# THE UNIVERSITY OF MISSOURI RESEARCH REACTOR, ITS FUEL AND PRODUCTIVITY

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## INTRODUCTION

This paper describes the University of Missouri Research Reactor (MURR) and presents a summary of contributions to education, research, and service. These efforts have helped offset the impact on the U. S. economy of research from other countries. Special emphasis is placed on fuel design developments that have allowed MURR to keep the cost megawatt day (MWD) of fuel essentially constant. Also noted is the fact that the United States has missed some research opportunities because of a hold-the-line attitude. The slipping position of U.S. research reactors is compared with the rest of the world.

As will be further outlined in the text, the MURR cannot (with available technology) decrease its U-235 enrichment level and maintain present research capabilities and fuel cycle costs. Data is presented to show how MURR, if permitted to use advanced fuel technology, could reduce fuel fabrication costs and onsite U-235 inventory. In addition it is shown that MURR could increase its capabilities provided that arbitrary institutional limits are removed.

## DESCRIPTION OF MURR

The University of Missouri Research Reactor (MURR) is the highest flux steady state reactor at a U.S. university. Its purpose is to produce neutron and gamma radiation and to use this radiation for research, education, and service. Table 1, 2 and 3* summarize the accomplishments of MURR during the year 1977-1978 in these areas.

The MURR was among the last of the high flux research reactors designed and built in the U.S. It was designed to take maximum advantage of available technology to achieve maximum flux density. The design includes use of fully enriched uranium and maximum weight percent loading. Table 4 lists basic characteristics of the MURR fuel design. Figure 1 presents a horizontal section through the core of the reactor showing the flux trap, annulus of eight fuel elements, the pressure vessel, control blades, irradiation facilities and beam tubes. At the current licensed power of 10 MW, the peak thermal neutron flux in the flux trap is $6 \times 10^{14}$ n/cm$^2$-sec. Corresponding source flux

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* Figures and Tables follow text.

## TABLE I

## RESEARCH

Supported by MURR - July 1977 - June 1978

- Supported the research of 108 faculty and 76 graduate students from 31 departments of the University of Missouri and 14 other universities.
- Supported the research leading to 52 journal and proceedings publications from the University of Missouri and other universities.
- Supported research leading to 41 papers presented at professional meetings.
- Supported research leading to the granting of 4 Ph.D. Degrees and 8 Masters Degrees.
- Provided the financial support for 8 faculty (8 FTE), 21 graduate students (14 FTE) and 16 undergraduate students (14.5 FTE).
- Secured research equipment worth $119,000 by gifts, loans, and grants and worth $187,000 by purchases from MURR funds.
- Supported 61 grants and contracts totaling $7,521,638.
- Supplied 166 shipments of 39 different isotopes.
- Made 262 neutron radiographs for 8 students and faculty from 4 departments.
- Analyzed about 4900 samples using neutron activation analysis.
- Provided expert testimony in 7 court cases.

## TABLE 2

## EDUCATION

Supported by MURR - July 1977 - June 1978

- Tours for 3,256.
- Speakers for 52 seminars, colloquia, and talks.
- Lectures for 35 class hours.
- 7 instructors for 24 credit hours of courses.
- 2 international conferences.

## TABLE 3

## SERVICE

Provided by MURR - July 1977 - June 1978

Provided service to 6 other universities within the State of Missouri and 26 outside of Missouri.

Provides service to 27 State and Federal agencies.

Supported 14 research projects directly related to Missouri.

Supported 3 research projects directly related to energy conversation and development.

Supported 4 Missouri industries and 47 out-of-state industries.

## TABLE 4

## Characteristics of MURR Fuel - Nov 1978

| | |
|---|---|
| Elements/Core | 8 |
| Weight U/El | 775 GMS |
| Weight U/Core | 6.2 KG |
| U Enrichment | 93% |
| Weight % U | 41% |
| Type | $UAl_x$ plates |
| # Plates/Element | 24 |
| Fuel Life | 150 MWD/element |
| Core Life | about 4 months |
| Max. Fission Density | $1.8 \times 10^{21}$ F/CC |
| Power Density | 300 KW/liter |

