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TITLE

NPR PHYSICS STARTUP TESTING PROGRAM

7

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C. E. Bowers

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January 7, 1963

M. C. Leverett, Manager
Research and Engineering
N-Reactor Department

W. M. Mathis, Manager
N-Reactor Plant
N-Reactor Department

NPR PHYSICS STARTUP TESTING PROGRAM

Ref: HW-72345, "NPR Physics Startup Testing
Program," C. E. Bowers, April 25, 1962

The referenced document outlines, and describes in considerable detail, the proposed N-Reactor physics startup testing program. This document is being used as a working basis for the preparation of detailed procedures and arrangements for the startup tests.

The referenced document was issued and approved prior to the organization of the N-Reactor Department; thus, the approval signatures which appear, with the exception of Mr. Mathis', are no longer valid.

Since some six to nine months will elapse before final documentation and approval of the detailed test procedures and arrangements can be completed, I feel that it is appropriate that N-Reactor Department Management approval be obtained now for the referenced document, which still forms the basis for detailed startup test planning.

The document does, of course, contain a few minor errors which can now be corrected. In addition, the assignment of responsibilities for the planning and execution of the physics testing should be revised to reflect the reorganization. However, the intent and technical content of the document remain clear; therefore, to expedite the completion of the detailed physics testing procedure a revision sheet has been prepared which lists all

corrections, and changes associated with the new organization.
It is requested that the document be re-approved as revised,
and that the revision sheets and new approval sheet be attached
to the original document.

W. S. Nechodom, Supervisor
Process Physics

Approved: R. E. Trumble, Manager
Process Evaluation and Control

WSN:bh

Enclosures: Approval sheet
Revision sheets

cc: TW Ambrose	JE Kaveckis
ER Astley	HR Kosmata
GF Bailey	MC Leverett
JL Benson	CG Lewis
CE Bowers	WM Mathis
JH Brown	WS Nechodom
AC Callen	R. Nilson
RD Carter	RW Reid
DL Condotta	OC Schroeder
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RT Jessen	

APPROVALS: HW-72345, "NPR Physics Startup Testing Program,"
C. E. Bowers, April 25, 1962, as modified by
attached revisions.

Manager, Process Evaluation and Control
Research and Engineering Section
N-Reactor Department

Manager, Research and Engineering
N-Reactor Department

Manager, N-Reactor Plant
N-Reactor Department

REVISIONS

1. P. 7, Para. 3, last sentence should read, "... through joint efforts of Research and Engineering, and N-Reactor Plant personnel."
2. P. 13, Para. 1, first sentence should read, "... through joint efforts of N-Reactor Plant, and Research and Engineering."

Para. 4 should read, "... from Facilities Engineering Section, IPD, and from the Hanford Laboratories Operation."
3. P. 18, Sentence 3 should read, "N-Reactor Plant personnel, with the direct assistance of Research and Engineering Section personnel,"
4. P. 22, 2.1.1, Para. 1, first sentence should read, "... arranged by the Research and Engineering Section)"

Para. 2, first sentence should read, "... two perforated tubular carbon steel elements"
5. P. 25, 2.1.4, a., last sentence should read, "... jointly by Research and Engineering, and N-Reactor Plant personnel"
6. P. 26, 2.2, Para. 1, first sentence should read, "... are to be performed by N-Reactor Plant personnel except that used specifically by Research and Engineering personnel"

2.2, Para. 1, references to the Operational Physics Operation should read, "Research and Engineering Section."
7. P. 27, 2.4.1, paragraphs 4 and 5. References to Operational Physics should be changed to "Research and Engineering."
8. P. 30, 10. Dummy aluminum should be changed to "Dummy steel."
9. P. 38, 2.4.9, Para. 2, sentence 2 should read, "... since the reactivity transient will occur during a change of 160C in reactor core temperature by the process"
10. P. 42, 3.1.1.3, Responsibilities should read: Research and Engineering Section
N-Reactor Plant Section
(HLO assistance)
11. P. 48, 3.1.2.3, Responsibilities should read: Research and Engineering Section
N-Reactor Plant Section
12. P. 49, 3.1.3.3, Responsibilities should read: Research and Engineering Section
N-Reactor Plant Section

3.1.3.4, Para. 1, should read, " ... the array has $\sim$ 200 tubes.

13. P. 50, 3.1.4.3, Responsibilities should read: Research and Engineering Section
N-Reactor Plant Section
 14. P. 55, 3.1.5.3, Responsibilities should read: Research and Engineering Section ..
N-Reactor Plant Section ...
NPR Project Section ...
 15. P. 58, 3.1.6.3, Responsibilities should read: Research and Engineering Section
N-Reactor Plant Section
 16. P. 62, 3.1.7.3, Responsibilities should read: Research and Engineering Section
N-Reactor Plant Section
 17. P. 64, 3.1.8.3, Responsibilities should read: Research and Engineering Section
N-Reactor Plant Section
Hanford Laboratories Operation
- Remarks should read: Details will be worked out by HLO and
Research and Engineering Section
personnel.
18. P. 65, 3.1.9.3, Responsibilities should read: Research and Engineering Section
N-Reactor Plant Section
 19. P. 78, 3.1.10.3, Responsibilities should read: Research and Engineering Section
N-Reactor Plant Section
Hanford Laboratories Operation
 20. P. 83, Para. 2, sentence 5 should read, "... by mutual agreement between the
Research and Engineering Section, and the N-Reactor Plant Section"

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NPR PHYSICS STARTUP TESTING PROGRAM

By:

C. E. Bowers

Operational Physics Sub-Section
Research and Engineering Section

April 25, 1962

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NPR PHYSICS STARTUP TESTING PROGRAM

Introduction and Purpose

The New Production Reactor, as compared to existing Hanford reactors, employs new and unique design concepts. To properly evaluate these design concepts and their effects on reactor operations, nuclear safety, and reactor life, a comprehensive testing program is planned; this program, with its objectives and restrictions, is discussed in this report. It has been developed along the same line as the C and K Reactors test programs, and is expected to require a total time of 6-8 weeks of round-the-clock testing. This estimate includes fuel loading time, but does not include time allotments for engineering acceptance tests prior to power operation nor does it include any of the time necessary for engineering and physics tests during the extensive power ascension program.

The purpose of the NPR Startup Physics Testing Program is simply to obtain as much basic physics information as possible, within the obvious bounds of reason and economics, before the reactor is released for routine operation. An earlier report^{/1/} summarized the broad area of physics information deemed necessary for operation within established efficiency and safety criteria; the latter document was circulated for comments as to "appropriateness, practicability, and completeness of the functional outline." This document, which utilizes the solicited comments, will authorize the contained itemized listing of the tests required to determine physical "constants" presently considered worthy of (and amenable to) measurement during pre-operation reactor testing.

The main body of this report is presented in three parts. The first section describes startup hazards and restrictions, reactor and component safety provisions prior to loading, and the itemized listing of quantities to be measured. The second includes preliminary material and plant conditions and a brief description of the individual tests. The third section (the Appendix), written in procedure language, comprises a rather detailed description of each individual test on a tentative basis; final test details and procedures, which will lie within the boundaries authorized by this document, will be established through joint efforts of Operational Physics and NPR Operations sub-section personnel.

This document authorizes the procurement of the data listed in the table on page 19. The detailed procedures mentioned above, and provided prior to startup, will generally follow the basic outlines presented in Appendix I. Any significant deviation in additional time requirements, safety implications, or scope of the test program will be requested in a supplementary approval document covering the specific deviations.

Summary

The entire test program, from initial loading to preparation for production operation, is described.

