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PPF Box 346

S E C R E T

ENCLOSURE "C"

DRAFT

ATOMIC ENERGY COMMISSION

RESEARCH REACTORS FOR FOREIGN APPLICATION

Report to the General Manager
by the Director of Reactor Development

Encl C

THE PROBLEM

1. To review research reactor designs and fissionable material requirements for a program of aid in construction of small scale reactors in foreign countries.

SUMMARY

2. The National Security Council has recommended that immediate steps be taken to initiate a program of aid in construction of small scale reactors, including provision of fissionable material in the requisite amounts, under bilateral Agreements for Cooperation. The NSC has specified that the fissionable material for these reactors should not be of weapons quality.

3. There are at least four distinct types of small research reactors which can be constructed in foreign countries within present technology as part of this program, (See Table I of Appendix) based on determination that uranium containing 20% U-235 or less is considered not of weapons quality. Additional designs undoubtedly will be developed commercially.

4. American industry has ample training and capacity to participate in this program within bounds of probable requirements by foreign countries including complete construction of research reactors if so desired.

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5. It is believed that an adequate program of assistance in construction of small scale research reactors can be undertaken within unclassified technology or classified technology of low sensitivity. U. S. participation will not cause significant diversion of fissionable material or trained personnel from the nuclear weapons program or the power reactors program.

6. Allocation of 100 Kg of U-235 contained in uranium at an isotopic concentration of 20% or less is sufficient for initiation of a reasonable program involving from 3 to 50 research facilities providing neutron fluxes up to 10^{14} n/cm^2/sec.

7. The first reactors of this program probably could be in operation within one year from the date of the Agreement for Cooperation if built by trained American personnel. Somewhat longer times would be involved if U. S. assistance is limited to technical consultation.

8. There is a wide range of applications for research reactors and an equally wide range of costs dependent upon specific designs and operating programs. Reactors of the types likely to be important to this program range from less than $100,000 to several millions of dollars for construction, and from a few tens of thousands to several hundreds of thousands of dollars per year operating costs.

STAFF JUDGMENTS

9. The Office of Special Projects concurs in the recommendations of this paper. Copies have been made available to the Divisions of Finance, Military Application, and Information Services, and to the General Counsel.

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RECOMMENDATIONS

10. The General Manager recommends that the Atomic Energy Commission:

a. Determine that (i) enriched uranium assay up to 10% U-235 is not of "weapons quality" in any amount and (ii) enriched uranium of assay between 10 and 20% U-235 is not of "weapons significance" in amounts not greater than that given by a formula such as $\text{Kg (total U)} = \frac{2}{e^{1.7}}$ although in theory this quantity of material might permit fabrication of a single weapon of 1 Kt yield.

b. Determine that material falling within the criteria of item a. may be considered not of "weapons quality" within the meaning of the recommendations of the National Security Council pertaining to small scale reactors for foreign countries as contained in NSC 5431/1.

c. Approve allocation, subject to approval of the President, of 100 Kgs of U-235 in uranium enriched to 20% or less U-235 content, for use in construction of small scale research reactors and for other research purposes in selected foreign countries as implementation of the National Security Council recommendations for such a program under Agreements for Cooperation as provided in the Atomic Energy Act of 1954.

d. Authorize the General Manager to advise U. S. industrial groups known to be active in research reactor designs of this materials restriction for foreign application so that they may make appropriate revision in their designs and prepare to assist in this program.

e. Note that except for special provisions of specific bilateral Agreements for Cooperation, it is assumed that foreign countries will secure reactors or component parts thereof through commercial channels and that the Commission will make source and special nuclear material available on a loan basis.

f. Note that this amount of material could provide the initial charge and material in preparation and processing for from three to perhaps fifty research reactors or critical assemblies, depending upon specific design selections.

g. Note that first actual fuel delivery may be required in calendar year 1955.

h. Note that no new specific reactor design projects at AEC expense are contemplated for this program, but that industry is expected to develop additional designs.