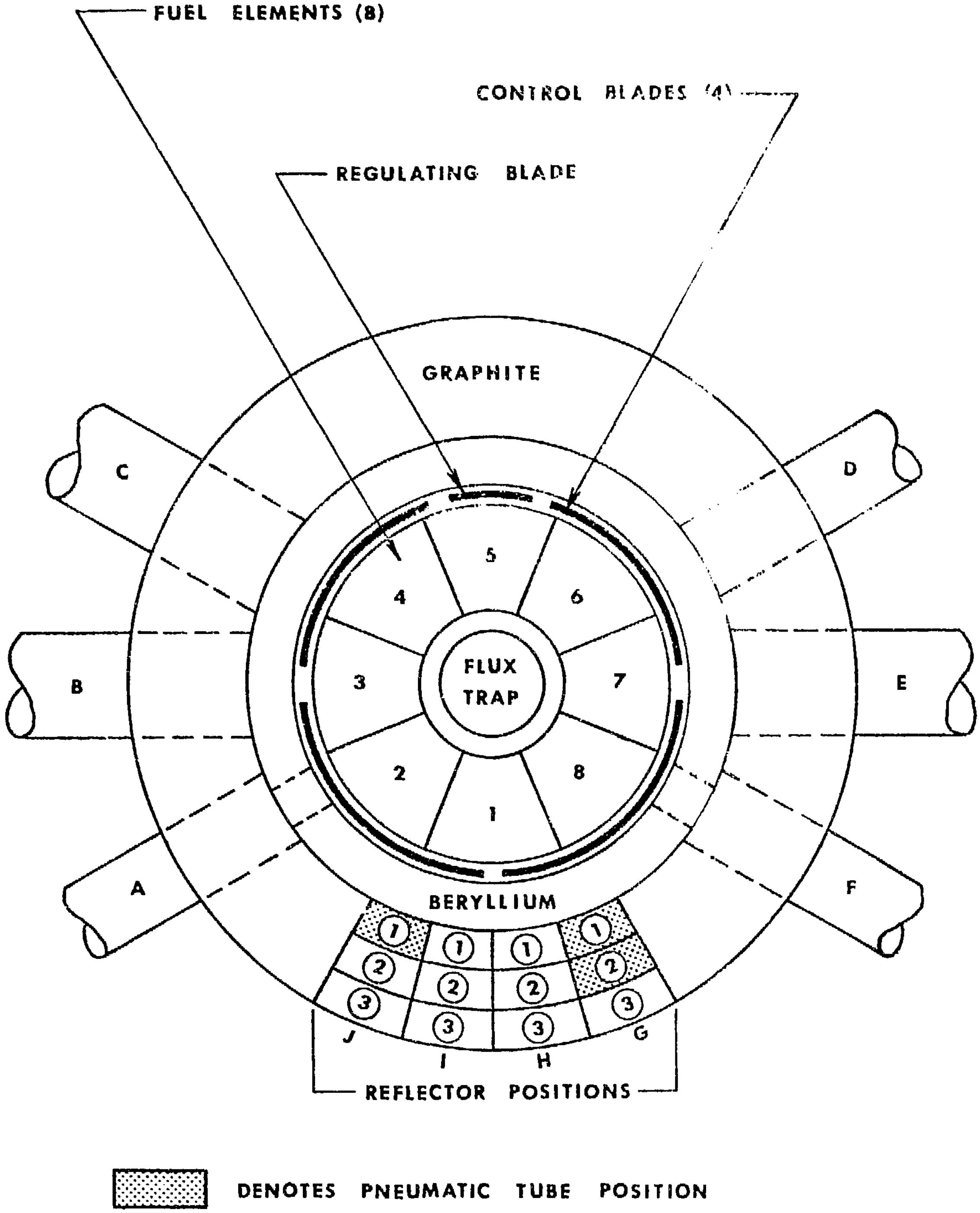

Fig. 1. Flux trap, beamport and reflector experimental facilities (not to scale).

in the beam tubes is $1.2\times10^{14}$ n/cm$^2$-sec.

The cost history of the fabrication of MURR fuel elements is outlined in Table 5. One notes that while the element fabrication cost almost doubled from Core 1 bought in 1965 to Core 20 purchased in 1977 the cost/MWD was held almost constant by applying advances in technology such as uranium aluminide cores and increased element burnup. This is a prime example of increasing productivity. The 50% increased in costs indicated for Cores 21 through 23 results almost solely from increased costs for security and administration.

