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UNITED STATES ATOMIC ENERGY COMMISSION

(MMPP-75-2)

THE NUCLEAR RESEARCH REACTOR AT THE UNIVERSITY OF MICHIGAN

An Evaluation of the Hazards of Operation and Provisions for Limiting These Hazards

By
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Russell B. Mesler
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April 22, 1954

Michigan Memorial-Phoenix Project
University of Michigan
Ann Arbor, Michigan

Classification Changed to *Unclassified*

By authority of *Edgar Murphy*   Date *1/10/1956*

By *D Beller*   Date *9/24/2019*

Verified by *C Williamson (OSTI)* Date *10/28/2019*

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Physics

THE NUCLEAR RESEARCH REACTOR AT THE UNIVERSITY OF MICHIGAN

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SUMMARY

1. The maximum credible accident to the University of
Michigan reactor is believed to be slow dissolution of the
fuel elements with the subsequent release of fission pro-
ducts to the pool water if:

    a. The combined effect of any group of experiments
        subject to simultaneous instantaneous removal from
        the neutron flux is held below .016 $\Delta K/K_{eff}$

    b. The maximum $\Delta K/K_{eff}$ held by safety-shim rods is
        less than .016

It is possible to operate the reactor at power levels up
to 1 MW and in a manner necessary to carry out a useful
research program while observing operational limitations
(a) and (b).

2. It is estimated that leakage from the reactor building
can be held to less than five per cent per twenty-four
hours by employing certain design features which will add
about \$40,000 to the cost of the building.

3. The radiation dose to an observer outside the reactor
building during the first hour following the start of the
maximum credible accident is estimated to be:

a. Less than 0.24 reps during the first hour due to γ radiation through building walls

b. Less than 10 reps during the first hour to the thyroid from inhalation (calculated at 500 feet from reactor building under inversion conditions with 3 mph wind)

Both estimates above assume that the fission products, Xe, Kr, Br and Iodine, escape into the atmosphere of the building from the pool. All these elements are water soluble. In addition, it is possible that the iodine and bromine could be present in the fuel elements as iodides and bromides, and thus not be released from the pool water into the building atmosphere during slow dissolution of the fuel elements. Thus, the actual maximum credible accident may be much smaller than the one used in arriving at the above dosages.

4. Automatic monitors will be employed to set off area alarms during the early stages of the maximum credible accident. In fact, it is anticipated that these alarms will ring long before any fission products have been released into the pool water.

5. It is requested that the Advisory Committee on Reactor Safeguards recommend to the Atomic Energy Commission that the University of Michigan be authorized to operate

according to the tentative operating schedule presented
in Appendix B a swimming pool type research reactor with
aluminum fuel plates.

THE MAXIMUM CREDIBLE ACCIDENT

TO THE UNIVERSITY OF MICHIGAN REACTOR

The borax report (ANL 5211) has been examined and the
data and material in this report confirm the calculations
made in MMPP 75-1 which show that the instantaneous ad-
dition of about 1.8 per cent $\Delta K/K_{eff}$ to the barely
critical University of Michigan swimming pool reactor
would melt the meat of the hottest fuel element if the
ambient coolant-moderator temperature were 70° F.

It is therefore postulated that if no experiment or
group of experiments subject to instantaneous removal from
the neutron flux affects $\Delta K/K_{eff}$ by more than 0.016

and

if the reactivity held down by the safety-shim and control
rods does not exceed 0.016 $\Delta K/K_{eff}$ then no accident can
cause any portion of the active lattice to melt   If no
portion of the active lattice can melt then the possibility
of an explosive reaction between aluminum and water is
nonexistent.

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The instantaneous addition of 1.6 per cent $\Delta K/K_{eff}$ to the reactor is estimated to cause the center of the hottest fuel plate to rise to about 900° F. (some 300° F. below the melting point) for an initial coolant-moderator temperature of 70° F.

Tests run at the University of Michigan indicate that the fuel elements cannot be dissolved in less than twelve hours at 80° F. by means of mercury salts. Batch chemical processing plant conditions will effect complete dissolution of aluminum fuel elements in four hours, but the conditions required for this dissolution rate are not credible in a swimming pool reactor installation.

The minimum credible time which the active lattice could be dissolved by accident or otherwise is postulated to be greater than twelve hours.