After it has been determined that all components are functioning as expected, that safety circuit trips are properly set, and that all instrumentation is responding properly, the loading will begin. Standard NPR fuel elements, approximately 2 feet long, 22 lbs/foot, 0.95 per cent U-235, will be loaded. Initial charges will have

/1/ HW-68373, NPR Startup Physics Tests - Part I - Functional Requirements
C. E. Bowers, 2-1-61

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the standard downstream dummy charge, will be one fuel element short of full length, and will have no upstream dummies. The reactor atmosphere will be ~100 per cent helium.

The minimum wet critical configuration will require approximately 200 tubes in a rectangular array with a wet reflector whose nuclear effect will differ only slightly from a dry reflector. Water flow during early charging will be initiated in some tubes just prior to charging, with a minimum of 84 tubes initially dry. The effect of water in the "reflector" will be determined during early loading. There will be no dry critical test; dry lattice reactivity will be determined in single column and block tests to follow.

The loading will be increased incrementally by sufficient additional tubes to provide an excess reactivity of ~2 milli-k, controlled by rods just grazing the core (i.e., rod penetration into the active lattice and its accompanying disturbance of lattice characteristics will be avoided). During the loading increase the final element will be added to the original short charges and all succeeding charges, and the migration area in three dimensions will be determined by observing the multiplication-versus-leakage relationship as the pile effective size is increased.

With the pile excess held at ~2 milli-k, single column reactivity effects will be measured for various flattening and non-standard charges. The pile will then be uniformly heated by converting pumping power to heat through steam injection into the primary pumps (ATP-2405, included as Appendix III) and the temperature-reactivity relationship studied. Subcritical monitoring techniques will be used here.

The pile reactivity will be increased to ~12 mk and a block test to measure natural uranium (and possibly "E-N" loading) multiplication performed.

The local strength of the horizontal rod and ball 3X systems will be determined by inserting selected arrays of controls into a configuration of known reactivity and measuring the resulting changes. The effects of lattice temperature and rod coolant loss on control strength will be estimated by utilizing data from this test and the earlier temperature-reactivity measurements. Control response time will be determined.

The pile loading will then be completed, and control and safety system capacities measured. The rod system will be calibrated over about two-thirds of its range; expected startup and equilibrium configurations will be evaluated; isotope rods, if any, will be surveyed. An additional check on temperature versus lattice reactivity will be made by heating the fully loaded pile to ~500°F through the heating process of ATP-2405. An attempt will be made to separate metal-coolant temperature effects from the moderator effect by sharply reducing inlet temperature in steps and observing the reactivity transient, utilizing subcritical techniques, as the moderator cools; system feedback effects will be observed during the process.

The nuclear instrumentation will be checked and calibrated during the test program. Special chambers will provide extra sensitivity during early stages of loading;

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they will furnish information and feed into the reactor safety circuits through normal (operating) recorders and meters. At an appropriate point in the process (when core fluxes near normal chamber positions are high enough for good sensitivity) the monitoring process will be "turned over" to the standard operating chambers. During and after completion of the loading, all regular nuclear instrumentation will be calibrated and tested for proper safety system response. Final checkout will occur during the power ascension program, in which the power level will be increased in steps and held constant at selected low levels to facilitate safety circuit testing and allow complete radiation surveys of the entire reactor complex.

Final operating rod calibration and xenon-samarium transient measurements will be taken following a shutdown from equilibrium conditions after the reactor has been run productively for several weeks. These tests will be described in detail in separate documentation as required, but an estimate of their time requirements is included in this authorization report.

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PART 1: Preliminary Considerations

This section deals with justification, hazards, component conditions, and other items which are of necessity considered prior to loading.

1.1 Justification

It is inherently impossible to place an exact monetary value on the benefits derived from any reactor startup program; nevertheless, there is no doubt that past test programs have more than paid for themselves in increased production, to say nothing of improved safety characteristics. Present reactor flattening efficiencies, startup methods, and general operating control techniques are in part directly traceable to knowledge gained during original startup tests. For both safety and efficiency reasons, it is prudent that the physical parameters of the process be known.

In NPR, the need for pre-operation experimental measurements is even more pronounced than at existing reactors. N Reactor is quite large, with a comparatively high k_{∞} (1.075 compared to ~ 1.040 at the K Reactors) which is strongly dependent upon operating conditions; furthermore, the control system is large and versatile. Therefore, there is virtually an unlimited number of different operating conditions possible, with an accompanying unlimited number of critical rod configurations. Obviously, some of these conditions and configurations will be more efficient than others, and it would of course be desirable to determine the optimum set of operating procedures for each given reactor condition. Such optimization depends quite naturally upon the degree to which reactor parameters are known; exact knowledge can be gained only by physical measurement.

The question occasionally arises: "Is it not possible to measure all necessary quantities during regular productive operation?" The answer is a qualified yes; necessary quantities may be estimated during productive operation, but never again will the opportunity arise to conduct closely controlled, laboratory-caliber experiments in the relatively uncluttered environment of the unirradiated reactor. Measurement accuracy attainable at this time can never be duplicated.

The proposed startup program requires approximately four to six weeks. Based on a twenty-five year reactor life, the tests would pay for themselves if they resulted in even one-half per cent increase in efficiency; there is little doubt that improved physics knowledge has been responsible for considerably more than one-half per cent production efficiency improvement in existing reactors. The primary justification for startup physics is of course the prevention of unsafe and inefficient operation due to insufficient knowledge of reactor parameters.

1.2 Analytical Methods

Since the K Reactor startup tests, powerful tools have been developed for the analysis of experimental results; these are the various multi-energy-group computer codes. These codes allow accuracy and detail that were

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impossible to attain with one-energy-group approximations. In the case of NPR, use of such multi-group techniques is almost mandatory, since the undermoderated lattice results in a relatively high fast-to-thermal neutron flux ratio.

Specifically, these tests have been designed and will probably be analyzed by recourse to the three-energy-group IBM Code SWAP^{2/} in its latest form. This code was utilized extensively in the PRTR startup program, and satisfactorily predicted all test phases.

1.3 Hazards and Restrictions

Because the reactor is being operated for the first time, and many variables are unknown or highly uncertain, certain hazards will be less defined than will be the case during subsequent normal operation. In addition, of course, the normal hazards associated with routine reactor operation will be present. The net effect will be to impose certain restrictions on all portions of the experimental program to guarantee reactor and personnel safety at all times.

The hazards peculiar to the startup test program may be broken down into two broad categories, Radiation Protection and Operating Hazards. The first of these includes all aspects of irradiated material handling; the second encompasses operation of a previously untried nuclear reactor, with instrumentation and controls not yet calibrated for the specific loadings of the test program. The two categories will be discussed separately.

1.3.1 Radiation Protection

All work in radiation zones associated with this test program will be done under necessary radiation monitoring coverage and on special work permits subject to NPR Operations approval. Contaminated radiation zones will be kept to a minimum; those existing will be clearly marked. No radiation exposure will be permitted in areas frequented by construction personnel. "Dry runs" of startup test procedures involving potentially significant radiation exposures will be made in advance.

Since irradiated material will be manually removed from the reactor, special considerations are required. In general, any material removed from the reactor must be dumped into the storage basin if the exposure rate from individual elements is over 50 mr/hour at one foot. Any conditions of higher exposure rates, such as might be encountered with foils and pins used in flux traverses, will be carried out only under full monitoring conditions. Material with lower readings may be re-used if practical.

The existence of neutron and gamma beams is possible in NPR, due to the large void volumes associated with the steam venting system.

^{2/} Adapted from Program F3 - IBM 704, Three-Group Neutron Diffusion Calculation, JG Keppler et al, by J. R. Lilley, J. J. Regimbal, G. F. Bailey, et al

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No access will be allowed to any location until it has been determined that no beams are present, or existing beams have been evaluated.