## BACKGROUND OF RECENT RESEARCH REACTOR DEVELOPMENT

To appreciate the need for increases in capabilities of US research reactors, one needs to compare the state of research reactor development in the USA for the last 10 years as compared to the rest of the world. The need for neutron research has been clearly and positively stated in the recent study by the USA National Academy of Science.

The first research reactors were built in the USA and the USA had a commanding lead through the 1950's. The following tables show what happened when the US attitude shifted to one of hold-the-line and make-do-with-present-capabilities. Table 6 presents the research reactors now left in the USA. One notes that two have been downgraded in operating time till they are almost impotent. Only modest upgrading has been achieved because of the difficulty of overcoming NRC restrictions and lack of a positive attitude. One notes that no new research reactors have gone critical in the USA since 1967. The power levels are quantized at 2, 5, 10, 40, 100 MW. This quantitization is caused by institutional limits, not by technical limits. Table 7 shows the research reactors that have been shut down in the USA. We have shut down about half our peak capability. How does this USA experience compare to the rest of the world?

Table 8 outlines the research reactors in three developed countries (England, France & Germany) that have about the same population as the USA. The ILL, which went critical in 1972, has surpassed the USA reactors in research and has shifted the center of neutron scattering to Europe. The ILL is backed up by a set of medium flux research reactors. One notes that two are due to be shut down but a new reactor is being built to replace Saclay. Most of these reactors have been upgraded to their technical limits, not just to some administrative limit. One might argue that the score is now equal if this was the end of the story, but it isn't. The rest of the world is building new and replacement reactors. (Table 9). The USA is building none. The net result as indicated in Table 10 is that the USA has slipped into secondary position in this kind of research and development and fuel development. This is because we have not used all our technical capabilities to provide maximum research capability.

## POSSIBLE MURR FUEL CHANGES

Having shown that we are getting behind in research, let me now turn back to the purpose of this meeting, namely changes in fuel. The MURR has not done a detailed study, but from our knowledge of our present fuel behaviour we can make some estimates. Critically conditions of MURR are summarized in Figure 2 and Table 11. The MURR needs a core containing

## TABLE 5

## Cost History of MURR Fuel Elements
(Fabrication Only)

| | | |
|---|---|---|
| Uranium-Aluminum Alloy | | |
| I | $ 5450 | $ 75 |
| II, III | 5500 | 81 |
| IV, V | 5300 | 77 |
| VI | 6250 | 90 |
| Uranium-Aluminide Intermetallic | | |
| VII, VIII | 4500 | 50 |
| IX, X, XI | 5200 | 53 |
| XII, XIII, XIV | 5200 | 52 |
| XV, XVI, XVII | 7750 | 78<br>(99 MWD/EL) |
| | | 52<br>(150 MWD/EL) |
| XVIII, XIX, XX | 9500 | 63 |
| XXI, XXII, XXIII | ~ 14000 | 93 |

# TABLE 6

## Research Reactors* Operating in U.S.A. October 1978

| Reactor | Power (MW)/Operating Schedule (%) | First Critical | Recent Upgrade/Date |
|---|---|---|---|
| CP-5 | 5/20 | 1953 | ↓ 20% September 1978 |
| Omega-West | 8/20 | 1957 | ↓ 20% |
| ORR | 30/90 | 1958 | |
| MITR | 5/90 | 1958 | ↑ 1978 |
| UNCR | 5/90 | 1961 | |
| SUNY (Buffalo) | 2/90 | 1961 | |
| FORD | 2/70 | 1963 | |
| Rhode Island | 2/90 | 1964 | |
| HFBR | 40/90 | 1965 | ↑ 60 MW/1979 - cold source |
| HFIR | 100/90 | 1965 | |
| MURR | 10/90 | 1966 | ↑ 10 MW/1974-150 hr/wk |
| NBSR | 10/90 | 1967 | ↑ 20 MW/1979 - cold source |

*Reactors that have fluxes and operating schedules such that they do or could do good neutron diffraction - this was used as a lower limit to separate those reactors that do more research from those reactors that are more oriented toward teaching and training.