The maximum credible accident is then the dissolution of the fuel over a greater than twelve hour period with the subsequent release of the fission products into the pool water. It has been assumed that the volatile fission products, Xe, Kr, Br and I, will diffuse into the atmosphere of the building although this depends to some extent on the pH and temperature of the pool water at the time of the accident.

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DETROIT 26, MICHIGAN

CABLE ADDRESS
SMITHGRY-DETROIT

April 19, 1954

File No. 9049

University of Michigan
Ann Arbor, Michigan

Attention: Mr. Lynn W. Fry
             Supervising Architect

Gentlemen:

We recommend a properly designed windowless concrete structure for housing the University of Michigan Research Reactor.

Our studies indicate that concrete construction would be the best positive method of achieving the desired degree of air impermeability as well as radiation shielding, and at the same time keep construction at a reasonable minimum cost.

Calculation based on research of the permeability of concrete to water vapor indicates that it is feasible to construct this concrete building so that the leakage of air is not more than 5% of the volume over a period of 24 hours.

The walls should be concrete with a minimum thickness of 12 inches, reinforced on both faces to control shrinkage. The specifications would provide for proper density of concrete and careful control of placing and curing. The roof should also be poured concrete.

Special attention should be given to construction joints and they should be held to a minimum number.

The inside surfaces of the building should be treated with a thin film of Gunite or similar material and finished with 3 coats of aluminum paint. All exterior openings should be kept to a minimum. These openings would require special treatment to assure quick and positive closing and sealing should an "incident" occur.

Very truly yours,

SMITH, HINCHMAN & GRYLLS, INC.

P. J. Ketelhut
Project Director

PJK/bjl
cc: L. Widdoes

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RADIATION DOSES TO PERSONNEL
OUTSIDE THE REACTOR BUILDING IN
THE EVENT OF THE MAXIMUM CREDIBLE ACCIDENT

The escape of gaseous and volatile fission products
from the reactor is a matter of concern. This escape not
only represents a danger to people inside the building but
also to people outside. Calculations have been made in an
attempt to evaluate the danger to people outside the re-
actor building. This danger arises in two ways. First,
the activity in the building air would represent a source
of radiation shielded by the building walls. Second, any
escape of contaminated building air might deliver an inha-
lation dose to a person outside the building.

A brief survey of the volatile fission products was
made which covered the isotopes of Xe, Kr, I and Br and
any of their short life daughters. Those isotopes which
have long half-lifes ($>$1 year), no gammas, low yields or
very short half-lifes ($<$1min) and no short-life gamma
emitting daughters were eliminated from further con-
sideration. The remaining isotopes are shown in Table I
along with their half-lives, fission yield, gamma energy

Table I

VOLATILE FISSION PRODUCTS

Isotope	Half Life	Fission Yield Per Cent	Gamma Energy	Gamma Yield Per Cent	Gamma Energy Per Fission
Kr^{87}	78 m	3	0.027 Mev	100	0.0009 Mev
Kr^{88}	2.77 h	4	----	---	
Rb^{88}	17.8 m	4	2.8	weak	
			1.85	weak	
			0.9	weak	0.0200
I^{131}	8.0 d	2.8	0.364		
			0.284	85	
			0.638	15	0.0112
I^{132}	2.4 h	3.6	.85	50	
			1.4	50	0.0406
I^{133}	21 h	4.6	0.53	94	
			0.85	5	
			1.4	1	0.0253
I^{134}	50.8 m	5.7	>2.3	1.5	0.0855
I^{135}	6.68 h	5.6	2.4	2	
			1.8	4	0.0840
Xe^{133}	5.27 d	6.29	0.085	100	0.0053
Xe^{135}	15.3 m	1.8	0.52	100	0.0094
	9.2 h	5.9	0.245	100	0.0147
					0.2969

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and yield, and gamma energy per fission. In some instances where reliable information was lacking high estimates were made.

The total gamma energy yield of the volatile fission products was estimated as 0.29 MEV per fission with equilibrium concentrations of all the isotopes. This source of radiation does not decay rapidly over the first few hours.

Of this source of gamma energy 85 per cent is due to iodine isotopes, 8 per cent to xenon isotopes and 7 per cent to the daughter of Kr^{88}. No bromine isotope contributes an important amount.