1.3.2 Operating Hazards

Procedures, backed by special instrumentation, will be designed to preclude operating hazards during the test program. The reactor safety circuit will be energized during all periods of fuel loading or operation, and all reactor components will be normal and unbypassed, including normal reactor control systems and instrumentation to the extent they would perform their intended function in the reactor as loaded. In addition, special neutron level monitors will be inserted at points of high sensitivity in and near the loading; some of these special monitors will be included in the safety circuits; others will serve as indicators for manual action. At least two monitors will be calibrated for activity versus neutron flux, so that power levels for the small loadings may be estimated directly from count rates; neutron level trips will be set at 1-10 kw (reactor total power) during small pile tests.

During the entire test program, primary safety responsibility will be limited to two people, the designated responsible physicist and the Operations manager or designate. The designated physicist will personally direct all actions which may increase the reactivity of the system. Any nonroutine decisions will be made jointly by the two responsible persons. Ultimate responsibility for the safety of the reactor rests with the Operations Manager or his delegate; commensurate with this responsibility, he also has the final authority with regard to terminating or preventing actions which he deems unsafe. Although physics personnel will be taking many readings on reactor instrumentation, only Operations personnel will handle any control activation devices.

In the approach-to-critical experiment, the initial loading is designed to be considerably subcritical. Instrument responses will be carefully observed for normalcy before additional fuel is charged. After the loading reaches an estimated 50 per cent of critical size, a new critical size estimate will be made after each three columns are added, until the pile multiplication reaches an estimated 0.99; from this point, a new critical estimate will be made after each additional column is charged. All criticality estimates will be made by extrapolating the inverse count rate ($\frac{1}{n}$) to zero. The safety circuit will be activated during all loading and monitoring phases. Horizontal rods 44, 46, 55, 64, and 66 may be reserved for the setback function and used for all planned shutdowns.

Appendix II describes period measuring techniques and associated safety precautions in detail.

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1.4 Special Instrumentation and Equipment

Exact specifications for neutron sensitive chambers to be used for rate of rise and level protection are to be established through joint efforts of N Operations and Operational Physics personnel prior to the startup program. Such chambers must meet four basic requirements:

1. They must meet the criterion of adequate sensitivity to provide automatic shutdown prior to fuel damage for any credible reactivity ramp situation.
2. They must possess adequate sensitivity to give good statistics in a subcritical pile; this indicates use of BF_3 proportional counters or equivalent.
3. They must be less than 4-1/2" in diameter, and preferably less than 2" to fit into the available stack openings.
4. At least three chambers meeting requirement (1) above must be compatible with the permanently installed nuclear instrumentation to allow easy makeup of the safety circuits.

Two of the ionization chambers will be located in traverse opening No. 5, and one in traverse opening No. 4, size permitting. If it is impossible or impractical to obtain suitable chambers of this small size, rods 35, 47, and 65 will be removed, and the associated 4-1/2" square channels made available for larger chambers. In either event, the chambers will feed into the Number 1 Safety Circuit through the operating level recorders. These chambers will remain in the scram circuit until the pile is loaded sufficiently to provide a good shutdown background signal through normal subcritical monitors. At this point (to be established on the spot), loading will be halted and will continue only after the low level instrumentation is restored to normal (i.e., chambers in normal locations are included in the safety circuit), and any associated rods returned to service. See Figures I-A and I-B for expected chamber locations.

In addition, highly-sensitive fission-chamber instrumentation will be required for count rate monitoring during temperature effect measurements.

Consultation and mechanical assistance with the procurement and operation of all special equipment will be solicited from Facilities Engineering Operation and ELO.

FIGURE I-A
APPROXIMATE INSTRUMENT CHAMBER
LOCATION FOR INITIAL CRITICAL LOADING

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FIGURE 1-B

SCHEMATIC OF INSTRUMENT CHAMBER LOCATIONS AT
CRITICAL LOADING

(P_1) (P_2) BF_3 Proportional Chambers
 (C_1) (C_2) (C_3) Ionization Chambers
 (In safety circuit)

1.5 Neutron Spatial and Energy Distributions

Since the K Reactor startup tests, major advances have been made in the field of lattice analysis based on experimentally determined energy-related flux distributions. Detailed knowledge of the neutron energy spectrum is now possible utilizing irradiated metallic foils with known nuclear characteristics, and various multi-group computer codes to mathematically fit observed flux distributions. An extensive program is scheduled for NPR startup.

Final measurement procedures and details will be worked out with the cooperation and assistance of Hanford Laboratories experimental groups, and are outside the scope of this document. It is intended that the integrated test program include conventional thermal flux and cadmium-ratio measurements, plus more sophisticated (and inherently more difficult) spectral measurements. (For example, fast neutron spectral measurements utilizing photographic plate techniques, and neutron temperature measurements employing Lutetium foils, will be attempted.)

Locations of traverses is easier to specify. Foil traverses will be run in process channel 1757, graphite cross-cooling channel #1890, and Ball 3X channel #49; during traversing, the ball channel will be bypassed from the safety circuit.

This portion of the test program does not affect the basic safety instrumentation requirements of the startup, nor pose any significant reactor time or safety problems.

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FIGURE II

SCHEMATIC OF FOIL TRAVERSE LOCATIONS

- Ⓐ BALL 3X CHANNEL 49
- Ⓑ GRAPHITE COOLING CHANNEL 1890
- Ⓒ PROCESS CHANNEL 1757

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1.6 Detailed Experimental Procedures

It is not the purpose of the present report to supply detailed operating procedures for the entire test program; rather, it is intended that this document serve as the basis, justification, and outline for the tests. Data requirements are listed, and ground rules established; operational details must of necessity be generated with operational personnel. N Reactor Operations, with the direct assistance of Operational Physics Operation, will provide a step-by-step, detailed guide, covering the entire test program from initial loading to normal operating level. The detailed procedures will be available several weeks prior to actual start-up, and will be similar in format to Appendix I of this report.

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Page 191.7 List of Planned Measurement Categories in Probable Sequence

<u>Reactor Parameter</u>	<u>Reasons for Measurement</u>	<u>Method</u>	<u>Associated Problems, Remarks</u>	<u>Approximate Time Req'ts, Hours</u>
1) Minimum Critical size	Basis for most of succeeding test program; defines k_{∞} of lattice	Load fuel in planned sequence; monitor neutron count rate and plot inverse ($\frac{1}{n}$); critical occurs at point where plot extrapolates to zero.	Critical size is extremely small, and consequently hard to define accurately. Reflector augmentation difficult to measure due to thermal flux peaking.	72
2) Migration area	M^2 is a basic lattice constant necessary to determine k_{∞} and excess reactivity of full loading.	Determine slope of $mk/\mu b^*$ by charging tubes beyond critical size and measuring resulting pile periods, plus subcritical counting to relate k_{eff} of subcritical pile to count rate.	Must be run in at least 2 dimensions; difficult due to large reactivity increase per column. Space-dependent due to rectangular lattice and graphite anisotropy.	36
3,4) Single column and block reactivity measurements	Determine relative reactivity effects of a number of materials not designated as primary fuels.	Measure change in reactivity of small supercritical loading as central column(s) is (are) replaced by test material.	Small pile effects must be converted to full-pile effects by analytical processes.	96
5) Lattice Temp. reactivity relationship in unpoisoned lattice	Determine lattice reactivity and control strength changes resulting from temperature variations.	Increase temperature in small pile by heating process of ATP-2405; determine reactivity variations by subcritical counting techniques.	Time-consuming due to slow heating rate of ATP-2405; uniform temp. distribution which results is not representative of operating cell gradients.	96
6,7) Local Strength of Rod and Ball 3X Systems	Necessary for hazards analyses and operating restrictions.	(1) Insert rod(s), and (2) drop selected columns(s) of balls into small loading near critical; add fuel in regulated manner to re-establish respective criticals.	Possibility of added rows or columns not being complete, requiring approximate interpretations. Some discharging of fuel may be required at some stages.	84