## TABLE 7

### Research Reactors Shut Down in U.S.A. 1965-1978

| Reactor | Power | Date Shutdown | Degrade |
|---|---|---|---|
| BGRR | 20 | 1969 | |
| MTR | 40 | 1970 | Could still be third best in U.S. |
| NRR | 1 | 1970 | |
| K-West | ? | 1970 | Only "hot source" in U.S. |
| AMRR | 5 | 1970 | |
| BRR | 2 | 1974 | |
| NASA | 60 | 1974 | |
| IRL | 5 | 1975 | |
| Puerto Rico | 2 | 1976 | |
| LPTR | 3 | 1978 | |
| ALRR | 5 | 1978 | |
| CP-5 | 5 | | 20% |
| Omega West | 8 | | 20% |
| GTRR | 5 | | 20% |
| GETR | 50 | 1977 | Temporary |
| LLL | 2 | 1978 | "Shut down" |

# TABLE 8

Research Reactors in the Three Member Countries*

| | | Power ((MW) |
|---|---|---|
| Geesthact | | 5 |
| Hahn Meitner Institute, Berlin | | 5-↑10 MW 1980 |
| Jülich (Dido) | | 23 |
| Karlsruhe | | 44 ↓ 1980 |
| Harwell | Dido | 25 |
| | Pluto | 25 |
| CENG | Siloé | 35 |
| | Mélusine | 8-↑12 MW 1980 |
| Saclay (EL3) | | 20 ↓ |
| ILL | | 57 |

*England, France, Germany - same population as U.S.

# TABLE 9

## Research Reactors under Construction (1978) - World Wide

1BR-11 Pulsed Reactor, Dubna, U.S.S.R.

4 MW thermal average, 5 $10^{16}$ n/cm$^2$ peak pulse flux
1979 completion

Saclay Research Reactor, France

14 MW, dedicated LENS facility, mid-1979 operation

Leningrad Research Reactor, U.S.S.R.

100 MW, 3 $10^{15}$ n/cm$^2$ sec flux, 1980 operation

Trombay Research - Isotope Production Reactor, India

100 MW, relative low flux $10^{14}$ n/cm$^2$ sec

Swierk Research Reactor, Poland

30 MW

Kyoto Research Reactor, Japan

30 MW, 1981 completion

Iraq - 30 MW, foundation poured

Ghana - 8 MW, under construction

Australia - is considering building a new reactor

West Germany - has completed study and is considering construction

No new research reactors seriously considered for U.S.A.

## TABLE 10

## Missed Opportunities by U.S.A. in Research Reactors

| | U.S.A. | Others |
|---|---|---|
| Research | 1/3 | 2/3 |
| New Reactors | 0 | 8 |
| Reactor $\phi t$ Upgrade | +10% - 50% | Extensive |
| Flux Tailoring (cold/hot sources) | 0/0 | 7/2 |
| Small Angle Neutron scattering spectrometers | 2 | 8 |
| Back Scattering Spectrometers | 0 | Several |
| Isotope Production | Decreasing | Increasing |
| Silicon Semiconductor Production | 1 | 20 |
| Dollar Savings | little | |