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i. Note that the panel of consultants to be established by October 1, 1954 under terms of a separate paper and representatives of U. S. industry can assist foreign countries in the design and planning of unclassified research reactors.

j. Note that actual construction and foreign delivery of reactors or components, including fuel elements, will not be undertaken prior to negotiation of Agreement for Cooperation in accordance with the Atomic Energy Act of 1954.

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APPENDIX

BACKGROUND AND DISCUSSION

1. Recommendations of the National Security Council for Courses of Action to be taken to implement the Atomic Energy Act of 1954 are contained in report NSC 5431/1. Two phases of these recommendations are considered in this paper. The National Security Council recommended that the United States:

a. Earmark initially a reasonable amount of U-235 of less than weapon quality of U. S. material, for use in small scale reactors and for other research purposes abroad.

b. Initiate a program of aid in construction of small scale reactors in selected countries, under Agreements for Cooperation which do not involve U. S. funds for such construction.

2. It is apparent from other sections of NSC 5431/1 that the small scale reactors referenced in these recommendations are research reactors designed to provide neutrons for experimentation and research at fluxes in the range of 10^{12} to 10^{14} neutrons per square centimeter per second. Certainly such reactors are essential tools for the development of the technology which must be the foundation of any eventual nuclear power industry. Probably the best evidence of the importance of small scale research type reactors is the fact that the United States has built 19 reactors which might be so classified, 7 of which provide peak neutron fluxes in the range of 10^{12} to 10^{14} neutrons per square centimeter per second. Fifteen of these reactors are still in operation, and a substantial number of additional reactors of this type are in the construction or planning stage in this country.

3. Small scale research reactors have been and can be used for a multitude of purposes. Some of the many uses are listed below:

a. Production of radioisotopes for use in medicine chemistry, biology, agriculture, and other fields of research or industrial control;

b. Medical therapy by use of external beams of neutrons and gamma rays;

c. Solid-state physics research by neutron diffraction techniques on external beams, intense neutron bombardment in the reactor, and by use of artificially produced radioisotopes;

d. Studies on nuclear properties of matter such as cross sections for capture or scattering of neutrons, gamma ray spectrum induced by neutron capture, and radiation attenuation;

e. Reactor physics measurements making use of the reactor as a source of neutrons for exponential experiments or by direct study of the reactor's operating characteristics;

f. Reactor engineering experiments on such things as radiation effects on corrosion, strength of materials, disassociation of fluids, and instrumentation.

4. There are many nuclear systems which might be used in the design of a research reactor. Choice of a specific design will depend upon a number of factors, including (a) intended uses, (b) experience or background of operating group, (c) types of materials (including fuel) available for construction, and (d) amount of money available. The use of enriched U-235 as fuel permits one to achieve high neutron fluxes in research reactors of relatively small volume and low total power, thus at relatively low cost compared with natural uranium fueled reactors using graphite or even heavy water as moderator. Because of the advantage for enriched fuel, essentially all research reactors recently constructed or now in the construction or planning stage in this country are based on use of enriched fuel. The effects of going from 93% U-235 commonly used in the United States to lower enrichments, not of weapons quality, is discussed later.

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5. The business of building research reactors in the United States has not yet matured to the point of dealing in truly standard designs. It has advanced considerably in this direction, however, and there are at least ten industrial organizations in this country who have announced their interest in design, engineering and/or construction of research reactors. At least four of these industrial organizations have prepared brochures describing proposed types of research reactor designs and offering their services in this field.

6. Further indication of industrial activity, interest, and preparedness in the reactor field is found in the history of the Army Packaged Power Reactor Project. Thirty-three companies finally were selected as qualified to receive invitations to bid on this reactor. Over half of these companies are known to have subsidiaries or offices in foreign countries, exclusive of Canada. It seems clear from this that American industry is prepared now to participate in assistance to foreign countries in the research reactor field to whatever extent may prove desirable.

