widely held belief that England is in real danger of running out of coal.

To an outsider, and an American, the European effort in atomic energy is impressive for its intelligence and its purposefulness. Of course I believe, on the heavy technological level, it would progress much more rapidly if, as Odd Dahl suggested, the separate small enterprises could be merged into a much larger one. In particular, as was discussed by some of the representatives at the Oslo conference, technological flexibility would be gained if the European countries could jointly subsidize a small diffusion plant.

Of the lessons which I learned during my visit, perhaps the most important was learned at the banquet given for the visitors by the Christian Michelsens Institute in Oslo. After dinner the toasting began in traditional Norwegian fashion. At one point Dr. Randers got up and, in the course of his toast, expressed the tremendous astonishment with which the Europeans had received our report that the MTR neutron flux is in the 10^{14} range as compared with the 10^{12} flux levels that the European reactors have reached. And he asked, somewhat wistfully, how the much smaller and much poorer European countries could expect to compete with the United States in nuclear energy development.

I tried to answer Dr. Randers' gracious words, on behalf of our country, with what I think is the essential lesson which our American atomic energy effort can learn from the experience of our European compatriots; namely, that, to coin a phrase, money isn't everything; that while we have more money in total, and more money per scientist, we seem to have, perhaps because of this, less time to think, to plan, to consider than do our European colleagues. Wherever I went in the European nuclear energy laboratories I could not help being struck with the thoroughness, the scholarship, and the understanding with which the technical problems are being attacked. This scholarliness has already borne fruit in certain basic areas, such as the Swedish work on kinetics of neutron moderation, or some of the English work on neutron spectrometry, where I had to admit the Europeans excel us. So I suppose that what we can learn more than anything from European nuclear energy is just this quiet, scholarly, thorough approach toward big technology which certainly will bear fruit in future European developmental successes and which we ought to cultivate in order to temper our own tendency toward technological flamboyance.

V. SOME INDUSTRIAL PLANS FOR RESEARCH REACTORS

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REACTORS FOR GENERAL RESEARCH USE

by Harry Pearlman*

North American Aviation has had a program of reactor technology since February, 1946. Our interest in research reactors dates from December, 1948, when we were asked by the Research Division of the AEC to undertake a study and development program on a reactor designed for general research use. At that time, there were no reactors except at the National Laboratories; and we were concerned, at first, with making them a little more accessible.

For that reason, perhaps, one of our principal aims in undertaking the research reactor study was to provide safety. The reactor was to be so safe—both by its inherent nuclear characteristics and by the arrangement of the mechanical control—that it could be constructed in populated areas in any city, preferably located close to universities or research institutes, so that it would be conveniently accessible to research personnel.

In the summary report which we issued more than four years ago, we considered designs which were based on a variety of core configurations: the heterogeneous metal core, water cooled and moderated; the homogeneous, solution-type core, or water boiler; and a homogeneous solid core.

On the safety criterion alone, we concluded that the solid homogeneous core reactor possessed certain advantages. However, with the advances in reactor art which have occurred in the intervening years, it has become clear that reactors utilizing any of these configurations that I have mentioned are comparatively safe. Or perhaps we should say they are safe enough.

Furthermore, it develops that the particular kinds of reactor which you can build around these different cores have advantages which are uniquely suitable for certain different ranges of applications in research. For the requirements of our own program at North American Aviation, we have found that a low power water boiler type is extremely useful. Of course all water boilers are based on the developments at Los Alamos. It is a pleasure to record here our appreciation to the Los Alamos Scientific Laboratory, and especially to Dr. King, for their pioneering contributions to reactor development.

However, our reactor contains certain simplifications which may be evidenced from Fig. 1. This figure shows the reactor as it is installed in our laboratory, inside a former airframe assembly plant in Downey, California. The reactor went critical in April, 1952, and it has been in steady operation ever since. One wall of the two-foot thick concrete blocks is removed here, to show a structure consisting of two tanks. The top tank contains an ex-

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Fig. 1—Over-all view of North American reactor.

ponential experiment, which is discussed later. The reactor proper is housed in the lower tank, which is six feet high and five feet in diameter.

This tank contains graphite which is packed around the central, one-foot diameter core tank. In this reactor the fuel solution consists of uranyl nitrate in ordinary distilled water. The gas handling system is contained in another stainless steel tank. Figure 1 also shows part of the filling system for the fuel, and two of the boron trifluoride ionization chambers, which are part of the power instrumentation system.

Figure 2 shows the reactor schematically. The following components are evident: the atmosphere handling system; the control and safety rod assembly; the core and the fuel loading system; the instrumentation; and the reactor tank, packed with graphite.

Passing right through the sphere, in the same manner as in the SUPO reactor which Dr. King has described, is a central exposure tube. Not shown are eight removable graphite stringers, approximately $4" \times 4"$ in section, which are roughly tangential to the sphere. These comprise the exposure facilities for this little reactor, along with the top of the tank, which is the top of a graphite thermal column.

Figure 3 presents more detail on the gas handling system. This is a closed system. Because of the powers at which we operate in Downey, the volume of radiolytic gas produced is not very great. During reactor operation, gas collects on one side of a neoprene bag which divides the stainless steel tank into two volumes. When we have collected enough decomposed water and gaseous fission products to be of interest for some reason or other, we apply helium pressure on the bag and collect the products in a tank.

At a maximum power of two watts, a maximum flux of 8×10^7 neutrons per square centimeter per second is available. This is a very low flux. However, it is adequate for a very broad variety of experiments which touch upon the interests of a large number of university departments.

For example, this flux is adequate to make radioisotopes at tracer levels in a number of elements. You have to pick those in which the cross-sections are right, of course.

Figure 4 shows the production of a tracer quantity of Iridium-192, which was performed as a rush job for the chemistry department of a local university. The calculations which we made indicated that with metallic iridium—we started with a sample of about a gram containing 39 per cent iridium-191 and 61 per cent iridium-193—and with an estimated flux of approximately 5×10^7 , we could expect a saturation activity of a little more than one millicurie per gram of iridium.

It turns out that the smallest activity which the radiochemists thought they could count with any accuracy was 0.01 millicuries per gram of iridium. After we had satisfied ourselves that we did not have to worry about the iridium-194 contaminant for reasons of its short half-life and relatively smaller cross-sections, we estimated that if we exposed for one day, we could wind up with this minimum activity. Actually, we exposed for 26 hours, at a flux of 7.5×10^7 , and the measured activity which was reported back to us turned out to be exactly 0.01 millicuries per gram of iridium. That is a fortuitous agreement.

Figure 5 shows another application of the reactor which may eventually become of interest to departments of physics or departments of nuclear engineering. The reactor provides a beam of neutrons of about 10^6 per square centimeter-second, which are well thermalized, and which we use as a source for driving exponential experiments. We have a quantity of D_2O in the upper tank (to which I referred before), and we suspend uranium rods in the D_2O in accordance with a predetermined pattern.

By suitable placement of indium foils, and by measuring the activity induced in them, we can measure the distribution of neutrons in the tank. In this way, we obtain information useful for particular lattice configurations, and we also obtain a check on the general theory.

Figure 6 shows a more powerful version of the reactor, which was constructed at another laboratory by North American Aviation. It operates at 2000 watts; a cooling system and a gas-handling system must be provided. The functions of the gas-handling system are to contain the gas; to combine catalytically the hydrogen and oxygen and return the water to the core; to maintain automatically pre-determined pressure, which is set to be a little bit below atmospheric; and to provide an arrangement whereby fission product activities in the gas phase may be removed at will.

Fig. 2—Schematic diagram of the reactor.

Fig. 3—Gas handling system of reactor.