* "Milli-k per micro-buck"

1.7 List of Planned Measurement Categories in Probable Sequence (Cont'd.)

<u>Reactor Parameter</u>	<u>Reasons for Measurement</u>	<u>Method</u>	<u>Associated Problems, Remarks</u>	<u>Approximate Time Req'ts, Hours</u>
8) Lattice Parameter Measurements	Obtain as much information as possible about lattice; e.g., flux distributions, neutron energy distributions, resonance integral, cadmium ratios, etc.	Foil and pin traverses, ion chamber monitoring, etc., in both small loadings and fully loaded pile.	Handling of irradiated materials. Coordination of these measurements simultaneous with other tests.	--
9) Control and safety system capacities in fully loaded reactor	Determine capability of systems to stop and control nuclear reactions in reactor; measure flexibility of rod system for operating control.	Find minimum number of control elements required to hold unit subcritical; sequentially calibrate rod system as a whole and as selected configurations by use of artificial poison transient.	Time consuming; large potential reactivity of full pile necessitates.	144
10) Full pile temp. transients, control strength, and base configurations	Operational optimization (temperature coefficients); safety and control studies; coolant loss studies, system feedback effects; establishment of check-point configurations for later long-term reactivity change evaluations.	Heat pile by process of ATP-2405; determine number of elements required to hold subcritical. Measure pile reactivity variation as function of uniform lattice temperature. Plan rod configurations feasible for repeat during later operations.	Same as small loading test (4) above.	96
11) Preoperational checks, instrument calibration, etc.	Determine response and limitations of reactor instrumentation before significant power level is reached.	Record response to known reactivity and operating conditions.	Will be conducted largely by assigned N Reactor Physicist with assistance of startup physics team.	72
12) Final HCR calibration and xenon transient measurement	Check and improve preliminary calibrations of (7) above.	Utilizing xenon transient after significant exposure has been logged, calibrate rod system in planned withdrawal order.	Time-consuming; will require high xenon concentration and consequently will probably be run weeks or months after rest of test program is complete.	72

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Figure III

Flow Chart for Startup Testing (Minimum Time Estimate)

PART 2: General Test Conditions and Descriptions

The test program is described from the standpoint of reactor and component conditions, material requirements, water flow, specifications, safety requirements, division of responsibility, and scheduling details. Each individual test is described in a generalized summary.

2.1 Startup Conditions

It is expected that all critical reactor components will be normal and functioning before loading commences. Detailed test procedures, to be issued prior to actual start of loading, will include specific requirements and allowable relaxations. In general, the following conditions will hold at the beginning of testing:

- 2.1.1 Approximately 400 tons of production quality primary fuel (plus small quantities of special materials whose availability will be arranged by Operational Physics Operation) should be available prior to the start of the loading. In addition, approximately ten tons each of reject natural and enriched uranium will be required. The reject material will receive essentially zero irradiation, and so will be available for recanning or possible use in any separations "shakedown" tests (e.g., zirconium removal process). Preliminary contacts* indicate an interest on the part of CPD in small quantities of fuel for such purposes.

The standard downstream dummy pattern will be used for all charging; this is made up of two perforated tubular aluminum elements each 13.875 inches in length, and four elements each 27.75 inches in length. After the initial critical loading is complete, all charges will include an upstream dummy charge identical to the downstream dummy pattern.

2.1.2 Process Water

In general, very little heat (maximum 10 kw) will be generated in the fuel during the startup testing program. Furthermore, coolant flow rates and purity requirements, from a physics standpoint, are not particularly stringent during this time. Therefore, general water characteristic specifications will be based on engineering requirements.

Full flow capability is desirable by the beginning of Test #5, Lattice Temperature Coefficient Measurement; by this time, all three loops will have been checked out and found normal.

The reactivity effect of the graphite cross-cooling system will be measured by noting the difference in reactivity due to introduction of water into the system in the critical size loading; the cross-coolant system should thus be drained prior to and during the loading to initial critical.

During the initial loading-to-critical process, selective flow patterns are required to determine the effect of water in the reflector. The following tubes are to be maintained in the dry condition until after the first seventy charges are loaded:

*Personal Communication - R. G. Barnes, October, 1961

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1552 through 1564	13 tubes
1652 through 1664	13 "
1752 1952 2152 2352	
1753 1953 2153 2353	
1763 1963 2163 2363	
1764 1964 2164 2364	32 "
1852 2052 2252 2452	
1853 2053 2253 2453	
1863 2063 2263 2463	
1864 2064 2264 2464	
2552 through 2564	13 "
2652 through 2664	13 "
Total	84 tubes

Each of the process tubes in the above list will be in the following condition prior to commencing loading:

- The inlet "butterfly" valves will have stops set* in the zero flow position.
- The outlet valves will be specified for tube flow to diversion in the rear.
- The diversion riser will be in the drained condition.
- Front and rear nozzles will be uncapped.

After the first 71 tubes are charged, flow will be restored to the above listed tubes, and loading will proceed. The time required for restoring flow to the 84 initially dry tubes is estimated to be ~10 man hours (3 men, ~3.5 hours each concurrently). This time requirement is justified for 84 tubes on the basis of the physics data obtained; it is assumed that the associated butterfly valves will be initially installed with stops set at zero flow.

Perfect dryness is desired, but is not essential for this phase. It is, however, necessary in the single column measurements on dry enriched and natural uranium. It may be necessary to insert a blanking flange in the inlet nozzle, and remove the residual water from the process tube by either swabbing or suction (using, for example, a small diameter flexible vacuum tube). This drying process, will be necessary only once, in tube 1758; it will be desirable to dry charge the tube twice, and a suitable lubricant will be required. The feasibility of dry charging is currently under study and will be determined by a mockup test.** (In the event that dry charging causes intolerable damage, it will be necessary to develop some means of evacuating essentially all the water from a fully charged tube.)

*The inlet butterfly valves may be modified during or after installation in such a way that it will not be possible to adjust the valve to a zero flow condition. If this is done before the physics test program, special provisions will be made to leave the 84 tubes unmodified and to ensure that their butterfly valves are modified after the tests are completed. If a blanking flange is used in the inlet nozzle for the single dry column tests, this flange should be installed in such a way that it will be very conspicuous and/or other arrangements should be made in order to minimize the chances of starting up the reactor without removing this flange.

**Personal Communication, H. D. Lenkersdorffer, April 10, 1962

FIGURE IV

INITIAL WATER FLOW CONFIGURATION

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The process for isolating and drying this individual tube will consist of setting the valve stop to zero flow, diverting to drain in the rear, uncapping both ends, and evacuating the water.

During the dry natural uranium block test, it will be sufficient to divert flow and uncap both ends of the tubes; the effects of residual water is considered to be small and tolerable. (See shaded area, Figure X, for location of natural uranium block.)

2.1.3 Reactor Atmosphere

The reactor gas composition should be 95-100 per cent helium when the first critical size loading is complete.