The longer life isotopes are present in the largest amounts. The I^{131} represents a volume at 70° F. and 1 atmosphere of 35 cc and the Xe^{133} 48cc. The amount of I^{131} is about two tenths of a gram which is soluble in about a liter of water. The vapor pressure of iodine at pool temperatures is about 1 mm of Hg.

Limiting Factors

Three factors act to limit the danger to people outside the building: 1) It should be possible to evacuate all people from the danger area within one hour of the first release of radioactivity. 2) The contaminated air escapes the building at a limited rate. 3) The activity escapes from the fuel plates at a rate limited

by the rate of dissolution of the fuel.

Radiation Through The Walls

The walls of the building act to shield people outside
the building from direct radiation coming from contaminated
air within the building. As an estimate of the maximum
dose to a person just outside the reactor building a
simplified geometry was considered. The contaminated
building air was considered as a cylindrical volume source
without self-absorption. The dose rate on the axis of the
cylinder at a point just on the other side of a slab shield
was computed. The diameter and height of the cylinder was
taken as 50 feet.

The source was taken to be the volatile fission pro-
ducts shown in Table I. The total gamma energy was taken
as 0.29 MEV per fission and the photonenergy as 1 MEV.
Equilibrium concentrations at 1 MW were assumed.

The results of these calculations showed that for
all volatile activity and for a twelve inch ordinary con-
crete wall (143 lbs/cu ft) the dose rate was 6 reps/hr
(for a 9 in. wall, 25 reps/hr; and for a 6 in. wall 100
reps/hr). The rate of dissolution would limit the amount
present in the first hour. Twelve hours is the fastest
dissolution time believed possible so that only an average
of four per cent of the total activity would be present
the first hour, assuming a linear dissolution rate. The

dose rates under these conditions would be:

.24 reps/hr for a 12" wall

1.0 reps/hr for a 9" wall

4.0 reps/hr for a 6" wall

Inhalation Dose

The escape of contaminated air from the building presents the possibility of someone outside the building receiving an inhalation dose. A method has already been developed for calculating the dose from a point source of radioactivity[4] Also, it has already been shown that I^{131}, because of its 8 day half-life and because it concentrates in the thyroid, delivers far larger inhalation doses than the other volatile fission products.

Contaminated air as it escaped the building would be very concentrated but as it traveled away from its source it would become diluted. However, in its concentrated form it would not displace a large volume. As it became diluted it would spread or fan out to cover a larger volume. Thus, closer to the source larger doses could be delivered but the geometric probability of being exposed would be smaller. Any activity which leaked out of the building above ground level would not reach ground level until it had traveled some distance and thus had been diluted.

Another factor in the possible dosage received would

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be wind direction and speed. It seems reasonable to expect that wind direction would change several times in the course of an hour.

In view of these difficulties maximum dosages over an hour were calculated at a distance of 500 feet downwind from the source assuming a rather slow 3 mph wind speed. This has been done in the belief that these numbers would give a reasonable indication of the danger involved.

At 500 feet downwind, under inversion conditions, the bulk of the activity is within twenty feet of the centerline of travel. Under lapse conditions it is within 100 feet of the centerline.

Using the formulae given in MMPP 75-1, the maximum inhalation dosage delivered by <u>all the equilibrium</u> I^{131} at 1 MW at a point 500 feet downwind would be 66,000 reps and 3,500 reps under inversion and lapse conditions respectively.

Assuming that only eight per cent of the activity escapes the reactor in the first hour (twelve hour dissolution time), that only 0.2 per cent of this escapes the building during the first hour (five per cent per day leakage) the doses would be 10 and 0.56 reps during the first hour following the maximum credible accident under inversion and lapse conditions respectively.

Whereas 25 reps is considered the maximum whole body

dose to be delivered over a short time the maximum dose to the thyroid is larger   Dr. Hymer L. Friedell, Professor of Radiology, Western Reserve University, suggests 150 to 300 reps as a permissible dose to the thyroid.[3]

Even in view of the larger permissible doses to the thyroid I^{131} is still the most dangerous isotope by a factor of about 20 compared to Xe.

The method of calculating I^{131} doses used here has been checked with a method by Burnett in ORNL 1550. His method gave values which are 72 per cent of the values obtained here.