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Normal Ir contains 39% Ir¹⁹¹ and 61% Ir¹⁹³

$$\sigma_{\text{Ir}^{191}} = 7 \times 10^{-22} \text{ cm}^2; \sigma_{\text{Ir}^{193}} = 1.2 \times 10^{-22} \text{ cm}^2; \bar{n}\bar{v}_{\text{WBNS}} \simeq 5 \times 10^7 \text{ cm}^{-2} \text{ sec}^{-1} \text{ (at } \sim 2 \text{ watts)}$$

$$(t_{1/2})_{\text{Ir}^{192}} = 75 \text{ days}; (t_{1/2})_{\text{Ir}^{194}} = 19 \text{ hours}$$

$$(A_{\infty})_{\text{Ir}^{192}} = \frac{1}{3.7 \times 10^{10}} \left[\bar{n}\bar{v}_{\text{WBNS}} (\text{cm}^{-2} \text{ sec}^{-1}) \times \sigma_{\text{Ir}^{191}} (\text{cm}^2) \times N_{\text{Ir}^{191}} (\text{gm}^{-1}) \right]$$

$$A_{\infty} = 1.1 \text{ mc/gm Ir}$$

For exposure time $T \leq 0.2 (t_{1/2})_{\text{Ir}^{192}}$, or $T \leq 15 \text{ days}$

$$A \simeq \frac{0.69}{75} A_{\infty} T \text{ mc/gm Ir (T in days)}$$

If $T = 1$: $A \simeq 0.01 \text{ mc/gm Ir}$

Actual exposure: 26 hours, $\bar{n}\bar{v}t = 7 \times 10^{12}$; ($\bar{n}\bar{v} \simeq 7.5 \times 10^7 \text{ cm}^{-2} \text{ sec}^{-1}$)

Measured activity: 0.01 mc/gm Ir

Fig. 4—Production of Ir¹⁹² (specific activity $\leq 0.01 \text{ mc/gm of Ir}$) by Ir¹⁹¹(n, γ)Ir¹⁹² in the WBNS.

Fig. 5—Exponential experiment assembly.

Fig. 6—A more powerful version of the North American reactor.

This reactor went critical in November, 1953, and has been in successful operation since.

Figure 7 shows a version of the Bulk Shielding Facility Reactor which you saw earlier today, and which we have designed for a particular application. Our version of this reactor type favors an above-ground pool, but there is enough water left below grade so that if the side wall should fail, there would still be some coverage of the core. In this reactor, operating at a power of 100 kilowatts, we estimate a flux of about 2×10^{12} . Water makes a very fine shield; and for purposes of irradiating large and irregular objects, this reactor configuration has great advantages. However, in principle any kind of core could be used with a water shield—in the same manner that cobalt-60 sources and reactor fuel slugs have been shielded with water for a long time. There are many purposes which we feel are better served by a more conventional concrete shield.

Figure 8 shows a reactor with a solid homogeneous graphite core consisting of a mixture of uranium and graphite. This reactor is a North American Aviation development. The design possesses unusual safety features, one of which is that it is cooled by D_2O —a small amount, circulated in a closed loop. The reactor develops a flux of about 2×10^{12} at a thermal power of about 150 kilowatts. The design includes about 20 exposure holes, multiple specimen irradiation tubes, and so on.

Costs are a most important factor in the consideration of a reactor by the university. Figure 9 shows a breakdown of the costs of the simplest reactor which I have illustrated here so far; namely, our "water boiler neutron source." You can see that most of it went into the design. This perhaps underscores the points which have been made by previous speakers that when you make the first reactor, you pay a relatively large amount for the design that goes into it. We feel that this reactor can be duplicated anywhere for a cost of \$75,000, including the building—because this reactor does not require a separate building. It can be placed in an existing structure. (If Dr. Diddle had come to us instead of to Dr. Snell, we would have set him straight!) The more powerful water boiler which I illustrated before was built in an existing structure. No special building was put up for it.

If you go from this simple facility—simple yet versatile—to a 50 kilowatt water boiler or 100 kilowatt pool type reactor, you are going to add an amount ranging from \$150,000 to \$200,000 (or possibly more, depending on the complexity of the exposure facilities) to the \$75,000 figure which I have quoted. Exposure facilities vary in their cost. For example, if you decide that you don't want a thermal column in a pool type reactor, we believe that we can furnish between 12 and 15 exposure tubes for the cost of that thermal column.

We at North American feel, as other speakers here have expressed themselves, that standardization is the key to getting reactors down to the cost range of some accelerators. But this standardization rests, we believe, on an evaluation of the possible kinds of exposure facilities, and of the required power, which can only come from wide experience in building and operating many reactors.

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AECU-2900

Fig. 7—Version of Bulk Shielding facility.

Fig. 8—Homogeneous graphite research reactor.

Fig. 9 — Breakdown of cost of a simple reactor.

REACTOR ASSEMBLY BY UNITIZED COMPONENTS

by Seymour Oestricher*

When we started our initial study of research reactors, we were impressed with the necessity for providing a facility which would be safe, flexible, and inexpensive. It became apparent the design of such a facility could be approached in a manner identical to that used in the design of our proprietary machines; namely, to standardize and unitize components as far as possible to provide the desired elements of safety, flexibility, and low cost.

Standardization of components is unsurpassed as a method of cost reduction. Unitizing components (the design and construction of machines through the use of components made of independent unit packages) leads to great flexibility and ease of modification. In a unitized system, unit packages may be easily removed or replaced to satisfy a wide variety of requirements. Let me give an example of the soundness of the principle of unitization: cigarette packers are machines designed to pack, wrap and seal definite size, weight, and shape cigarettes, just as research reactors are machines designed to furnish definite amounts, intensities, and configurations of neutron fluxes. A few years ago cigarette packers were in the field packaging 2500 cigarettes per minute when the king-size cigarette made its debut. What happened to these machines? Because of unitized design of the original machine, a simple replacement of the cigarette compressor turret unit and arbor turret unit converted this regular size packer to a king-size packer. An enormous capital investment was thus protected by the initial unitized design.

In like manner, assume that we have assembled a research reactor installation that meets all the minimum requirements. As a result, the beam holes have available flux levels which vary within limits specified by the control rod drive and control equipment. After some years of operation, a new project presents itself which requires closer limits on flux level. In order to meet this new requirement, a more sensitive control is needed. With unitized design, an appropriate control unit could replace the old one, simply and expeditiously; moreover, if only limited funds are available for modification, not all controls need be changed. For example, if there are four control rods, we need change only the units controlling the rod nearest to the beam hole whose flux need be regulated. For this rod, we replace the drive, position, and control units. The result is the same as that experienced with the cigarette packer. A new requirement has been met, by the simple replacement of the minimum number of units permitting the modification to be made at the lowest possible cost.

At present, there are approximately a half-dozen research or test reactors in operation, with another half-dozen planned. All of these installations have basic similarities whether

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they be heterogeneous or homogeneous type fuel systems. It is with these similarities that we have started our initial work. We can run the gamut of research reactors from the LITR to SUPO and find that they all contain some common devices, as seen in Fig. 1; for example, rod drives, position pick-off mechanisms, controls and instrumentation, lattice systems, fuel or fuel assemblies, handling equipment, and experiment facilities. These devices may take different forms in the different reactors, but all can be traced to one of the previously mentioned general headings. By sub-dividing these general headings into small packages, one will be able to select a great variety of combinations. The greater the number of sub-divisions, the greater will be the flexibility of the final assembly. Under such a system, it appears that a reactor can be custom built for a specific need simply by the proper selection of component packages. We have started to unitize some components, and plans are being formulated to make the combinations as extensive as possible. The ultimate goal would be to have a catalog listing the various units and their specifications. To build a reactor to suit a specific need, one would simply select the appropriate pieces for assembly. Present day machine design very closely follows this pattern.