2.1.4 Safety Requirements

Safety conditions will be checked with special care, with the following conditions individually met prior to loading:

- a. It must be ascertained that all components of the HCR and Ball 3X Systems are functioning properly, and that associated safety circuits are made up and correctly set (any allowable by-passes to be specified in detailed test procedures to be written later). At the beginning of actual loading, all low-level trips will be set at positions corresponding to 10 kw or less. Subsequent trip settings will be determined jointly by Operational Physics and N Operations personnel, and will correspond to ≤ 150 per cent of anticipated levels.
- b. All reactor instrumentation, including water flow, temperature, and nuclear monitoring equipment, should be checked for operability prior to commencement of loading. This includes normal operational instrumentation in all three level ranges, plus the additional instruments especially procured for the experimental program.
- c. At least one of the proportional counters to monitor approach to critical must be located immediately adjacent to the loading and moved as necessary as the loading progresses; it must have been previously calibrated in the standard pile to relate count rate to neutron flux; another previously calibrated counter will be located in the center process channel until the critical state is reached.
- d. Three ionization type chambers will be installed in positions in or adjacent to the loading; two will be located in traverse channel #5 (a 2"x3" hole penetrating the reactor from side to side) and one in traverse opening #4. All three chambers will be connected in the safety circuit through the standard level-trip instrumentation, utilizing a minimum of two which will be

unbypassed at all times. Sensitivity requirements and other details will be worked out several months prior to startup; the objective will be to provide chambers compatible with the normal safety circuit instrumentation. (If chambers of the proper sensitivity cannot be obtained in the size required to use in traverse openings, horizontal rods 35, 47, and 65 will be removed and the associated 4-1/2" square channels utilized for ion chambers during the loading process.)

- e. All safety instrumentation will be checked for in-reactor response, prior to the loading of any fuel, by insertion of a neutron source into process channel 1656 and observation of each instrument.

2.2 Division of Responsibilities

1. All operational functions associated with the startup are to be performed by N Operations personnel; this includes operation of all equipment and instrumentation except that used specifically by Operational Physics personnel for measurements. Normal operating records such as the console log and established data sheets will be recorded in complete form by N Reactor Operations.
2. Special equipment in addition to that installed in the reactor will be supplied and operated by Operational Physics personnel. Complete test records and data will be maintained by Operational Physics Operation; personnel of this Operation will provide N Operations with all required direct physics support during the test program.

2.3 Scheduling and Time Allotments

It is impossible to specify exactly time requirements for each individual test at this stage. The following is a tentative time breakdown which should be representative in reflecting the over-all requirements, provided that no significant contingencies develop.

1. Minimum critical size determination, wet and dry reflector effects, flux traverses	72 - 120 hours
2. Migration area, dk/dB^2	36 - 60
3. Single column and block reactivity measurements	96 - 208
4. Small pile temperature coefficient of reactivity	96 - 128
5. Horizontal rod local strength	36 - 60
6. Ball 3X local strength	48 - 80
7. Full pile loading, control capacity	144 - 240
8. Full pile temperature coefficients	96 - 128

9. Miscellaneous (e.g., instrument calibrations, speed of control, and various pre-operational checks)	72 - 120 hours
10. Re-check on rod system strength and calibration, using xenon transient, System Feedback Tests	72 - 120
Total	4 - 6 weeks

2.4 Description of Individual Tests

2.4.1 Minimum Critical Sizes

Since the dry NPR lattice reactivity is such that the dry full pile loading with no poison inserted will probably be subcritical, we are concerned only with wet critical studies. The minimum critical size is defined as the minimum number of fully charged tubes which will support a chain reaction in the cold reactor under optimum loading and geometry conditions. Calculations by the author indicate that there is little difference in critical sizes whether the surrounding uncharged process channels are water-filled or empty, the minimum size in each case being ~ 200 tubes for a cylindrical loading and slightly more for a rectangle.

The minimum critical size will be determined with water in the surrounding process tubes, both with and without graphite cross-cooling water. The initial configuration will be a rectangular array of partially charged tubes (one element short of full length) in the center of the reactor. All controls will be out, and all safety circuits will be functional with trips set at a nominal level. The inverse count rate ($\frac{1}{n}$) will be monitored by special proportional counters located in and adjacent to the loading, as well as by standard in-pile instruments.

Water will be withheld initially from a minimum of tubes. After completion of 70 central charges, flow will be introduced into the surrounding tubes in two successive annular stages, to assess the effect of water content on reflector augmentation. <

The tubes will be charged downward from a 14-tube base running from number 2451 to 2464 (see Fig. IV); criticality is expected when the rectangle is extended downward to tube row 11 (~200 tubes). All charging will be done under continuous monitoring, and the reactivity status of the pile will be continually recorded by Operational Physics personnel.

Charging sequence will be provided by Operational Physics; after the loading has increased to ~100 tubes a conservative rate will be adopted, such that no more than three tubes will be added at a time, and a two-minute waiting period will be observed between additions; one or more rods will be inserted prior to each charging step and carefully withdrawn after the three tubes are charged. An even more conservative rate (one tube at a time) will be adopted when $k_{eff} \approx .990$.

After the critical size with no graphite cross-coolant has been established, several control rods will be inserted, graphite coolant initiated, and the reactivity re-measured; some slight adjustment of in-pile fuel inventory may be necessary.

2.4.2 Migration Area Measurements

Existing Hanford reactors have cores that are characteristically symmetric, and consequently the neutron migration area is not dependent upon direction in the front face plane. Therefore, one measurement of M^2 was considered sufficient in previous startup tests.

This is not the case in NPR; the rectangular lattice produces vertical-horizontal anisotropy, and the large void fraction results in considerable neutron streaming parallel to the process channels. The net effect is sufficient to require three measures of the migration area: M_x^2 , M_y^2 , and M_z^2 . Proper weighting of the three experimentally determined components will result in an effective migration area for the core. The technique used will be the standard one, based on the approximation $dk/dB^2 \approx -M^2$. The migration area measurements will begin with the small critical loading (which is composed of columns short of full length by one 24" element).

The first quantity to be measured is the effective longitudinal migration area (M_z^2); this is accomplished by adding the originally uncharged final element to each of the charged tubes in the small critical loading and measuring the increase in reactivity (expected to be ~ 0.6 milli-k).

Next, the vertical dependence (M_y^2) is measured by discharging fuel from the top of the small loading (horizontal row 25, Figures IV, V) and measuring the change in reactivity, using subcritical counting.

Finally, the horizontal dependence (M_x^2) is measured by adding fuel to the near side (vertical row 52, Figures IV, V) and measuring resultant reactivity changes.

These measurements may prove a bit tricky due to the small critical size and accompanying large dk/dB^2 ; it is estimated that each tube added to the minimum critical size will increase the reactivity by ~ 0.3 mk. It is possible, then, that the limiting period (>10 seconds) will be reached before the test is complete. In order to guarantee securing sufficient data, measurements will continue as above until the limiting period is reached; then, one or more pairs of rod tips (e.g., rods 35 and 65, 43 and 73, 47 and 77, etc.) will be inserted as shims symmetrically in the critical loading to reduce potential k_{excess} with other rods out to ~ 0.5 mk prior to continuation of loading.

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FIGURE V

MIGRATION AREA TESTS

The measurement is presented pictorially in the following sketch:

Minimum Critical Size

2.4.3 Single Column Reactivity Measurements

The relative absorption rates, and hence reactivity effects, of single columns are most easily approximated by the "danger coefficient" or substitution technique. This method provides for the measurement of the reactivity effect of the test column in a small supercritical loading, and subsequent conversion to full pile effects; it was used extensively at K reactor startups.^{/3/}

The substitution tests will be run in the small loading at a time when the loading has a potential excess of ~ 2 mk. The period will be carefully measured with no controls inserted and a uniform 0.95 per cent loading; rods 44, 46, 55, 65, 74 and 76 will be inserted to restore a subcritical state. Next, the central column will be discharged and subsequently replaced with various charges whose reactivity effects are desired. After each replacement, the rods will be withdrawn and the revised period measured; the reactivity effect is obtained from the observed change in period. Possible reactivity drifts, due to

^{/3/} HW-37158 PT 3, "Reactivity Effects of Fuel and Target Materials (K Reactor Startup)" - C. L. Miller, April 2, 1956

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atmospheric changes, etc., will be determined by periodically remeasuring the loading reactivity with the central column charged water.