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SAFETY MEASURES TO BE TAKEN TO REDUCE THE DAMAGE

FROM THE MAXIMUM CREDIBLE ACCIDENT, AND TO REDUCE

THE CHANCES OF ANYONE RECEIVING AN OVERDOSE

OF RADIATION IN CASE THIS ACCIDENT DOES OCCUR

The following safety measures have been discussed in MMPP 75-1:

1. All buildings within 500 feet of the reactor building will be low population density research buildings.

2. No housing units will be constructed within 1500 feet of the reactor.

3. The North Campus area will be connected to an automatic radiation warning system.

4. Automatic signalling system to plant security headquarters is set up when building is locked at night. Any entry to the building or movement within the building disturbs an ultrasonic sound pattern which sets off the alarm.

5. Trained operators will be in charge of reactor operation.

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In addition to these safety precautions, it now seems feasible to monitor the conductivity or the activity of the deionized pool water. This would provide a warning that extraneous material is entering the pool. Since the cladding must dissolve before the fuel such a system would provide sufficient warning of incipient dissolution of the fuel so that all persons could be evacuated to a distance of at least 1500 feet from the reactor before any fission products were released into the pool. Thus, even in the case of the maximum credible accident no one need receive even 25 R of radiation.

OPERATIONAL AND DESIGN LIMITATIONS ON REACTIVITY
FOR THE UNIVERSITY OF MICHIGAN REACTOR

1. Operational policy will limit the $\Delta K/K_{eff}$ held by safety-shim rods to the **minimum** possible. In no case will this $\Delta K/K_{eff}$ exceed 0.016.

2. Operational policy will limit any one experiment to the smallest practical effect on K_{eff}. But in no event will the combined effect of any group of experiments subject to simultaneous instantaneous removal from the neutron flux be allowed to affect K_{eff} by more than 1.6 per cent

THE USE OF STAINLESS STEEL FUEL ELEMENTS
IN THE UNIVERSITY OF MICHIGAN REACTOR

Stainless steel fuel elements for use in the University of Michigan reactor have been investigated. The results of this investigation are as follows:

1. The use of stainless steel fuel elements will require at least 5.5 kg of U^{235} in order to operate in the manner planned with 4.4 kg in aluminum

elements.

2. To achieve the same neutron flux level with stainless steel as with aluminum fuel elements the power level must be raised by a factor of about 1.25. This raises the amount of fission products stored in the core at any one time by the same factor

3. There is considerable doubt that <u>unclassified</u> stainless steel fuel elements <u>thoroughly</u> <u>tested</u> to 10 per cent burnup will be available by late summer of 1955. The University of Michigan research reactor is scheduled to go critical by August of 1955.

4. The cost of fabricating steel elements is estimated to be three times that for the aluminum fuel elements.

5. The stainless steel critical assembly which requires only 4.5 kg of U^{235} for criticality consists of twenty-five 4-plate fuel elements containing about 180 gms of U^{235} per element. This critical assembly has about 22 per cent of the heat transfer area of a twenty-five element 18 plate aluminum assembly. It is not obvious that this stainless steel assembly would withstand as severe transient conditions as the

18 plate aluminum assembly. Therefore, the transient characteristics of the stainless steel assembly should be tested in a Borax type experiment before it is incorporated in a university research reactor.

6. An explosive reaction between stainless steel and water is thermodynamically possible although the data indicate that this reaction would be less violent than that between aluminum and water.

$$Fe + H_2O \longrightarrow FeO + H_2$$
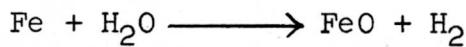
$$\Delta F_{1973^\circ K} = -2 \text{ K Cal} \quad (1)$$

$$\Delta H_{1400^\circ K} = -6.214 \text{ K Cal} \quad (2)$$

Appendix A

THE EXCESS REACTIVITY REQUIRED TO OPERATE
THE UNIVERSITY OF MICHIGAN RESEARCH REACTOR

Excess reactivity is necessary for operation and to
overcome the reactivity absorbing effects of the antici-
pated water temperature rise, beam holes and experiments
in beam holes, experiments in the core, burnup, low cross
section fission products, and Xe and Sm poisoning. It may
also be necessary to introduce an incremental fuel element
to reach criticality, thus introducing excess reactivity
over and above that needed to overcome the previous
effects.