Unitizing also helps in the safety aspect. Standardized units, because of their proven performance can be installed without further development or extensive component testing after the initial units have been approved. The instrumentation and controls of the reactor are composed of three separate, but inter-related groups: start-up, operation, and safety. Within each group, separate functions may be performed by any of the several different plug-in units, depending upon operational criteria. For example, assume that our sensitivity requirements for rod position calls for automatic rod position of ± 0.01 inch. This would dictate one type of drive unit and corresponding servo control unit. The interlocks and wiring would be such that the control unit could be replaced by a manual control unit giving ± 0.10 inch sensitivity, if such were found to be adequate, and the over-all safety system would not be affected.

We have been talking about packaged units in general terms; specifically, what are these units and of what do they consist? Let us briefly describe some of them.

The rod drive system is one which actuates rod motion whether the rod be control, shim, or safety. The rod drive system is made up of a motor package drive unit, which transmits motor power to a rod drive shaft; a position pick-off unit, which tells position of the rod; and the rod connector which transmits the rod drive motion to the rod itself.

An inexpensive rod drive motor package unit would contain a gearhead motor, one set of change gears, a shaft to drive the position pick-off unit and a shaft to drive the rod.

For a more exacting motor package unit, one that can be operated directly from a feedback system, a unit is provided which contains a servo drive motor, precision reduction and change gears, a shaft for the position unit drive, and a rod drive shaft. Either type of motor package unit can be provided with or without a motor disconnect clutch. Identical mounting locations and shaft locations make these units interchangeable.

The position pick-off units follow the same unitized pattern. One unit utilizes a potentiometer with appropriate coupling and mounting plate; another utilizes a synchro as a transmitting source; and the third contains a tachometer for the unit performance as a rate pick-off rather than a position pick-off device. The choice of unit or units depends upon the proposed use of this system, the life desired, and the cost. All packages have the same mounting and coupling locations and can be used interchangeably with any of the rod drive units.

If we consider the assembly only of the motor package units and the position pick-off units, the interchangeability of these two packages provides us with 12 assembled combinations, which is a good indication of the flexibility which can be achieved by unitizing components.

Next we have rod connectors. These are the mechanisms which connect the drive unit output shaft to the control rod or safety rod. One type is a remote mechanical latching and unlatching device operated by a differential motion of the drive. The second type of connector is an electro-magnetic type similar to those found on the BSF safety rods. The third is a straight mechanical threaded connection with no quick disconnects. Standard type fittings are to be used on the control and safety rods which permit any and all of the rod connectors to be used with any and all rods.

Fig. 1—Devices common to all reactors.

The control and instrumentation may also be unitized. The amplifiers and control units may be packaged as plug-in packages. Each rod control switch, indicator and indicator drive or servo may be packaged as a unit so that it may be pulled out of the panel as one piece for replacement or modification or bench maintenance. The packaging of control and instrument devices can become quite extensive. The console and racks are made with standard sized blanks through which appropriate instruments and instrument assemblies can be mounted or replaced. Examples of this will be shown on slides.

Handling Equipment can and is being made standard for either remote or manually actuated items. Fuel handling tongs, lattice component locking and unlocking tools, bolt removal tools, specimen insertion and removal tongs, instrument handling tools, dollies and casks, and various manipulators are some of the units which are being standardized.

At yesterday's meeting we saw slides of solid fuel elements which can be fabricated for "swimming pool" type reactors. This is an indication that standardization is approaching the fuel section of reactors.

Sections of lattice structure can be prefabricated as can be sections of water treatment systems. Heat exchangers and pumps are packaged into standard capacities and then units paralleled to provide wide ranges of heat dissipation.

At this point it would be appropriate to show some illustrations of components that have been packaged for reactors. The slides show details of rod drives and associated components which have evolved from units designed for several reactor systems.

Figure 2 shows a motor package designed to drive a combination control-safety rod on automatic control from a feedback system. It contains a servo motor (low inertia rotor) to ensure a high speed of response. Specifications to which this unit was designed required the rod to be scrambled from the motor end, since its function dictated the use of a solid rod connector. For this purpose, a clutch is provided and the rod never released by its connector. Therefore, you will note that indication is never lost, since there is no break in the mechanical chain from the rod to the indicator unit. This unit may be provided with a solid motor coupling instead of a disconnect clutch, if the function of the unit will permit use of an uncoupling type of rod connector. It must be understood, however, that indication is lost during scram, if a disconnect type rod connector is used.

Either type of position pick-off may be used. Another unit which may be provided, and which we have designed and developed, is a two-synchro system for very fine control. The final selection of components depends on individual requirements.

Figure 3 shows a less expensive packaged unit which may be used for a shim rod or safety rod drives, and in some cases, may be used for control rod drives. This illustration shows no disconnect at the motor. If a scram device is required, a proper rod connector must be used, such as a magnetic coupled device. However, if continuous indication is required, even during scram, a clutch can be provided. Here again it can be seen that position pick-off units are interchangeable.

Figure 4 shows a control unit ready for insertion into a control panel. This package contains the indicator, indicator drives, limit switches, and all control switches. The control panel has already been wired. After the control unit is plugged in, the system is ready to operate.

The amplifier, in Fig. 5, has been built on a standard chassis to fit into a wired rack. The unit plugs in automatically upon insertion into the rack.

All these components and others are being studied in order to arrive at specific designs and the manufacturing costs thereof.

We believe that developments in reactor design to date have progressed far enough to justify serious work on standardizing and unitizing the major research reactor components. In fact, several months ago AMF expressed its interest to the AEC in designing and building, with private funds, a reactor for industrial and basic research and is currently undertaking a feasibility study toward this end. Our design approach is that described in this paper. We are convinced that, by standardizing and unitizing components, a reactor can be conveniently built which will be reliable in performance, flexible in being able to meet a wide variety of operating conditions, and at minimum cost.

Fig. 2—Motor package designed to drive combination control-safety rod.

Fig. 3—Less expensive packaged drive unit.

Fig. 4—Control unit ready for insertion into control panel.

Fig. 5—Amplifier unit.

REACTOR DESIGN CONSIDERATIONS

by H. R. Kroeger*

Bendix has considered only the swimming pool type research reactor. Professor Gomberg has given, I think, an excellent description of this reactor. However, I do have three figures which show different arrangements of the shield and tubes.

The arrangement in Fig. 1 shows some possible beam ports, as well as some cooling equipment located outside the pool itself, a movable core structure, and a control room in the upper right-hand corner. Figure 2 illustrates a somewhat different position of the balcony, and more possible beam ports. I think there is a total of 16 at the reactor core level, plus some possible angle beam ports looking down towards the core.

Figure 3 represents another possible arrangement. Note that at the bottom of the core is a transition piece which would allow forced circulation of water down through the core. One feature here is the integral experimental portion of the floor which would assure the continuous precise alignment over long periods of time, required by some experimental work.

We note that there has been some question as to the amount of flux, the type of reactor and the power of the reactor. I think we should point out here that the flux in the reactor may or may not be important. The flux in the beam tube where it can be used is important. With reference to this reactor, there are certain things that can be done to increase the flux.

1. The aluminum-to-water ratio can be lowered; by building the fuel element with less aluminum, you can actually reduce the amount of fuel necessary for criticality and for a given power the flux will improve somewhat.
2. You can install an optimum reflector of metallic beryllium. This would cost approximately \$25,000 to \$35,000 for even a fairly thin reflector. This perhaps is one reason why a water reflector is generally considered.
3. The geometry of the reactor can be optimized.