The following column loadings will be measured at a minimum, in the order indicated:

1. Primary fuel plus boron spline
2. Water column
3. Air channel
4. Dry 0.947 per cent uranium
5. Dry natural uranium
6. Wet natural uranium
7. Wet natural uranium plus boron spline
8. Water column (reactivity drift check)
9. Lead cadmium column
10. Dummy ^{steel} ~~aluminum~~
11. Any other anticipated fuel (e.g., uranium oxide) or flattening materials, special assemblies*, etc.
12. Rod and ball columns (ceramic and boron-steel balls)
13. Water column

The relationship between small-pile values and fully-loaded values will be established by flux-weighting techniques to establish nominal reactivity effects; the actual effect then in the operating reactor will be a function of the flattening efficiency.

The possibility of reactivity measurements by the pile oscillator technique is being investigated. This method, which involves oscillation of a sample in the reactor and analysis of the resulting power variation, offers up to twenty times the sensitivity of the "danger coefficient" technique. If the method appears feasible in the geometries to be encountered in NPR, its use will be programmed for NPR startup. Test hazards will not be increased if this method, which has been used extensively and successfully at other installations, is selected.

*For example, an attempt will be made to design a special charge to observe the reactivity effect of varying the volume of water in a process channel.

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2.4.4 Lattice Temperature - Reactivity Measurements

The dependence of lattice reactivity upon uniform lattice temperature will be determined in a small supercritical size pile; the total potential reactivity will be 2-3 milli-k. Test design will be such that the distorting effects of control rods will be minimized, and reactor safety will be enhanced by the fact that most measurements will be made in a subcritical assembly.

One or two horizontal rods will be calibrated over the range of 2-3 milli-k for use as a standard reactivity base and to allow subcritical normallization. The following equations describe this normallization:

The fundamental subcritical multiplication relationship is given by

$$C_1 = C_0 \left(\frac{1}{1-k_1} \right)$$

where C_1 is the count rate at $t = t_1$,

and C_0 is the source count rate.

Since the "source rate" in this case is constant, (e.g., spontaneous fission) we can relate various count rates and subcritical multiplication factors as follows:

$$\frac{C_{1+1}}{C_1} = \frac{1-k_1}{1-k_{1+1}}$$

Thus, the test will consist of calibrating 2-3 milli-k worth of control rods, heating the pile to the point of criticality with all rods removed, then establishing working relationships by inserting known (calibrated) amounts of negative reactivity to arrive at a known subcritical multiplication factor. Finally, subsequent multiplication factors (at elevated temperatures) will be computed from the established relationships.

The heating process will continue over the range 20C - 200C; an attempt will be made to separate prompt and delayed transients (e.g., metal and coolant versus graphite temperature effects) by rapid, stepwise cooling of the lattice. The heating and cooling mechanism will be that of ATP 2405, described in the Appendix, which converts pumping power to reactor heat.

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FIGURE VI

SCHEMATIC OUTLINE OF LATTICE TEMPERATURE TESTS

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2.4.5 Block Reactivity Measurements

The single column substitution technique offers a simple and quick method for roughly determining the reactivity effects of single columns. However, the accuracy is not sufficient to allow extrapolation to full-pile or large-block loadings. In fact, the single column in a foreign lattice may have a considerably different reactivity effect than the same column in a full pile of identical material, due to different migration characteristics. Therefore, for materials whose multiplication must be known to relatively high accuracy, some other measurement technique must be devised. Such materials include fuel configurations of greater reactivity than the primary fuel, or of lower reactivity if extensive use of the less reactive element is planned.

For measuring the lattice reactivity of natural uranium (and possibly of an E-N type loading), a block substitution test is planned. This test will be conducted in the small pile after the danger coefficient measurements have been concluded, and a total of 12 milli-k worth of fuel has been added, with peripheral rods holding the excess reactivity.

The natural uranium will be substituted a column at a time for the primary fuel in the center of the loading of known reactivity. The reactivity change per column will be calculated from period measurements, and the process continued until the reactivity change per column, $\Delta\rho$, approaches a constant value, or the number of replaced columns reaches 24, which is set as a limit. The infinite multiplication constant for the test material will be estimated by extrapolating to a full pile loading by means of flux-weighting reactivity evaluation methods.

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First natural uranium
charged into small sub-
critical loading

Substitution
Progresses

24 Columns
Substituted

FIGURE VII

BLOCK REACTIVITY MEASUREMENTS

2.4.6 Control Rod and Ball 3X Local Strength

Control element strengths may most easily be determined during startup tests by the local control strength technique; the "local strength" is defined as the equivalent reduction in multiplication in a given "zone of action" caused by insertion of the control. This concept is a consequence of J. A. Wheeler's "Principle of Equivalence"^{/4/} which postulates that an individual control may be considered to cause a characteristic reduction in multiplication in a zone of a given size, or a proportionately smaller effect in a larger zone; thus the equivalent strength in any zone of action may be determined.

The choice of the size of the zone is generally based upon the geometry of the control system, an individual element being assigned an area based on the average volume per element. (This average volume is determined by dividing the volume covered by the control system by the number of individual control elements.) In the N Reactor control system, the rods are arranged on a lattice of 32" x 36"; elementary calculations lead to a radius for the zone of action of 19.15" or 48.65 centimeters; ball channels are arranged on a 32" x 32" lattice, leading to a radius of 45.858 centimeters. The individual-local strength is not directly measured; rather, the "strength" of a rod or an array of rods is measured in a particular loading (the "small pile"); the result is converted to a localized effect in keeping with the "Principle of Equivalence." The measurement takes place in a block loading of known reactivity, of approximately 12 milli-k potential excess. A vertical bank of control rods is inserted into the unit and all others are carefully withdrawn; the critical size pile with the rod bank inserted is established by charging or discharging fuel as required. The local strength of a row of ceramic-ball columns is determined by replacing the rod bank with a group of ball-columns and measuring the resulting reactivity change.

In the rod test, the relative strength of rods with and without cooling water will be determined.

2.4.7 Lattice Parameter Measurements

Many fundamental lattice constants may be experimentally measured by appropriate foil and pin flux traverses, since quite a bit of data can be gleaned from a judicious study of lattice flux distributions. It is planned to irradiate specially designed slugs containing foils and/or pins while other tests are in progress; thus the additional time requirement will be minor.

The general method involves selective placement of detectors of various sensitivities into the receptacle slug, irradiation for a minimum time, and then measurement of the induced activity by a

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gamma-ray scintillation spectrometer. At a minimum, foils of five different compositions will be required:

- 1) Natural uranium
- 2) A high U^{235} content alloy to yield gross U^{235} fission
- 3) Copper for "thermal" flux distributions
- 4) Depleted uranium for plutonium buildup data
- 5) Plutonium

The cooperation and assistance of HLO personnel is anticipated for setting up final measurement procedures and details. It is intended that sufficient data will be obtained for use in determining the following parameters as a minimum:

- 1) Disadvantage factor for fuel rods
- 2) ϵ (fast effect)
- 3) f (thermal utilization)
- 4) p (resonance escape probability)
- 5) Conversion efficiency
- 6) k_{∞}

Data collected will include flux distributions for various neutron energies and cadmium ratios.