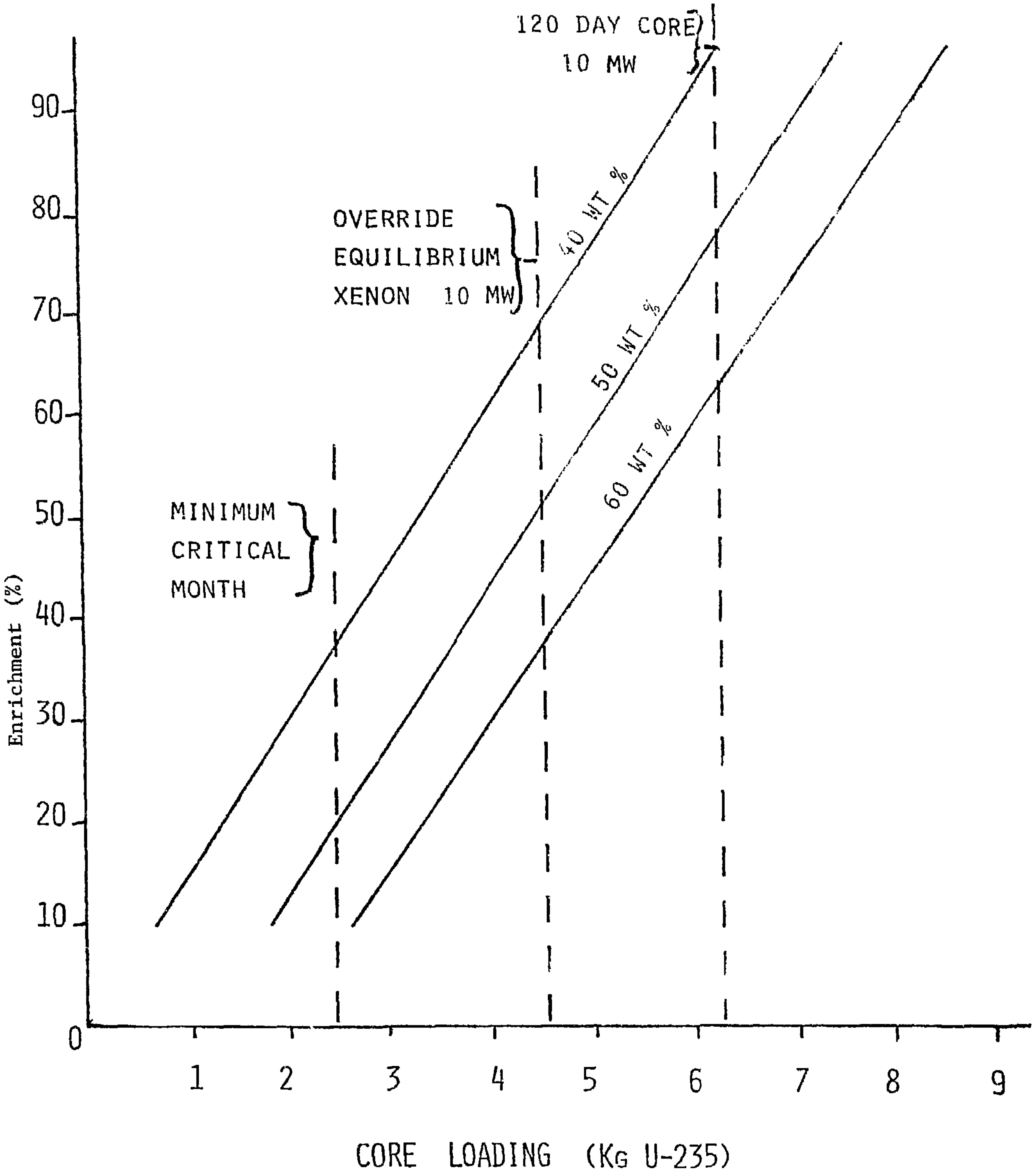

Fig. 2. Core Loading - MURR.

## TABLE 11

### Summary Data - $^{235}U$ Loading

### University of Missouri Research Reactor (MURR)

Current Technology - 40 Weight % U

| Enrichment Level | Weight $^{235}U$ (kg) |
|---|---|
| 10% | 0.665 |
| 20% | 1.33 |
| Minimum Critical Mass - MURR - 2.5 kg $^{235}U$ | |
| 50% | 3.325 |
| Operation at 10 MW Requires 4.5 kg $^{235}U$ to Override Equilibrium Xenon | |
| 93% | 6.2 |
| 70% | 4.65 |

A 50 weight percent loading capability implies that a 75% enrichment would be required to maintain 6.2 kg $^{235}U$

A 60 weight percent loading capability implies that a 64% enrichment would be required to maintain 6.2 kg $^{235}U$

2.5 kg U-235 to attain criticality, 4.5 kg to override equilibrium Xenon at 10MW (but with a very short core life), and 6.2 kg to provide for a reasonable core life of 120 days.

Table 12 and Figure 3 show the cost of fuel fabrication for 93% enriched and 70% enriched fuel at 40 wt %. To drop at 70% enrichment, MURR fuel cost would jump to $6,000,000/yr, a ridiculous and unacceptable number.