An attempt to approximate a spherical shape or at least improve the geometry would be of some slight advantage. A last possibility is, of course, actually operating at a greater power. The swimming pool type reactor does seem easily capable of operating above 100 kilowatts and perhaps even above 1000 kilowatts without excessive facility changes.

One point I would like to make—is that if there are to be a good number of research reactors of the swimming pool type, the supply of fuel elements is going to exceed the number of fuel elements in these reactors. There will always be some elements in-transit and in-process, both during fabrication and reprocessing. Actually, at the power levels mentioned so far, we anticipate a very long life for these fuel elements. However, if a large number of

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Fig. 1 — One possible arrangement of reactor facility.

Fig. 2—A possible reactor facility illustrating the feasibility of multiple beam ports.

Fig. 3—Another possible reactor design.

universities in this country obtain research reactors, this could be a problem. It has also been noted that heterogeneous fuel elements carry with them some self-protection from a security consideration. It would certainly be difficult to misplace a used element enclosed in several tons of shielding. This leads to a possibility that the AEC may wish to provide used fuel elements.

The large number of fuel elements that might be used brings up another point. Perhaps the AEC will be kind enough to standardize on a low aluminum-to-water ratio fuel element for research reactors. In the meantime, of course, I am sure the users will all take whatever the AEC might offer.

At the risk of being accused of crass commercialism, I would like to point out some things that Bendix has undertaken and would like to continue to undertake. I am sure that the other industrial groups will provide similar services.

While the actual design of the swimming pool type reactor is fairly well fixed, we would like to work with you in planning and designing the whole experimental facility. We might be able to assist you with a hazards summary presentation. We would like to help you build the complete facility and, finally, if it were desirable, we would undertake the responsibility for the initial operation of the unit.

DISCUSSION AND SUMMATION

by C. K. Beck and L. B. Borst

MR. PETERSON (Vanderbilt University): I wonder if consideration has been given to using instruments in experimental equipment placed in tubes or tanks under water, instead of being placed in the walls or in holes in the walls? This would be enormously more flexible.

MR. GOMBERG: We did give some consideration to this, but the uses that we feel would justify the expense involved in a reactor would have to be extremely broad. A number of experiments were proposed when we surveyed the university to find out whether we would be justified in producing for research use a device involving the investment of a fair amount of money, as opposed to spending it in other directions.

We first went to the faculty to find out what directions of research would be of interest. Analyzing these various experiments, we found that there were a substantial number which would not be suitable for canning, an operation under water. On that basis we went to the tank above water. We made that survey once. Mr. Wills and his staff, who are in active charge of the reactor design and execution of the plan at Ann Arbor, ran a similar survey to be sure we were going in the same direction.

I believe that we would come to the same conclusion today—that for very general use you should have some dry neutrons.

MR. BREAZEALE: You will find that a large number of instruments have been canned at the ORNL swimming pool—amplifiers, ion chambers, even a complete spectrometer, have been canned and put under water. In all cases, simply by supplying air pressure at perhaps an atmosphere and a half, a little bit higher than the water pressure at that point, there has been no trouble in this operation. As long as the air pressure is there, a small leak, of course, really means the air bubbles out instead of the water seeping in.

If anyone is contemplating this approach, I think it is well worthwhile to take the trouble of talking to Dr. Cochran at the ORNL swimming pool about the details of canning instruments. He has had wide experience in that field, perhaps as much as everybody else in the United States combined.

QUESTION: I am a little confused on the question of flux. Ordinarily speaking, you build a reactor to get a given neutron flux. We have two radically different designs here—the swimming pool, which has a solid fuel element; and the water boiler, which has a homogeneous or liquid fuel. Dr. King, what is the flux that you get with the water boiler at Los Alamos at a given power?

MR. KING: 1.7×10^{12} at 35 kilowatts. That is the order of magnitude.

QUESTION: What are the observed numbers of flux from the swimming pool?

MR. BREAZEALE: I can't give the exact answer as far as the swimming pool is concerned because the flux in terms of power depends so largely on the loading. With a complete reflector around the swimming pool, the number would be of the order of 10^{12} at a power level of 100 kilowatts, perhaps a little higher, although I don't think it would be as much as 2×10^{12} . On the other hand, if we have a water reflector, which means as a rule more elements, then of course

we dissipate more power for a given flux and perhaps the flux would be half of the number I have just quoted.

QUESTION: That reflector is beryllium?

MR. BREAZEAL: We are talking about beryllium oxide. We can quote no numbers for a pure beryllium reflector.

COMMENT: Of course water is a rather good attenuator of neutrons; that is, of source neutrons. And except for absorbing, the fluxes ought to be inversely proportional to the volume at a given power. The water boiler usually has a volume of about one cubic foot or less, and the swimming pool has about three or four cubic feet or more.

QUESTION: What volume do you usually have with, say, beryllium oxide or an H_2O reflector?

MR. BREAZEAL: With a BeO reflector on four sides, the volume will be more than 2 cubic feet. This again depends on the type of fuel element you have. There are so many variables that it is difficult to give an exact answer. Removing the beryllium oxide from all four sides and adding fuel elements to make the reactor critical again will increase the volume by almost a factor of 2, and will make it perhaps three and a half or four cubic feet.

MR. KNOX: I would like to point out that you can start at low power and low flux and add water cooling circulation systems if you wish, to give the system flexibility.

QUESTION: However, is this within the limitations of the safeguards report?

MR. KNOX: Yes. If one requires a high flux and cannot operate at such a level, instead of waiting until the development is such that it is safe, operate at a low power level but leave in the design places where you can place the equipment necessary for circulation when the reactor development is at such a stage that it will be allowable. It is possible to make almost the same standard units applicable to any of the fluxes that have been discussed here so far.

MR. KING: I have been a little bit surprised, in hearing of all of these designs, by the large amount of water that is being used as a reflector, since water is rather inefficient in conserving neutrons. The main purpose of the reactor is to have neutrons available for use. Water is a good neutron shield and not a good gamma shield. Materials like lead and bismuth can be made very convenient for shielding out neutrons, and of course they are extremely effective for shielding out gamma rays.

So I am surprised that there are so many designs which have surrounded the reactor with water and thereby eaten up a lot of their available neutrons, unless they run in a similar manner to the NRL reactor, with a good deal of facilities available, where there is no water between their irradiation ports and their core. I would think that it is advisable to have the maximum unnumber of holes through your water up to your core, because if you want to get beams out or irradiate samples, you do not want to greatly decrease the neutron intensity available by putting water between yourself and the core.

MR. GOMBERG: I would like to point out that for university teaching, there is an aspect of seeing what is going on, which means a good deal more than looking at "the black box."

So while it may cost you something in neutrons, if you can improve the instrument pedagogically, there are compensations for this loss of neutrons.

MR. KING: The question is: What do you see? You can take the rods out of the water boiler, examine them and there is not much to see. It may be that for several years to come in areas outside of Oak Ridge, just the very concept of seeing is a very important one and it is not an amusing one to convey. The inherent simplicity of the swimming pool reactor is a very important part of it, and the actual observation of a control involving nothing more than a sheet moving in and out, or a rod, is an extremely important one at the time of teaching.

There is one other important aspect in the use of the swimming pool for testing rather large units of shielding or other materials. There is a possibility of getting close to the reactor under properly controlled conditions. This has distinct advantages. I am not saying it is overriding, but to simply categorize the reactor as a source of neutrons is not quite the whole story.

MR. BREAZEAL: In a molybdenum and water reactor similar to the swimming pool, calculation shows that without a beryllium oxide reflector, you are losing in the water about one neutron per fission. You have to compare your different reactor designs with respect to

the availability of these neutrons. It isn't just a question of making the reactors as small and efficient as possible by using better reflector materials.