2.4.8 Completion of Loading; Full-pile Control Rod and Ball 3X Effectiveness and Speed of Control

Of fundamental importance in the over-all safety program in any reactor is a knowledge of control and safety system strengths. The tests to determine horizontal rod and Ball 3X strengths will be conducted after the reactor is completely loaded with primary fuel, plus sufficient uniformly charged poison to reduce the pile excess to ≤ 2 milli-k with all control rods withdrawn.

The first step involves determination of the statistical weight of the reactor in the control rod plane; this is the reactivity-versus-position function for a constant poison strength. It is determined by inserting a rod into the reactor (of known base reactivity) and measuring the change in period, and repeating for other selected rods.

Next, the system is partially calibrated (~ 60 milli-k of the 90+ milli-k system). This is done by sequentially discharging (or

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removing) poison to establish a reactivity of ~ 1.5 milli-k, compensating by inserting designated rod-pairs, and recharging fuel into any process channel emptied during the process. This procedure continues until the poison is entirely removed from the reactor.

Finally, the minimum numbers of rods and ball columns (independently) to hold the reactor subcritical are determined. This is accomplished by inserting all rods, and then removing designated rods while constantly monitoring neutron count rate to observe approach to criticality; next, a few designated ball channels are filled, and the rods slowly withdrawn to establish critical. This process continues until all rods are withdrawn and the system is near critical with the minimum number of full ball channels.

Different critical configurations will be established as a check on theoretical calculations of geometry effects on control system capacities.

Figure VIII

Reactivity Transient for Rod Calibrations

To facilitate safety analyses of the NPR complex it is necessary to determine time delays and effective penetration times for the safety systems. This will be accomplished by recording the flux response, as a function of time, to the rapid insertion of single rods and groups of rods, the entire control rod system as a whole, and samplings of the Ball 3X system.

The first of this group of measurements will determine the lapsed time between initiation of a LX scram signal and occurrence of a falling period. The reactor will be started up using normal procedures, and will be programmed to approach a rising period of 20 seconds at a total power level of ≤ 5 kilowatts. The period trip will be set at 20 seconds. A high speed oscilloscope and camera combination will record the flux transient and provide data for determining the Number One Safety Circuit effective response time for a period trip. A similar run will be made with a slower period and the level trip set at 3-5 kilowatts.

Next, the reactor will be started up and maintained at a level of 5-10 kilowatts. A LX trip will be initiated, and the reactor flux response recorded; this data may be used to estimate β/λ , the ratio of the delayed neutron fraction to the neutron lifetime. This measurement will be programmed to conclude a power run in which a flux traverse is made, and so will require no additional time.

2.4.9 Full Pile Temperature-Reactivity Transients and System Feedback Effects

In NPR, with its large water volume, temperature transients will be large and generally negative. In the initial loop heating-pressurization phase of startup alone, a 160C rise will occur in the average unit temperature. This corresponds to a decrease of 9-10 milli-k of reactivity, a rather large fraction of the total change from startup to equilibrium (~ 40 mk).

The recirculating feature of NPR allows achievement of nearly 250C increase in reactor temperature, utilizing pumping power alone.^{/5/} The test will be run after the rod system has been preliminarily calibrated, since the reactivity transient will be raised ~ 260 C by the process utilized in ATP-2405^{/6/} and then lowered in steps. Reactivity variations will be measured periodically during the process.

The heating process will produce data for a composite transient only (i.e., the combined metal, graphite, and water temperature effects); the cooling process will be used to separate effects. Inlet water temperature will be sharply reduced in steps, and the graphite temperature will be allowed to drop normally; the decaying transient will be an exponential with a period established by the graphite cooling period. Reactivity will be

^{/5/} Personal communication, H.R. Kosmata, October, 1961

^{/6/} ATP-2405 (See Appendix III)

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determined by subcritical techniques to avoid fast periods and accompanying problems.

This test will provide a basis (and some fundamental data) for conducting system feedback tests later in the operation of the reactor.

2.4.10 Power Ascension and Operating Power Tests; "Feedback"

The integrated three-loop NPR system produces many operating variables not encountered in the conventional once-through-cooling reactors of the present HAP0 variety. These new variables result from system interactions, or "feedback," in which the reactor complex responds as a whole to perturbations in some component variable. An extensive program to analyze NPR system feedback effects is planned for the early months of low-power operation, after the critical testing program is complete. Preliminary plans presented here will no doubt be modified to some extent by the startup technical crew and the assigned N Area physicist, based upon initial observations of the critical tests.

Timing of this portion of the testing program will be consistent with the power ascension program, which is roughly summarized below/7/ (items falling exclusively in the category of "Physics Testing" are underlined):

<u>Timing</u> <u>(Months)</u>	<u>Event</u>
0-2	<u>Physics Zero Power Tests; Preliminary Instrument Calibrations</u>
2-3	Shutdown; System Completion Tests
3-5	0-10% Power Demonstration Runs; <u>Instrument Calibrations; Some Feedback Tests</u> (Physics & Engineering)
5-6	Shutdown; System Completion Checks
6-7	Operation at 10% Design Level; <u>Some Feedback Tests</u>
7-9	Linear Increase from 10% to 50% Design Level
9-12.75	Operation at 50% Design Level; <u>Additional Feedback Tests</u>
12.75-13	Shutdown; First Major Fuel Discharge and Inspection; <u>Xenon Transient - Rod Calibrations</u>

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<u>Timing</u> <u>(Months)</u>	<u>Event</u>
13-14.25	Linear Power Ascension, 50-75% Design Level
14.25-17	Operation at 75% Design Level
17-17.5	Shutdown; Major Fuel Discharge; <u>Additional Rod</u> <u>Calibrations if Necessary</u>

The "feedback" experiments will involve the rapid changing of one or more process variables and continuously recording the effects on and interactions with other variables. The primary driving functions to be utilized will be reactor inlet temperature and control rod reactivity, which can be manipulated easily. Interacting variables, in particular outlet temperature and power level, will be closely observed and recorded. The purposes of this testing will be:

1. Evaluate the reactor transfer function $\delta P(\omega)/\delta k(\omega)$
(P is power, k is multiplication factor).
2. Experimentally verify (and adjust if necessary) the conclusions of various analog computer studies utilizing primary loop and reactor simulators. ^{78/}
3. Evaluate applicable transport delay lags and time constants.

The testing will include the introduction of step, ramp, and oscillating perturbations in 1) control rod reactivity, and 2) reactor inlet temperature (at various power levels), and the recording of system responses to provide coupling data for internal system feedbacks in response to externally induced stimuli.

Fast recording monitors will be required on the following reactor parameters:

- Reactor Power Level
- Reactor Outlet Temperature
- Heat Exchanger Inlet Temperature
- Heat Exchanger Secondary Temperature (Pressure)
- Load Steam Flow (Heat Exchanger)
- Heat Exchanger Outlet Temperature
- Reactor Inlet Temperature

The tests are designed to produce less than a 10% change in power level (at allowable rates) in any given run; safety circuit trips will be set at 110% of the level at the beginning of the test. Furthermore, this "110%" level will correspond to a previously checked out level, so there will be no possibility of progressing to a power at which system capabilities have not been determined.

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PART 3: Appendices

3.1 Appendix I: Preliminary Summary of Test Procedures

The scope and objectives of the startup testing program are covered in the main body of this report. For information purposes, the tests are described below in a more complete, but still preliminary, form to indicate the format of procedures to be supplied. It is to be emphasized that the summary is general at this point, and may have to be altered for expediency or economy. All procedures will, however, fall within the scope of the main (authorization) portion of this document as regards nuclear safety, scheduling, and approximate cost.