7. The most popular designs for research reactors in the United States are the homogeneous "water boiler" and the heterogeneous "swimming pool". In addition to these, there is a detailed design available for a homogeneous graphite reactor. Major components of this design have been tested but none built. These concepts are described briefly below:

a. The "water boiler" concept consists of an aqueous solution of enriched uranium sulfate in a spherical or cylindrical stainless steel vessel. Less than one kg of enriched U-235 normally is required as fuel. This design generally has been limited to less than a hundred kilowatts and peak neutron fluxes of less than 10^{13}.

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b. The heterogeneous research reactor designs generally provide for plate type fuel elements of enriched U-235 clad with aluminum or stainless steel. These fuel elements are assembled in a tank of water which provides moderator, coolant, and shielding. The tank may be very large (hence - swimming pool) to provide flexibility in experimental arrangements, or may be only large enough to contain the core but provide for rapid flow and greater cooling capacity thus higher power and neutron fluxes. Power ratings for these designs generally start at about 100 KW and may extend to 30,000 KW (MTR) or more. Minimum fuel requirements are about 2.5 Kg of enriched U-235 with H_2O and 1.2 Kg with D_2O and neutron fluxes in the range of 10^{13} to 10^{14} may be provided.

c. The homogeneous graphite reactor provides a sealed core consisting of a homogeneous mixture of graphite and enriched U-235. The sealed core retains fission gases during its entire operating life and contributes to the special safety features of the over-all design concept. Minimum fuel requirement is 4 Kg of U-235. The existing design is for 160 KW to provide a peak neutron flux of 2×10^{12}.

Building and experimental facilities provided with each of these reactor types may vary considerably to suit individual needs. Typical design and performance specifications are summarized in Table I.

8. In addition to research reactors of the types described in paragraph 7, foreign countries undoubtedly will find it advantageous to their reactor development program to construct facilities for conducting critical assembly experiments (zero power reactors) or sub-critical (exponential) experiments. It is considered desirable that the proposed foreign assistance program include assistance in the construction of such facilities and in providing fuel for experimentation in them. It is anticipated that experiments with slightly enriched uranium (one or two percent U-235) will be of greatest interest in the immediate future, and that an average of perhaps 30 Kg of contained U-235 in uranium with an assay of one to two percent will be required for each such facility.

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9. While the recommendation of the National Security Council specified that material allocated to small scale research reactors should not be of weapons quality, there has been no official determination as to what range of uranium enrichment constitutes weapon quality. In the extreme, one might set the lower limit as that below which no nuclear explosion could be initiated under any circumstances. Any reactor, which must of necessity contain a critical mass to operate at all, is quite capable of a nuclear run away and, hence, might be conceivably used as a low grade weapon. The minimum enrichment which is capable of supporting a nuclear explosion with an infinite mass of material has been estimated as about 5%. Information from Los Alamos indicates that 10% enriched uranium is not suitable for any practical weapon but no definite upper limit can be set. For higher concentrations it would be possible to prevent assembly of a weapon by restricting the total amount of material issued of any given assay. For example, an approximate expression to show the amount of material of various assays required to produce a weapon of 1 kT yield of the type requiring minimum amounts of material is $\frac{2}{C^{1.7}}$ = kg of total U, where C is the fraction of U-235. Use of this formula shows 31 kg for 20% assay and 2 kg for fully enriched uranium. This formula is of limited usefulness for low assays and it is considered that 10% assay is safe in any quantity.

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TABLE I

Fuel Assembly Specifications and Core Designs

MTR (Present Design)		MTR (20% U-235)
No. plates/assembly	19	16
wt% U	18.5	44
U-235 Enrichment (%)	93	20
Clad-Core-Clad, thickness, (Mils)	15-20-15	15-45-15
Core Composition	U-Al alloy	UO_2-Al powder
U/assembly (gms)	214	1085
U-235/assembly (gms)	200	250
Total U-235	4.6 kg	5.75 kg
No. assemblies	23	23
No. shim rods	4	4
Power level	30 MW	30 MW
Ave. thermal flux ($n/cm^2/sec$)	1.4×10^{14}	1.2×10^{14}
Pu production (gm/d)	.012	0.6
Fuel cycle (Nominal)	25 days	32 days

Bulk Shielding Facility - "Swimming Pool"

BSF (Present design)		BSF (20% U-235)
No. plates/assembly	18	18
wt % U	14.3	44
U-235 Enrichment (%)	93	20
Clad-Core-Clad, thickness (mils)	20-20-20	15-30-15
Core composition	U-Al alloy	UO_2-Al powder
U/assembly (gm)	150	880
U-235/assembly (gm)	140	175
Total U-235	2.4 kg	3.0 kg

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TABLE I (Cont.)