MR. BORST: We seem to be having quite different approaches to design, depending on whether we are talking about pedagogical uses, a use for bulk types of tests, or a use of the reactor as a neutron source. Our approach has been that, with beam experiments, we will do fundamental physics; we are interested primarily in a high intensity point source of neutrons. The smaller we can make the source, the lower the power level. We can operate and still get the same flux. Dr. King, you quite rightly pointed out that the water does interfere with the flux at the available facilities. How efficient do you find water as a reflector in conservation of material as compared, for instance, with graphite? My question is: What would you guess the change in critical loading would be in going from a graphite reflector to a water reflector?

MR. KING: This is just a wild guess. In our early measurements on the reactor, when we were using sulfate solution, we found that beryllium oxide gave us about 565 grams. Graphite gave us about 700 grams in a similar geometry. We estimated by extrapolation that water would be something like 1200 grams.

MR. PEARLMAN: We have calculated this for our two conformations and we find that for the reactor completely water reflected versus the reactor reflected by carbon, there would be an excess reactivity of 8 per cent if you put carbon close around on three sides. This gives an indication of the difference. Of course the critical mass difference is considerably greater than that.

MR. M. D. PETERSON: I would like to say a word or two regarding this water problem. I am not talking to physicists who are building a reactor for beam experiments; they obviously have an entirely different reactor. But for many of the other uses that have been disclosed here, water is extremely helpful. You can observe the charging and discharging operations, the seating unit of the experimental work, and actually the complete operation of the reactor.

If your experiments require it, you can move your hole right up to the reactor. You can put the water or whatever you wish in between the two beryllium reflectors. So water becomes an exceedingly flexible device for almost everything except the specific long neutron beams experiments. For those, of course, one must have beam holes through the wall and you certainly will continue to have holes through the wall.

MR. BORST: I think it might also be well to point out that, while you need more uranium to use in water moderation, water itself is a good deal cheaper than graphite or beryllium.

MR. BECK: And of course the AEC furnishes the uranium!

MR. BORST: Water is cheap even in Salt Lake City.

MR. GREENFIELD (UCLA): I want to repeat a point made by Dr. Beck that in the present economics of these two alternative designs and the different kinds of uses, one factor which does not enter at all is the cost of the fissionable material. While it is true that at the present time it is furnished very kindly for free by the AEC, perhaps the day may come when this is not the case; and this may be a factor in designs which require a greater amount of fissionable material.

MR. KASACHAU: I concur with your statement. You are apparently mentioning particular dollar costs, which are zero at the present time. I would like to point out that we have another consideration: we are assuming that uranium is in infinite supply, without regard to price. It seems to me we should at least consider the question whether we can proliferate university reactors ad infinitum at four kilograms per shot.

MR. KNOX: A more flexible reactor takes more uranium. If you don't need the flexibility, that is good reason for not using that design.

MR. WIDDOES (U. of Michigan): I wanted to ask you, Dr. Beck, when you were giving us the details on your staff, you omitted mentioning who was handling the health physics. This is an important part. Can you comment on this a little more?

MR. BECK: There is a committee at the university which was set up to handle the blanket authorization of isotopes for the campus, the distribution of isotopes from the AEC. This committee also has had its authority extended to include consideration of reactor safety problems. It is made up of members from various divisions of the campus, plus three members from the reactor staff.

This committee has over-all approval of the general policies of operating the reactor and the approval of various projects with respect to health physics. This committee has one full-time man who has training in radiation safety, and he is responsible for supervising the use of all radioactivity on the campus. He spends about half his time in the reactor group. The rest of the time he is out with individual projects which may be on tracer studies or other things.

MR. WEXLER (Westinghouse): I would like to ask Dr. Knox whether, from the standpoint of securing AEC approval for a nuclear reactor, an industrial research laboratory would encounter problems in addition to those already discussed?

MR. KNOX: Yes, I think there will be some additional problems, possibly mainly involving patent rights. It might be well to emphasize that we have been talking, I think, about research reactors, neutron sources, training reactors and so on, and not pilot plant models for power development.

MR. KING: It seems to me it has been shown by all the speakers that high fluxes are essential. I would certainly say that people should seriously consider not going under 10^{12} neutrons/cm²/sec. This has certainly been our experience at Los Alamos. We started in the 10^{11} flux region and found a tremendous gain in getting into the 10^{12} region for almost all experiments.

I think it has been illustrated that perhaps a pile or reactor is not necessarily the best single tool that one can pick for the sole use of a physics department. I certainly agree in this with Dr. Snell. I think if one did experiments in physics only, a machine of the Van de Graaff type probably gives one more information. However, if one considers the usefulness to other departments, again speaking from experience at Los Alamos, I believe that the pile has been used by more different groups and has provided more information than any other single machine; I believe the Van de Graaffs probably have contributed most to precise fundamental physics experiments. I think this goes back to the premise that a reactor is probably the best single device that a university can have for general research.

The experiments that were pointed out as having been done in chemistry and physics here at Oak Ridge all indicate that special machines are available. It may well be that if a university has three or four other large research tools at its disposal, a pile will not contribute as much as it would to a university which has more or only a few such machines.

Another point I feel rather strongly about is that many experiments cannot conveniently be done under water. In discussing this problem, I don't want to compare the water boiler versus the swimming pool type as far as the core structure goes, because I think the MTR type of fuel elements have many advantages and the water boiler types have certain other advantages, which I think have been pointed out. I believe people should seriously consider, in the construction of their shield, making them the most versatile possible for the many types of experiments that have been described here. I don't think many of the research experiments that have been mentioned could have been done as well under water.

If one looks at types of piles used in the past which were designed for as many research projects as possible, such as the NRX pile, for example, or the modified water boiler, one finds that for general research it is not very advantageous to have to work or place equipment under water. I feel rather strongly on this point. This has nothing to do with core structure. It is simply a design of the shield that you use in the experiment.

One furthermore needs volume regions in which one can do experiments, and I believe water is a poor material for doing volume experiments. There are some experiments where one would like the fluxes to remain constant over a certain area, and this is extremely difficult to do in water, since the mean-free path for neutrons in water is so short. A graphite-type moderation section is therefore quite important.

MR. BONILLA: I hope that a list of experiments and research found most feasible and least feasible with the North Carolina, Penn State, and other later reactors will eventually be available. It is my understanding that such a list will probably not be put out for a year or more, but even a discussion now of the anticipated programs would be quite helpful.*

* A list of experiments in use at North Carolina State College follows this Discussion and Summation.

In particular, what we want from the list is, first: What research experiments can be readily carried out? I think that will improve further determinations of fundamental constants, radiation damage, and so forth. A lot of the material that should be done by physicists gets shoved over onto engineers as soon as it becomes routine.

Second would be what operation characteristic experiments can be readily carried out. Third—and I think this is most important: How are those two previous types of experiments suited for power reactor instruction, development, design, and operation? The fourth point is that a definite schedule for teaching purposes should be set up and adhered to. I have frequently seen separate facilities that became completely unavailable for teaching purposes, and even for some researches, unless they have become set up.

I have a last thought: Insofar as is reasonable, it seems to me that different types of reactors should be installed on the different campuses rather than a multiplication of identical models. I realize this means more cost, but it seems to me that the manufacturers might possibly try to consider this problem.

MR. PEARLMAN: The \$75,000 mentioned previously is for the uncooled water boiler, although the addition of a cooling system to go up to 7 kilowatts would add very little to the cost. I didn't get a chance to mention the plastic moderated reactor. I have some additional remarks at this point.