The degrees of hazard posed by these sources of ex-
cess reactivity are not all of the same magnitude. The
excess reactivity sources can reasonably be divided into
those sources overriden by shim rods and those counter-
balanced by loading. There is a justifiable agrument as
to which group the core experiments should be assigned
but the other sources fall logically into place.

Two different operating schedules are

summarized in Tables A I and A II.

Table A I

EXCESS REACTIVITY REQUIREMENTS FOR <u>MONTH LONG</u> RUN

AT A CONTINUOUS POWER LEVEL OF 1 MEGAWATT

Source of Reactivity Effect	Reactivity Effect
Loading Controlled Beam holes (4 six inch) (2 eight inch)	.0145
Beam hole experiments	.0026
Core experiments	< .0160*
Sub-total	< .0331
Rod Controlled 20° F. temperature rise	.0012
28 gm incremental fuel element	.0017
low cross section f.p.	.0006
burnup	.0018
Sm	.0040
Xe	< .0175
Sub-total	< .0268
TOTAL	< .0599

* This figure will be held as low as possible and in no case will exceed .0160 $\Delta K/K_{eff}$

Table A II

EXCESS REACTIVITY REQUIREMENTS FOR FIVE DAY A WEEK,

NINE HOUR A DAY OPERATION AT 1 MEGAWATT POWER LEVEL

Source of Reactivity Effect		Reactivity Effect
Loading Controlled	Beam holes (4 six inch) (2 eight inch)	.0145
	Beam hole experiments	.0026
	Core experiments	< .0160*
	Sub-total	< .0331
Rod Controlled	20° F. temperature rise	.0012
	28 gm incremental fuel element	.0017
	burnup plus low cross section f.p.	.0002
	Sm	.0004
	Xe	< .0087
	Sub-total	< .0122
	TOTAL	< .0453

Figure 1 is a graphical presentation of the excess reactivity which must be rod controlled for long continuous runs at a power level of 1 MW. Figure 2 is a graphical

---

* This value will be held as low as possible and in no case will exceed .0160 $\Delta K/K_{eff}$

presentation of the reactivity required to operate at 1
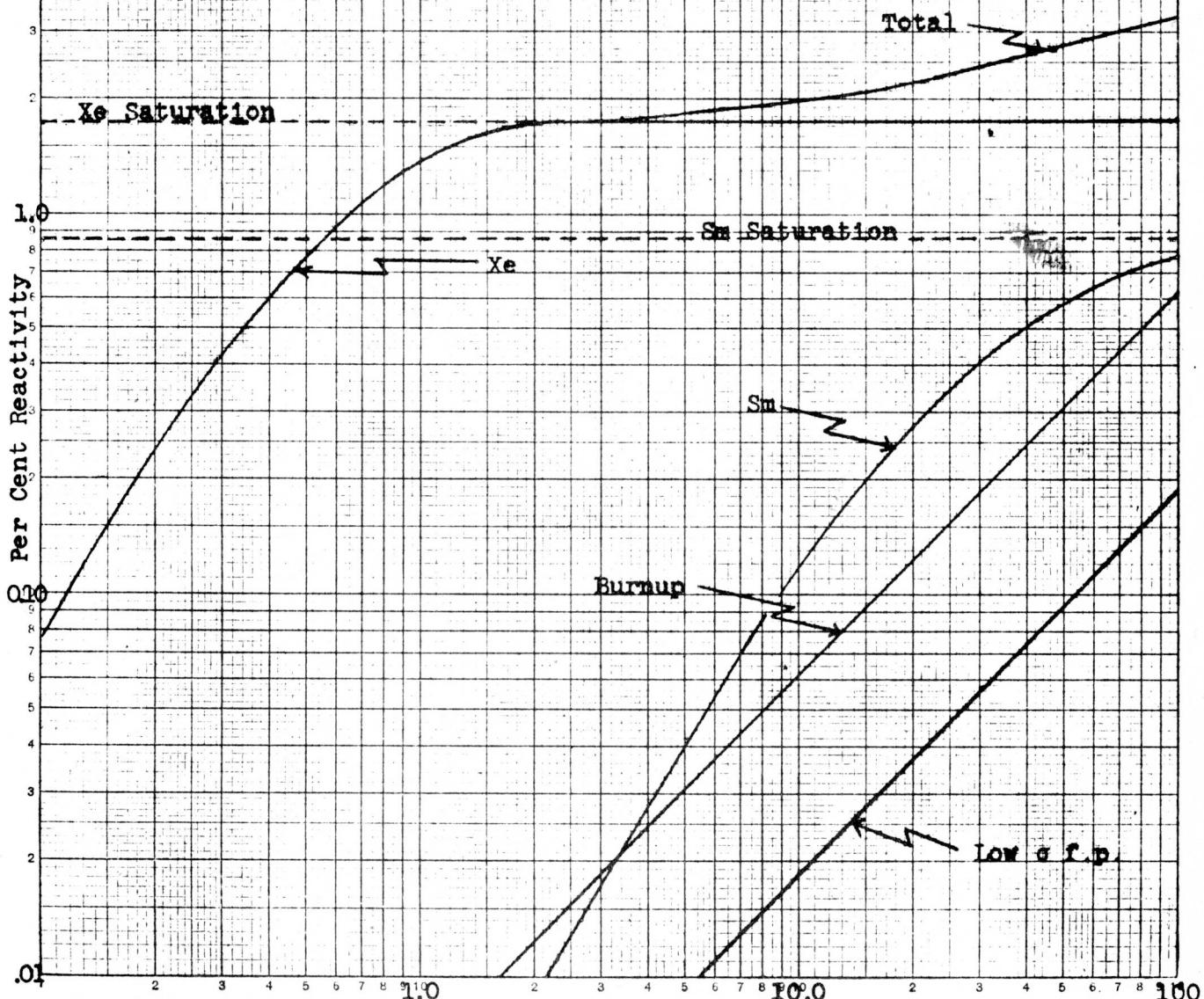MW power level nine hours per day, five days per week.