Bulk Shielding Facility - "Swimming Pool"

BSF (Present design)		BSF (20% U-235)
Number of assemblies	17	17
No. shim rods	3	3
Power level	100 KW	1000 KW
Ave.thermal flux ($n/cm^2/sec$)	10^{12}	7×10^{12}
Fuel Cycle	4000 days	500 days

Argonne Heavy Water Research Reactor

CP-5 (Present design)		CP-5 (20% U-235)
No. plates/assembly	10	10
wt% U	17.5	43%
Clad-Core-Clad thickness (mils)	20-20-20	15-30-15
Core Composition	U-Al Alloy	UO_2-Al powder
U/assembly (gms)	102	540
U-235/assembly (gms)	95.5	107
Total U-235	1.15 kg	1.4 kg
No. assemblies	12	13
Power level	1 MW	1 MW
Avg thermal flux (n/cm2/sec)	2×10^{13}	1.6×10^{13}
Fuel Cycle	190 days	230 days

	Water Boiler (Present Design-Supo)	Water Boiler(10%U-235)	
Core diameter	30 cm	(a) 30cm	(b) 40 cm
Liters H_2O	12.5	12.5	32.0
U/liter (gms)	78	720	460
Total U-235	880 grs	0.9 Kg	1.5 kg
Enrichment	88%	10%	10%
Power level	50 KW	50KW	300 KW
Ave. thermal flux ($n/cm^2/sec$)	1.3×10^{12}	1.1×10^{12}	4.4×10^{12}

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TABLE I (Cont.)

Design References

MTR	- ORNL	963	
BSF (swimming pool)	- ORNL	1105	
	- ORNL	991	
	- ORNL	1027	
Water Boiler	- LA -	1301,	LA-1337 N.C. State Report NCSC-46 B and W Report AEB-1
CP-5			ANL-4221, ANL 4779

TABLE II

Reactor Costs, Construction Times and Operating Personnel

Reactor Type	Power Level	Cost*	Construction Time
MTR	30 MW	$\$ 6 \times 10^6$	2 1/2 years
CP-5	1 MW	$\$ 2 \times 10^6$	2 years
BSF	1 MW	$\$0.5 \times 10^6$	1 1/2 years
SUPO	300 KW	$\$0.3 \times 10^6$	1 year

The minimum operating personnel for all reactor types equals four to six per shift.

* NOTE: Does not include building, site facilities or cost of fuel.