From the point of view of conserving fissionable material, we made a study of the use of moderators other than water. Polyethylene, for example, has got more hydrogens per cubic centimeter than water has, and it is our estimate that the critical mass of a low-power polyethylene moderated reactor would be in the neighborhood of 400 grams. In addition to providing a moderation, we thought that we might use polyethylene as a supporting material for a beryllium oxide reflector for this little unit.

Furthermore, it could be used as a matrix material in which we could impregnate lead and tungsten to form the shield. We call this collection of materials a table model reactor. It can fit on a fairly sturdy table. We estimate it weighs about 7 tons.

MR. BORST: That is a particularly interesting device; perhaps not interesting to chemists or to physicists or engineers. I have over-generalized. This is always dangerous. It may very well be interesting to chemists for tracer quantities of short-lived activities or small activations. This is the proverbial black box, which has one switch on the outside which says either "on" or "off."

The solid moderated unit that you mentioned—do you have any estimates on that cost? You are the only person who has presented such a proposal.

MR. PEARLMAN: Yes. The cost of that unit has been published as an estimate of \$500,000. That includes a very large thermal column and, as I have mentioned, something like 20 specialized exposure facilities. Much of the cost is involved in these. This unit was conceived to serve other means of a number of universities which might be located in a geographical area away from national laboratories, and for that reason was loaded with as many experimental facilities as we thought might be of use.

MR. BORST: Since the group on the platform seems not to have understood my question, the foregoing is the homogeneous graphite moderated uranium impregnated unit. Mr. Kroeger, do you have any opinions on the price or anything you can say about the price of the swimming pool?

MR. KROEGER: We were interested in our discussions with Dr. Breazeale that his costs should be quite low. As we progressed into the design and a further consideration of the swimming pool, we found that we had included quite a large ignorance factor. I think Dr. Borst wants me to quote some numbers. Let me qualify them first. So far, the different swimming pool reactors we have considered have been almost identical as far as core and controls and instruments. But for a total reactor facility, this is not a large portion of the cost. The greater portion will be in the different designs required by the pool and by the facilities built into the shield.

I did not mention the fact that certain applications require open radiation areas. They are essentially air spaces next to the reactor. Placing a thermal column on one side of a reactor and canning the graphite in the bottom of the pool does involve some added expense. So for

very round numbers, I think we might say that the cost is in the region of \$200,000 to \$300,000. If you want a swimming pool type reactor built to a price, there are lots of things you can do to lower the cost. Most of these things also lower the usability of the facility.

MR. BONILLA: The question of feasible experiments is a very real one. One of the professors asked me just a little while ago to suggest some experiments an engineering school might carry out. If you don't all write to him at once, I believe that Professor Murray might send you a list of the experiments they propose to do. He offered a few minutes ago to mail me one. I think that is another tip to the manufacturers of these reactors. I am making a lot of suggestions for work for them, but I would say that whenever they can get hold of a good list of possible—not only possible but convenient—experiments with each type of reactor they manufacture, that would be a good selling point.

MR. MURRAY: In answer to Professor Bonilla's comment, I would like to mention seven general areas of activity we have in mind. The first of these has to do with the contact with the reactor and the study of its operation; becoming familiar with its special features; and, in general, living with reactors long enough to be able to talk intelligently about them.

The second one has to do with the use of foil and detector techniques which are quite powerful, not only from the nuclear physics standpoint but from the study of reactor properties after they have been put in operation. You want to find out what the facilities can be used for. This includes not only measuring flux distributions but materials constants, the constants of reactor theory, checking materials which are of interest to the Atomic Energy Commission and to future reactors which have not yet been built.

As has been pointed out, engineers will be given the job of evaluating these constants because the physicists quickly grow tired of them. I hope my physicist cohorts don't shoot me for this when I get back.

The third item is the study in detail of the time variation of reactor power. This is largely an instrument observation study including control rod motion time responses integrated with temperature effects; temperature measurements, flow measurements, reactivity, additions, and the time response all integrated and checked against standard methods. This is largely for educational purposes, but may have some bearing on future developments.

The fourth item is shielding experiments which could be done either by the experiments that have been mentioned this morning—converter type systems—or direct neutron shielding. I am including in our list fundamental neutron physics experiments which, although they have been performed many times, are analogous to, say, Milliken's oil drop experiment, which serves for educational purposes.

Involved also would be the study of the value and use of different types of radiation detection instruments of particular application. Finally, aside from health physics training, which can obviously be picked up by the reactor, is the use of the production of isotopes and the handling thereof for experimental purposes.

MR. BORST: I would suggest that those universities interested in a reactor program, and knowing what can be done, get in touch with the various national laboratories. I think they will find that the periodic annual or monthly reports of the laboratories are valuable guides to the nature of the experiments that can be conducted.

MR. LANDIS: Mr. Pearlman, my question is directed to you. You said that to increase the power of your research reactor to perhaps 50 KW or 100 KW in the swimming pool case, you would probably need \$150,000 or \$200,000 in addition to the \$75,000 for the basic unit. Is that right?

MR. PEARLMAN: Yes, that is right.

MR. LANDIS: What I would like to clarify is: Does this additional money include the building or is it just for the reactor itself?

MR. PEARLMAN: The additional money is largely for the necessary expansion. This is a change in quality rather than quantity of the various components that go to make up the reactor. The WBNS is a versatile unit, as I will keep on insisting as long as I have an audience; but compared with what you can do in a reactor, if you get up into the 10^{12} flux region, its facilities are very meager indeed. So a good share of this additional cost goes into the utilization of the more powerful radiation field that you get in an effective way.

As for a building, it is our feeling that the reactor as I described it here does not need an additional building. It can be so designed as to contain the kind of envelope that Dr. McCullough mentioned. With certain extensions of this idea, this holds for the pool type reactor as well. I would like to digress a minute and say a little bit about nomenclature here. As an individual, I don't favor the use of the term "pool reactor" to designate a particular type. I think it designates a particular kind of shield. If you need a large exposure facility, a water shield in a tank is certainly an obvious way of getting it.

Along with this configuration, usually one has considered a particular type of core; and I repeat that this is happenstance. Almost any kind of core can be shielded in the same way. To speak now of Mr. Landis' question with regard to a 100 KW pool type reactor, the accessibility of the core which is part of its great attraction also brings with it some additional safety requirements in that, per se, if you want to look at the core, you cannot have this intermediate containing envelope. So we suggest perhaps that this might be included in the building.

However, the costs of such a building are not in the total figure that I have mentioned. That would be extra.

MR. LAMARSH (University of Kentucky): Dr. Murray has said that reactors should be used in connection with the university training of nuclear engineers. I wonder how much information with regard to the actual engineering design and construction of a reactor one can obtain from a permanent installation of the black box type? It seems to me that the emphasis of the conference has been on reactors as a neutron source for physicists, chemists, isotope production, and so forth. I am wondering about the possibility of the design of a flexible type of critical experiment. We already have the word from Dr. McCullough that these are intrinsically safer, for example, than the much more expensive permanent type reactors.

MR. BORST: If I may, I would like to answer this question. The question of pedagogy is the question of engineering of any industrial installation. One doesn't make a plastic petroleum refinery so students can watch the oil bubble through. The process information can be obtained out of books and a certain amount of familiarity can be obtained with the process by visits or by working in the installation.

I would say that the same is true of reactors. The question of critical assemblies only attacks one feature of a reactor; that is, the establishment of a chain reaction. As one gets into technology, the problems are not associated with the establishment of the chain reaction; the problems are those of heat dissipation, control, and materials damage at high levels. One will get no prototype information on these overwhelming engineering problems which confront the technology at the present time from critical assemblies.