We now leave the base of existing capability and consider technical development and higher wt % loadings. Table 12 and Figure 3 also present some of the possibilities. With 60% loading we could cut our cost/MWD to below what it was in 1965. Now that is using technical development to produce real productivity.

There is another real advantage in a higher wt % loadings at 93% enrichment, that of reduced annual fuel inventory. Table 13 and Figure 4 show our estimates of U-235 that not must be held in inventory for MURR to have a confident supply of fuel. This includes U-235 in fabrication, fresh fuel in storage, in use, and spent fuel awaiting shipment. One notes that by going to 60 wt % and 93% enrichment there is only 60% as much U-235 being held on site or in transit. The right hand axis shows an estimate of the cost of fuel inventories. Once again using 93% enriched fuel and 60 wt % loading provides a real cost savings, thus increased productivity.

While cost savings are important, we believe there is a more important goal. That goal is the one that true science always strives for and it is a goal that in the past the USA has strived for. That goal is increased capabilities. That 10 MW power limit of MURR is an institutional limit. The MURR is capable of increasing power to 15 MW with only minor engineering changes and no significant change in level of safety. And the MURR could be increased to 25 MW with moderate engineering changes and safety systems additions. These upgrades could be achieved if 60 wt %, 93% enriched fuel were provided.

Table 14 summarizes what gains and capabilities of productivity could be gained at MURR with fuel development leading to 60 wt % loading and 93% enrichment. These are the kinds of upgrades that reactors outside the USA have been making and it is how the USA should be developing. It is unscientific and not in past tradition of the USA to freeze into a base of present capabilities. It will kill research and development.

## REFERENCES

1. "Neutron Research on Condensed Matter: A Study of the Facilities and Scientific Opportunities in the United States" National Academy of Science (1977).

## TABLE 12

## Fuel Cycle Costs - Fabrication Only

| Enrichment Level (%) | $^{235}$U Content (Wt %) | Usable MWD 10 MW, 1 Hour Restart | Cost/Usable MWD | Annual Costs |
|---|---|---|---|---|
| | | (no core sweetening) | | |
| 93% | 6.2 kg (40%) | 550 | $200 | $600,000 |
| 93% | 6.2 kg (40%) | 1200 | $ 90 | $270,000 |
| | | (with core sweetening) | | |
| 70% | 4.76 kg (40%) | 50 | $2200 | $6,600,000 |
| 93% | 7.5 kg (50%) | 1700 | $ 65 | $195,000 |
| 70% | 5.8 kg (50%) | 300 | $ 380 | $1,140,000 |
| 93% | 9.3 kg (60%) | 2800 | $ 40 | $120,000 |
| 70% | 7.0 kg (60%) | 1200 | $ 90 | $270,000 |
| 50% | 5.0 kg (60%) | -0- | | |
| 20% | 2.0 kg (60%) | -0- | | |

## TABLE 13

### University of Missouri Research Reactor
### Annual Fuel Inventory Requirements
### (150 Hour/Week, 10 MW Power, 93% Enrichment)

Current 6.2 kg Core

| | Requirement | | Number Cores | kg-235 |
|---|---|---|---|---|
| OFF | 1 year in fabrication | | 3 | 18.6 |
| SITE | 2 years "fresh" in storage | | 6 | 37.2 |
| ON | 1 year in use | | 3 | 18.6 |
| SITE | 1 year awaiting spent fuel shipment | | 3 | 18.6 |
| | | TOTALS | 15 | 93 |

60 wt %, 9.3 kg

| | Requirement | | Number Cores | kg-235 |
|---|---|---|---|---|
| OFF | 1 year in fabrication | | 1.2 | 11.2 |
| SITE | 2 years "fresh" in storage | | 2.4 | 22.4 |
| ON | 1 year in use | | 1.2 | 11.2 |
| SITE | 1 year awaiting spend fuel shipment | | 1.2 | 11.2 |
| | | TOTAL | 6 | 56 |