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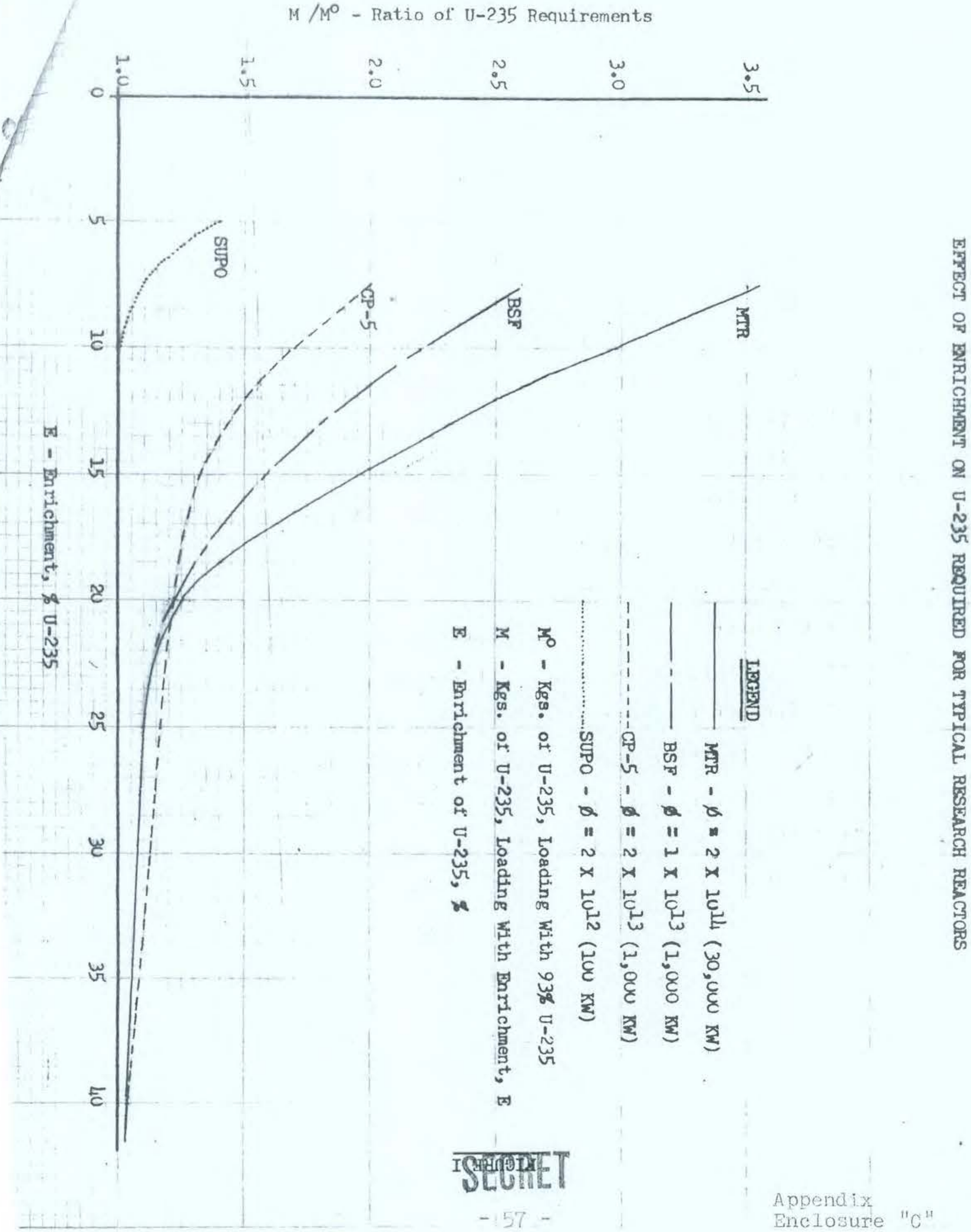

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low the fabrication of a single weapon of 1 k^T yield this would require the utmost ingenuity.

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10. Although the more advanced research reactors designed in this country use 93% U^{235}, similar reactors of comparable performance could be designed for considerably lower assay without a large sacrifice in cost or usefulness. Preliminary analysis indicates that use of 20% assay material rather than 93% assay requires only about 20 or 25% increase in U^{235} loading in the reactor and a correspondingly modest increase in the power level if the thermal neutron flux is to remain unchanged. This would entail relatively little additional cost for construction or operation. Below 20% assay the fuel loading increases sharply in most designs and with 10% assay the requirement may be two or three times that with 93% assay (see figure I). An increase in power level by a factor of two or three would represent a significant increase in cost, especially for a reactor designed for neutron fluxes higher than 10^{13}. For this reason, it would be advantageous to make available limited quantities of enriched uranium at assays as high as 20% of U^{235} for research reactors. It is recommended the following criteria be established:

(a) That enriched uranium of assay up to 10% U^{235} be regarded as not of weapons quality in any amount.

(b) That enriched uranium of assay between 10% and 20% U^{235} be regarded as not of weapons significance provided the total quantity held by any one country does not exceed that given by the formula, kg total U = $\frac{2}{C^{1.7}}$

Although in theory the maximum quantity of material permitted by this formula might allow the fabrication of a single weapon of 1 k^T yield this would require the utmost ingenuity.