Phoenix Project #75 predicts from their analysis of
the borax data[4] that at an operating temperature of
90° F. a step introduction of .0188 reactivity is necessary
to melt the hottest fuel element.

Numerous operation schemes which mitigate the rod
controlled reactivity problem are conceivable. For ex-
ample, to operate for one month at 1 MW a short shutdown
could be made in which an incremental fuel element is
added to the reactor. Thus, the rod controlled reactivity
need never exceed 1.6 per cent $\Delta K/K_{eff}$.

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Figure 1.

Reactivity Changes During Continuous
1 Megawatt Operation ($\varphi_0 = 5.5 \times 10^{12}$)

Days of Operation

at 1 Megawatt

23-24
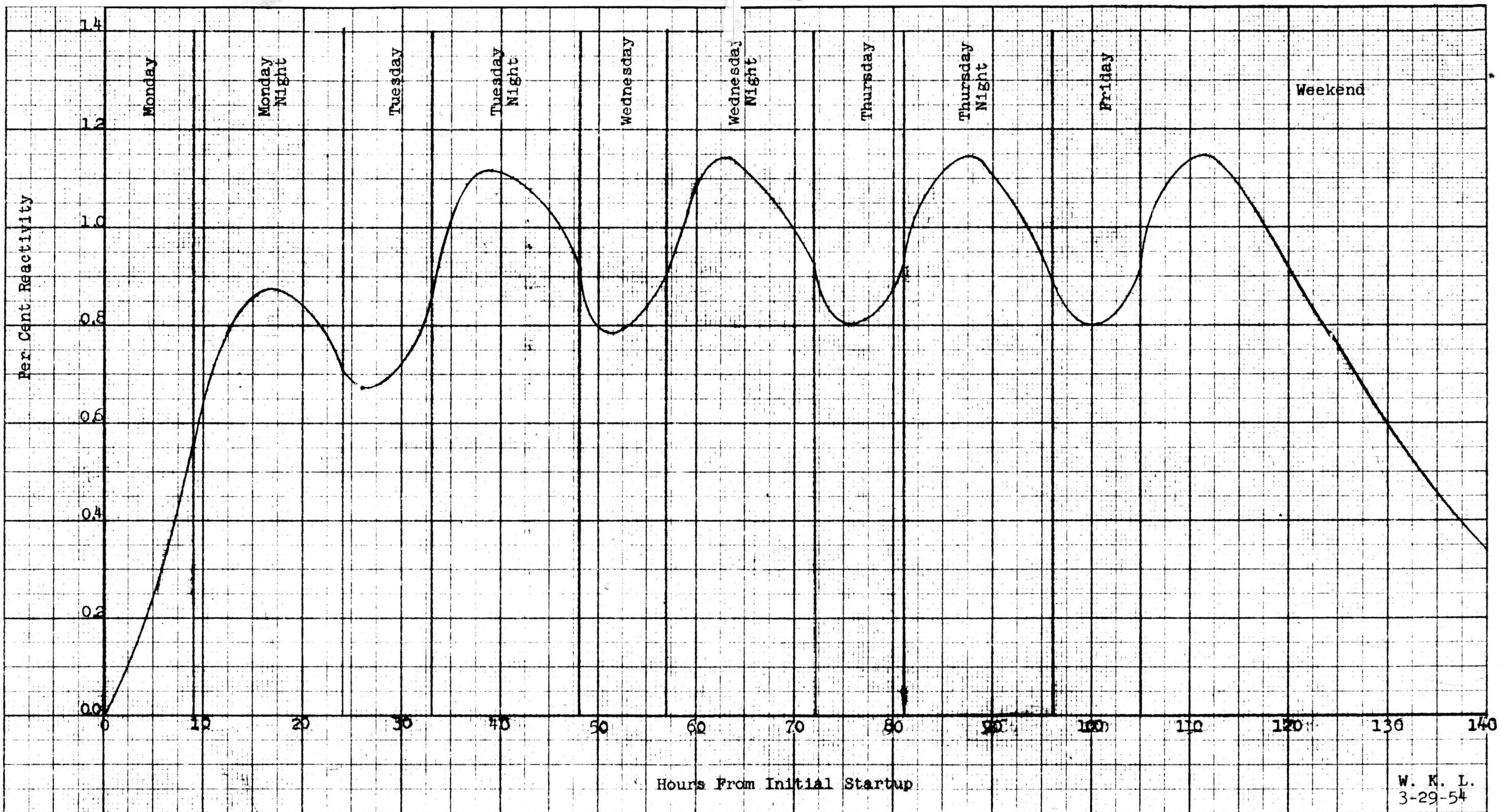
Fig. 2--Reactivity changes during daily operation at 1 megawatt ($\varphi_O = 5.5 \times 10^{12}$).

The graph axes:
- Y-axis: Per Cent Reactivity (0.0 to 1.4)
- X-axis: Hours From Initial Startup (0 to 140)

Column labels across the top: Monday, Monday Night, Tuesday, Tuesday Night, Wednesday, Wednesday Night, Thursday, Thursday Night, Friday, Weekend

W. K. L.
3-29-54

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Appendix B

TENTATIVE POWER LEVEL SCHEDULE
FOR FIRST YEAR OF NUCLEAR OPERATION

Prior to the charging of the first fuel loading the
cooling system, instruments, and control components will
be given a complete shakedown. The first critical experi-
ment will mark the beginning of nuclear operation. The
various activities of the first year of nuclear operation
cataloged under their respective power levels are visu-
alized as follows:

Zero Power Operation (3 months)

    1. Critical experiments on various lattice
       and reflector configurations

    2. Statistical weight experiments

    3. Control rod calibration

    4. Temperature coefficient (external heat)

Low Power Operation - 0 to 100 KW (5 months)

    1. Gain operational experience

    2. Temperature distributions

    3. Instrument calibration

    4. Shielding measurements

    5. Water activity

6. Flux distribution and measurements

7. Performance of control system

Gradual Power Increase To 300 KW (1 month)

1. Performance of reactor with forced circulation cooling

2. Water activation

3. Shielding studies

4. Temperature distribution

5. Performance of secondary cooling system

Operation Up To 1 MW (8 - 24 hours operation spread over two week period)

1. Performance of cooling system

2. Water activation

3. Shielding studies

4. Temperature distributions

Operation Up To Authorized Power Level (3 months)

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        November 1948

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3. Letter from Dr. Hymer L. Friedell, Western Reserve
   University, to Lawrence C. Widdoes, Project Engineer,
   Phoenix Project #75 March 15, 1954

4. MMPP 75-1

931 027

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