## TABLE 14

## Possible MURR Upgrades
## 60 Weight % - 93% Enriched

| | |
|---|---|
| Increased Power Levels | up to 25 MW |
| Increased Flux in Traps | up to $1.75 \times 10^{15}$ n/cm$^2$sec |
| Increased Flux in Beams (increased power) | up to $3 \times 10^{14}$ n/cm$^2$sec |
| Increased Flux in Beams (core shortening) | |
| 10 MW | $1.5 \times 10^{14}$ n/cm$^2$sec |
| 25 MW | $3.9 \times 10^{14}$ n/cm$^2$sec |
| Less 93% Enriched Uranium in Inventory and in Transit | 60% reduction |
| Cost Savings (fuel fabrication 10 MW) | $200,000/year |
| (fuel fabrication 25 MW) | $500,000/year |
| (inventory 10 MW) | $140,000/year |

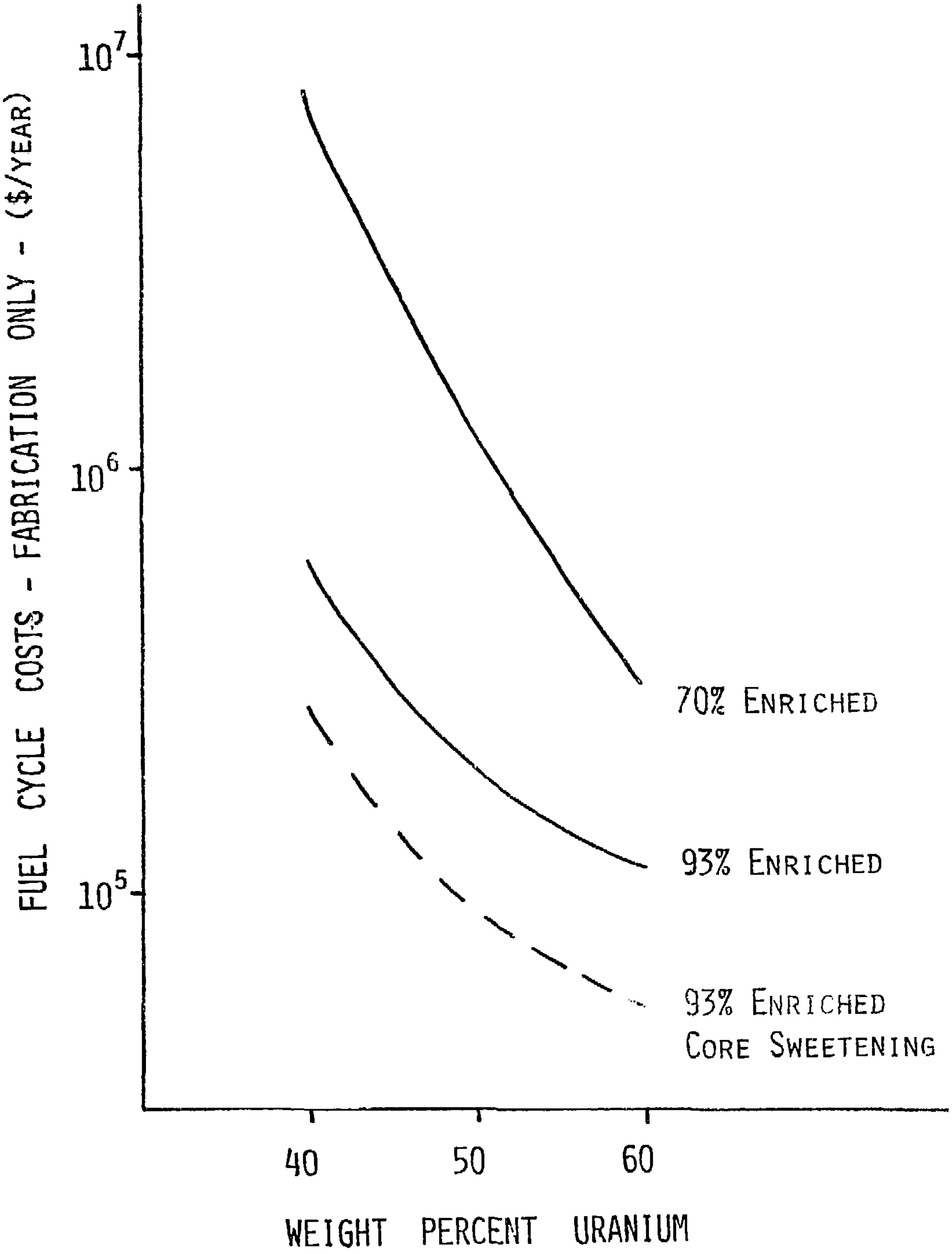

Fig. 3. Fuel Fabrication Costs.