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11. No reactors fueled with uranium containing 10% to 20% U-235 are in existance in the United States. Therefore, it cannot be stated that we have detailed designs of small scale research reactors "on the shelf" which are completely adapted to the use of this fuel. However, a brief examination of the designs of existing U. S. research reactor types reveals that by modifying the fuel element specifications only, these designs can be adapted to the use of low enrichment fuels.

12. In redesigning a research reactor to use low enrichment uranium in place of highly enriched uranium the principal problem lies in the design of the fuel element to accommodate the larger volume of uranium. In some cases this may require a slightly larger core but in general the reactor structure is not changed significantly. In homogeneous reactors, such as the water boiler, it is only necessary to increase the concentration of the reactor solution. There will, of course, be an increase in the total amount of U-235 to compensate for the neutron absorption in the additional U-238. This in turn will result in either a decrease in neutron flux if the same operating power level is maintained, or an increase in the power level if the thermal neutron flux is to remain unchanged. The latter may require minor changes in the cooling system. Highly enriched heterogeneous research reactors generally employ fuel elements of rather dilute (10-20%) alloys of uranium with some other metal such as aluminum. Use of 10 to 20% U-235 assay would increase the volume of the fuel elements by a factor of five to ten, if the same alloy composition were used. This in turn might require such undesirable changes as a significant   in the reactor size or a restriction in coolant-moderator flow passages. The desired alternative of increasing the uranium concentration

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in the fuel elements may require different materials, fabrication techniques, and fuel element types which have not been fully tested. For example, although cast uranium-aluminum alloys above 25% uranium have not proved satisfactory, sintered material of uranium oxide and aluminum with up to 47% uranium has been fabricated and is believed to be suitable on the basis of limited test experience. Also, uranium metal plates clad with aluminum or zirconium may prove satisfactory with further development. A comparison of the more significant characteristics of several types of reactors redesigned for 10 to 20% U-235 assay uranium with the original designs with highly enriched uranium is shown in Table I. Estimates of costs, construction times, and operating personnel required for these reactors are given in Table II.

13. In view of the great interest of industrial groups in research reactors, it is believed that these groups would conduct preliminary engineering design studies on reactors of the type listed in Table I at no cost to the AEC. They do, of course, need to be advised of the U. S. policy with respect to fuel for foreign research reactors. It may be necessary for the AEC to conduct some component development and engineering tests, particularly with respect to the modified fuel elements for these reactors as described in paragraph 12. Such work is expected to be relatively minor and probably can be absorbed within the present Commission program.

14. It is not possible to make an accurate prediction of the number of research reactors and critical or exponential assemblies that foreign countries will wish to construct under this program of assistance from the United States. One approach to initiation of such a program is to allocate a reasonable

quantity of material to be distributed on the basis of consideration of individual requests. Consideration of the design specifications in Table I leads to the conclusion that an initial allocation of 100 Kg of U-235 contained in uranium assaying 20 percent U-235 or less would be a reasonable quantity for initiation of the program. Most of the material probably could be distributed at an assay of 10% U-235 or less if necessary. This allocation could supply the initial charge and material in preparation and processing for from three to perhaps fifty units. The first delivery of material in this program would be required in calendar year 1955. Additional allocations for make up of burned out material or for new units probably will be necessary.

15. The importance of research reactors in general as development tools in nuclear technology and eventual emergence of a nuclear power industry needs no elaboration. The major significance of the proposed program of U. S. assistance in construction of several small scale reactors lies in the improved characteristics of these development tools made possible by the availability of enriched uranium. For example:

a. Use of 20% material rather than natural uranium permits construction of reasonably high flux reactors at low cost.

b. The use of enriched material introduces possibility of H_2O moderated machines and considerably increases the number of research reactor designs from which to choose.

c. Experience with enriched reactors is important in development of industrial nuclear power since many promising power reactor types use slightly enriched fuels.

d. High flux reactors have an advantage over low flux machines in the production of high specific activity isotopes, in conducting radiation damage studies, in carrying out neutron beam experiments and other basic nuclear research.