I think we have to rely on normal classroom procedures for training of engineers in this field just as we do in steam engineering practice, automotive engineering, aeronautical engineering, and so on.

MR. GOMBERG: This will be more or less a loaded question, but it is inspired by a letter I got just before I left Ann Arbor. We have been discussing the possibility of the support of nuclear engineering education on the part of industry. We have a letter—and this is not the only one—indicating that the way you do that is to send the boys into the factory and let them work there; never mind this nonsense about trying to educate them in schools. Obviously this is a loaded question, but it was an actual letter, the author of which I would rather not disclose at this time.

I would like to get the comments on whether we expect the industry to develop in a way that would render this apprenticeship type of training obsolete; or, now that we have spent two days discussing this type of thing, are we discussing a real engineering education need?

MR. KROEGER: I might just state some of our experiences along this line. You are all acquainted with ORSORT, the reactor technology school maintained here. It is our guess at Bendix that while we can bring a man into our group and train him in the way we want, he would only pick up a portion, say a half to two-thirds of what is obtained at ORSORT. With us it would take him a longer time, perhaps about eighteen months, to do this. We have a great admiration for ORSORT graduates.

MR. BORST: When one is going into a large development program, there is no substitute for the apprenticeship process at the present time because there simply is not sufficient

trained personnel. The engineers just have to dig as they go along, and they flounder and they make mistakes and you correct them and pretty soon you hope everything is going to come out all right. You look forward to a more rational type of engineering program where there would be a more reasonable approach, either at ORSORT or within the universities of the country.

MR. WIDDOES. I have only limited experience in the actual nuclear design field; but I can say rather quickly that it seems to me that most of the engineers in that field have a rather limited knowledge in the areas in which they are working; this shows up quite a bit.

MR. DREESE (Ohio State University): "Before presenting the Ohio proposal to the Board of Regents, wouldn't it be wise to wait until more information is declassified, because maybe we are going to have an obsolete design when the reactor is executed?" Of course this is the eternal problem of any rapidly developing field, and there is no absolute assurance that there isn't a very beautiful economical high flux unit waiting in the shadows ready to be declassified. As far as I am concerned, I am not going to hold my breath until that time, and we are going to proceed upon the basis of the declassified information at the present. I feel that there is no danger to commitments of funds. Is there any other point of view?

MR. KNOX: I think something that Dr. Johnson said yesterday bears on this point. He mentioned in general that the Commission would approve the loan of material for a proved, well-thought-out design. It appears to me that a statement of that sort indicates a trend of thinking which is equivalent to freezing on certain types of reactors which are available now. There is not in the AEC today any Commission-supported development of research reactors; and it appears to me unlikely that, say, five or I will be bold and say even ten years hence, we will have more of a choice than we can see before us today.

Unless the Commission changes its attitude, as expressed by Dr. Johnson, and supports what amounts to research reactor design development at universities, I see no relief from this picture.

MR. BORST: Any further questions?

MR. BONILLA: A question arises when you are restricted to one and one only source of technology and fabrication of uranium fuel elements and uranium alloys containing uranium. How can you vary these configurations if there is nowhere else to turn? Do you depend upon the bounty of the Commission?

MR. BORST: We presumably have, or we optimistically assume we have, a great power technology ahead of us. If we are going to make real contributions in the educational field to this power technology, there is some justification for wanting a steaming reactor. The particular point was whether a steaming reactor was likely to be declassified in the immediate future. My feeling is that no normal educational institution would be able to pay for it if it were.

MR. KNOX: I would like to say it is conceivable that the situation may change within a relatively few years, in view of the present proposal contained in the Atomic Energy Act relating to private ownership of fissionable material and production facilities, and the possible release of a good deal of the technology which might make possible experimentation on fuel elements and their manufacture outside the Commission.

I just mention this as a possibility, but it is conceivable that this could come about within one or two years, or this year.

MR. RICE (AEC): I think it is very difficult to look back through the technology of the development of accelerators, for instance, and see whether there is a government agency sponsoring the development of research tools. I don't see any reason why the people who want to sell reactors can't carry out this development, in a similar way to the ones who want to sell accelerators.

SUMMATION

MR. BORST: I think we had better close the general discussion at this point. I want to thank the panel members for their contributions and thank the audience for its attention.

I have been asked to summarize the conference. Having listened attentively, I find that there is so much that has been said, so many important things, that I think it virtually im-

possible to do anything but refer to the transcript for a complete summary of the conference.

Instead, I would like to propose that I consider myself, as Professor Diddle, as having gone down the wrong road to ruin and decided to build a reactor. It happens that Yaphank contains the New York State Mental Hospital. East Yaphank happens to have the coordinates of Brookhaven National Laboratory, and there may very well be a correlation between the two.

First of all, the person who gets an idea of building a reactor at a university should look into the purposes for which he expects the reactor to be used. He must explore the interest throughout the university to determine how wide the base of participation and interest will be, considering the size of the university, the student body, and the graduate program. Since I think that the undergraduate contribution can only be in the way of technician services and straight educational services, the principal contributions will come from the graduate school.

The virtue of a reactor is that it is more than a one-purpose tool. It is useful to the engineers, to the physical scientists, and to the biological scientists. I don't see how to bring in the philosophy department, but maybe some of you can figure that out. I have even been able to interest the business school and some of the social sciences in some of the problems involved.

First, one has to see where the funds come from. This is usually the province of the president or the university's administration. One thing I would counsel you: this is the easiest field in the world to oversell. It is very easy for you to get \$1,000,000 before you are convinced you ought to put in the time involved to build the reactor and to justify it.

I think before you start a program you want to figure on six years—two or three years for negotiation and construction; and two or three years for pay-off, to get the reactor through its initial stage and get enough research out of it to justify its construction. One has to think seriously about committing something like six years of his life to such a project as this. The band wagon rolls and rolls extremely easily, and once it gets started, it is virtually impossible to stop.

One has to decide between designs and we have seen three principal designs proposed, including the two which were compared most exclusively, the water boiler and the swimming pool. Because of its lateness in the program, the barbs were not aimed at the North American solid graphite uranium reactor design. The designs are conditioned upon the interests of the university and the function of the reactor: whether it is to be a medical facility, whether it is to be primarily aimed at engineering experiments which involve irradiation of large objects, or whether it is addressed more to the production of radioisotopes, or say the physicist's conventional beam experiments, where he wants a point source.

Let me point out that it is hardly fair to compare the water boiler and the swimming pool in terms of cost because there has not been the same effort at economy in the swimming pool that I think has gone into the water boiler design. The two distinguishing features—let's say they have comparable fluxes—are the critical loading and the power; and in terms of the words we received from the Chairman of the Advisory Committee on Reactor Safeguards, minimum power is a very real, tangible and desirable characteristic.

One must early in his negotiations contact Bill Knox in Washington on AEC arrangements so that the AEC is as well informed as is possible about the intentions of a local university. One may negotiate a study contract with little difficulty, which gives access to classified data and access to classified installations where one can get good advice from the people who have been in the field for many years. In fact, one would probably be overwhelmed with the advice one receives.

One must consider how the reactor is to be constructed, and whether to use a construction contractor, or to use the conventional university scrounge system. The scrounge system has a very serious limitation in this field. You can scrounge a cyclotron. Dr. Snell was chief scrounger, I was third assistant scrounger, at the University of Chicago; and we got deuterons for between \$25,000 and \$30,000. We had all the surplus bailing wire and equipment that we could find in any of the physics, chemistry, or other departments.

This is not the way to build a reactor, because the reactor has to be considered and conceived and presented for approval. There is much more in the way of negotiation for the fuel. One has to present a concrete and realistic safety program to the Advisory Committee for

Reactor Safeguards, and one can't be nebulous and diffuse about such a discussion because the accidents are neither nebulous nor diffuse. They are very concrete.