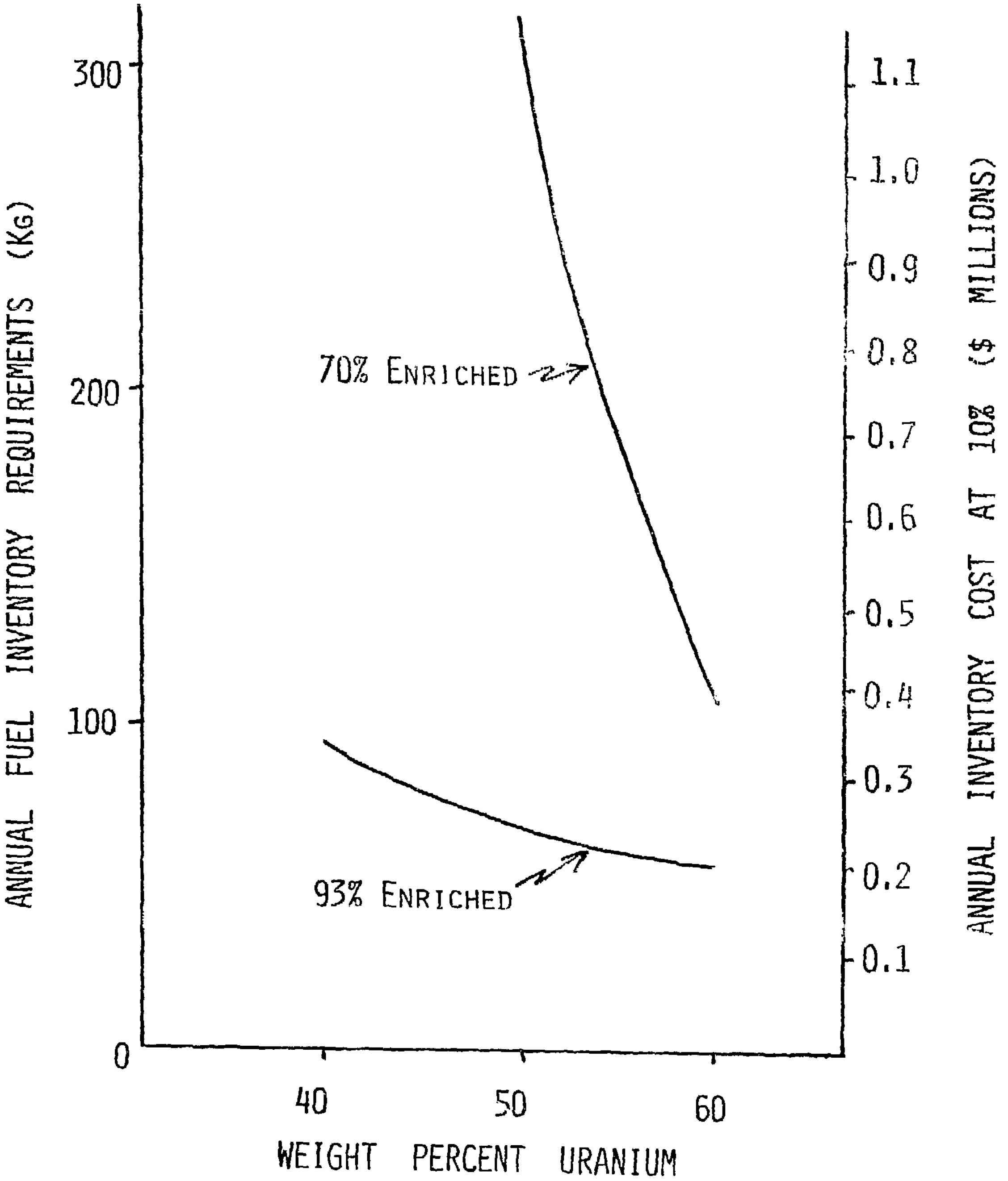

Fig. 4. $U^{235}$ Inventory Requirements.