Unless you have an extremely well informed, vigorous, and numerous group, I personally advise against the scrounge system. I have investigated this possibility at our university, and I don't feel that there is the level of participation necessary to carry the project out on the local scene. One has to have a study group, nevertheless, to make calculations of the performance characteristics of the reactor and to father the mechanical design. It is possible to buy a thing off the shelf presumably from one of the manufacturers, but it is highly desirable that the people who are going to use this equipment understand it and understand it fully and in detail. This means that one requires a group which will spend appreciable time on the design, the mechanical details, and particularly the calculations required before construction.

I would caution you about one thing. Reactor experimentation is uniformly massive. You saw at the X-10 reactor some of the equipment which usually involves a few tons of shielding. Watch for your floor loadings. You can't put it on a wooden floor. You have to have a concrete slab, and it has to have a good ability to take shielding. If you are going to run simultaneous experiments, you have to have each apparatus independent of the environment. That means good shielding against stray radiations coming from adjacent holes, or shielding to confine the radiation to the vicinity of the experiment.

Presumably at this stage you are ready for a presentation to the Atomic Energy Commission; it will have to be in the form of a formal report indicating a financial plan, a research program, an operational procedure, and an analysis of the characteristics and safety features of your proposed installation. On the basis of this presentation, the AEC will consult the Advisory Committee on Reactor Safeguards and determine whether your installation justifies the allocation of material.

Don't expect a contract which has as a provision that the AEC agrees to provide the material. The AEC will provide the material if it sees fit to do so, only upon the basis of a fully constructed reactor which is reviewed. One can, however, get some degree of assurance that the material will be available if you fulfill your part of the bargain.

The presentation to the Advisory Committee for Reactor Safeguards is most important and cannot be minimized. It requires a full understanding of your installation and definite ideas on how you expect to operate. It requires a well defined mechanical design, operating procedures, start-up procedures, and environmental studies. The environmental studies were not dwelled upon by Dr. McCullough, but necessarily involve the analysis of where waste materials go, and what the quantities and concentration of waste materials will be under various circumstances. A meteorological analysis is required which involves what is called a wind rose, giving wind velocities and directions, and an analysis of the prevalence of inversions. Predictions are required concerning what would happen, first of all, under normal operating conditions; and second, what would happen in the case of a catastrophe. These are two different aspects of the problem, and they must be treated separately.

One has to present information on the adjacency of private housing and industrial or public institutions—using the research reactors formula, 1 per cent of the square root of the power in kilowatts equals the radial distance in miles, within which you know you are going to be in trouble if something happens.

One must know seismic conditions and have some information on the seismic processes that can be expected, where fault lines are, what the extent of earthquakes might be, what the history of, for instance, masonry structures is—in other words, what the degree and probability and the expected location of earthquakes are. As I mentioned, in our location we will put in seismograph control. This however is an innovation which I do not believe has any precedent.

Subsequent to the Atomic Energy Commission's acceptance of the project, a contract will be negotiated through some branch of the AEC. The present contracts are negotiated through Oak Ridge.

At some time, depending on one's courage and one's faith, one commences construction. During the period of construction I have found it very important to have the operating crew on hand to observe the construction in the field. You just don't have any idea how valuable it is three years later to have somebody who was there and saw how things went together.

In addition, I have followed the policy of taking numerous pictures, so that at Brookhaven we have a very large album showing all sorts of trivia, which seemed completely useless but, when the time comes, are worth their weight in gold.

One must assemble an operating organization, whose first job will be, of course, to familiarize itself with the design and to follow construction and lay plans for the startup and the routine operation of the unit.

At the same time I strongly suggest that you stimulate the preparation of experiments, because the experimental program ordinarily takes about a year to get going; and one might better have the experimenters ready to use the reactor than to have the reactor completed and then the experimenters suddenly decide, "Oh, we have neutrons. What will we do with them?" One ought to base the experimental program on just as wide a foundation as is possible, because as distinct from cyclotrons and accelerators, this is not a one-experiment machine. One can build into a reactor as many experimental facilities as one can pay for. One can have large numbers of programs going on simultaneously, as evidence at Oak Ridge and elsewhere.

One starts up the reactor with lost sleep and hope, and one always finds a certain feeling of gratification when one sees this inanimate object suddenly start to multiply. You will be surprised what a thrill you get out of an exponentially rising counting rate. After the start-up program, which I consider to include the complete engineering evaluation of the structure — that is, the evaluation under steady state and transient conditions, its coefficients of temperature, bubbling and power. One generally gets the apparatus settled down within a year. Then it is time for the research scientists to come in and diddle with Professor Diddle.

W. G. POLLARD: I just want to say what a great pleasure it has been to have all of you here with us to help think through the many-faceted problems of university research reactors. It has been a pleasure to put on this conference, and we will look forward to hearing of all kinds of developments coming out of it.

REACTOR LABORATORY EXPERIMENTS

Prepared by R. L. Murray, North Carolina State College

The following experiments will be performed by advanced undergraduate and first-year graduate students in Nuclear Engineering at North Carolina State College. The course is Reactor Laboratory, Physics 531 with one-hour credit, 3-hour laboratory period per week for a semester. The intent of the course is to supplement the students' understanding of reactor principles and to familiarize them with classic experiments and standard reactor measurement techniques. The list is far from original, in that many ideas were taken from Pile Neutron Physics, Hughes (McGraw-Hill) and from the ORSORT Laboratory Course in Reactor Physics, AECU-2164.

1. Orientation-Inspection of reactor facilities

Study of drawings, equipment. Review of operation and procedures. Demonstration of critical experiment, start up, and rise to power.

2. Operation and Safety

Review of principles and practices of radiation hazard and protection. Use of survey instruments. Manipulation of shield facilities. Assistance in operation of reactor by students.

3. Time-dependent reactor behavior

- a. Measurement of rising and falling periods, calculation of reactivity from inhour equation.
- b. Comparison of response with reactor simulator and estimate of neutron lifetime of the reactor.

4. Control rod-temperature-power relation

- a. Measurement of reactivity for differential changes in control rod position over range of motion. Plot of S-shaped rod-reactivity characteristics.
- b. Power measurements by coolant flow and temperature rise. Relation of coolant flow rate, temperature, rod position and power. Evaluation of negative temperature coefficient. Cooling curve after shut down, with and without coolant flow.

5. Foil techniques

- a. Review of counting techniques.
- b. Measurement of cadmium ratio (activation of foils with and without cadmium cover) along axis of thermal column by use of gold, boron, and indium.
- c. Activation of copper wire, use of automatic counting and recording.

6. Diffusion lengths

Measure flux distribution throughout and near edges of paraffin, water and graphite extension of the thermal column. Calculate diffusion lengths, extrapolation lengths, and transport mean free paths.

7. Cross sections

Measurement of effect of Boron, Iron, and Copper samples on reactor period and reactivity (danger coefficient method). Compare cross sections of Fe, Cu with known value for B.

8. Isotopes

Irradiate samples of elements or mixtures in neutron flux. Measure activity and compare with predicted value. Safe handling methods.

9. Radiation Damage

Study of plastic samples irradiated for various times in reactor. Color, elasticity, strength, conductivity changes.

10. Shielding

- a. Attenuation of fast neutrons from converter source in hydrogenous shield. Use of transformations.
- b. Attenuation of gamma ray beams from exposure ports by slabs of material.

11. Neutron Diffraction

Use of laboratory model diffraction apparatus (crystal spectrometer). Selection of different monochromatic neutron beams. Measurement of transmission of neutrons.

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