3.1.1 Determination of Minimum Critical Size

3.1.1.1 Desired Results:

1. Minimum critical sizes, wet and dry surroundings
2. Material buckling of primary fuel
3. Reactivity effect of graphite cross-coolant loss

3.1.1.2 Instrumentation and Equipment:

A minimum of two ion chambers in the core in the safety system at all times (with single-trip protection) plus a minimum of two proportional counter systems, the chambers of which will be placed in and adjacent to the progressing loading; these special chambers shall have previously been calibrated in the standard pile to determine count rate-flux relationship. In addition, foils and pins plus associated counting equipment will be required for the flux measurements.

3.1.1.3 Time Requirement: 72-120 hours

Responsibilities: Operational Physics,
NPR Operations (HLO assistance)

Remarks: All fuel charges in this test will be one 24" fuel element short of full length to permit a longitudinal migration area measurement during Measurement #2.

3.1.1.4 Summary of Measurement - Method

1. Insert calibrated neutron proportional counter chamber into center of process channel #1758; insert additional p.c. chamber in process channel #1651 (all control and safety rods are out of the reactor).

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2. Insert ionization chambers to center of traverse opening #4 and to a point corresponding to vertical column #54 in traverse opening #5, with cables entering from near side; insert additional ionization chamber into traverse opening #5, initially positioned ~3 feet to right of centerline (vertical row #61), with cable entering from far side.
3. Connect two proportional counters to special control room counting and scaling equipment; connect three ionization chambers to normal operating level recorders.
4. Insert neutron source (PuBe, 2×10^7) in process channel #1656; check response of all startup instrumentation to determine operability; if normal conditions are observed, withdraw source and proceed with loading.
5. After it has been assured that all instruments are responding normally, start charging fuel as indicated in Figure X. The first 48 columns ("Zone 1" of Figure X) may be charged in any order at an unrestricted rate; subcritical monitoring will continue throughout the charging program. Reject quality .947% uranium should be charged initially in the following tubes, and production quality fuel in all others:

1557*	1755	1855	1956
1558*	1756	1856	1957
1656*	1757	1857	1958
1657*	1759	1858	1959
1658*	1760	1859	2057
1659*		1860	2058

} 23 tubes

2451* - 2464* ----- 14 tubes

*These tubes are in zones other than Zone 1.

6. After "Zone 1" has been completely charged, and it is ascertained that instrumentation is functioning adequately, charge tubes in "Zone 2" (Figure X). These tubes may be charged in any convenient order, but count rate data must be taken and recorded after each group of three tubes is charged.
7. After completing Zone 2, and recording a stable count rate, introduce flow into the surrounding envelope of originally dry tubes ("Region 2" of Figure IX). Take and record the stable neutron count rates from all indicating instruments.

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FIGURE IX : INITIAL CHARGING CONSIDERATIONS

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Legend and Explanation

1. Tubes in "Flow Region 1" are charged in two groups as per Figure X.
2. During charging of 71 tubes in Region 1, Flow Region 2 and 3 are maintained in a dry condition.
3. Finally, flow is initiated in Region 2, followed by Region 3, each region as a group.
4. A proportional counter is to be located in channel 1758 until critical is attained; the channel must be kept dry.

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8. Initiate flow in Region 3 (Figure IX); take and record stable count rates (wait two minutes).
9. Charge fuel into Zone 3 of Figure X; take count rate data after each three tubes are charged (wait two minutes); make a running estimate of the critical size by plotting inverse count rate versus number of fuel charges. Estimate critical size after Zone 3 is complete.
10. Charge fuel into Zone 4 of Figure X; estimate critical size. Complete step 11 or 12 as applicable.
11. If criticality is expected after 42 or fewer additional tubes are charged, continue charging on the following basis (for each of Zones 5-10):
 - a. Charge two tubes, in vertical columns 51 and 64 (i.e., when charging Zone 5 of Figure X, first charge tubes 1651 and 1664).
 - b. Wait two minutes; record count rate and multiplication date.
 - c. Estimate critical size.
 - d. Charge three tubes, indicated by numeral 2 in squares of Zones 5-10 in Figure I, staying in one horizontal row.
 - e. Wait two minutes; take count rate and estimate critical size.
 - f. Charge three tubes indicated by numeral 3; wait two minutes, take count rate, and estimate critical size. Repeat for tubes indicated by numerals 4, and finally for tubes numbered 5.
 - g. Proceed to next zone, and repeat steps a-f, until critical is expected with 20 tubes; then proceed to step 13.
12. If more than 42 additional tubes are calculated for criticality after Zone 4 has been charged, continue on a full zone basis; i.e., charge one zone of Zones 5-10; take count rate data and estimate critical size. Continue until criticality is expected within 42 tubes, and go to step 11 above.
13. At the time when calculations indicate criticality within twenty tubes, adopt a slower rate of charging, in which a count rate is taken after each tube is charged (two minute wait), and a new critical estimate is made.

14. The charging process will continue until the unit is ≤ 0.5 milli-k supercritical (with a measurable period). During the entire approach to critical, the proportional counter chamber originally located in channel 1651 will be moved so as to "lead" the loading; i.e., it will be located in row 17 while row 17 is being charged, etc. The other chamber will remain in 1758 as long as practical.

The probable location sequence for the "mobile" chamber is as follows:

1651	1354	1055
1552	1255	etc. (See Figure X)
1453	1156	

15. After the critical size is well established (by loading to a slightly supercritical size and measuring the period), insert control rods 44, 46, 55, 64 and 66. Initiate flow in graphite cross-cooling system; check as necessary to assure that flow is normal.
16. Withdraw rods 44 and 66; wait three minutes and record count rate.
17. Withdraw rods 46 and 64; wait three minutes and record count rate.
18. Withdraw 25 per cent of rod #55; record count rate. Continue withdrawing increments of 25 per cent (three-minute wait between increments) until the reactor is $\leq$ one milli-k supercritical or the rod is out of the reactor, whichever occurs first.
19. Insert the five rods and adjust loading as necessary, with a rods-out two-minute wait between tubes if additional fuel is required, to establish an excess reactivity of ≤ 0.5 milli-k.
20. The charging process will continue beyond critical to establish various supercritical rising periods (with at least three data points per period) and thus relate reactivity and pile size; each increment of fuel will be limited to 0.05 mk, with a two-minute wait before the next one. The limiting rising period with all rods out will be 10 seconds. Between count rate recordings, rods 44, 46, 55, 64, and 66 will be inserted to reduce the multiplication to < 1.000 .
21. After the limiting period is obtained, raise power to some nominal level (a few watts) and hold for a short time (a few minutes) while lattice and reactor flux distributions are taken by foil irradiation.
22. After flux measurements are completed, insert several rods (four or more centrally located rods such as rods 44, 46, 55, 64, and 66, which are included in the set-back circuit and reserved for this purpose).

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FIGURE X APPROACH - TO - CRITICAL CHARGING

Legend and Explanation:

1. Charge all tubes in Charging Zone 1 as a group, with no restriction on rate or sequence; take count rate data.
2. Charge all tubes in Zone 2 as a group and take count rate data.
3. Introduce ~~flow~~ into Flow Region 2 (Fig. IX) and take count rate data.
4. Introduce ~~flow~~ into flow Region 3; take count rate data.
5. Charge tubes in Zones 3 and 4 as groups, with no restrictions on charging order within a group.
6. Zones 5-10 will be charged in the order indicated in Zone 5. Rate will be restricted to three tubes at a time until criticality is imminent; at that time, charging will proceed on a single tube basis.
7. Zones 11-13 will be used if necessary for criticality, using indicated charging order.
8. Probable locations for "mobile" proportional counter are indicated by [X].

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3.1.2 Determination of Migration Area

3.1.2.1 Desired Results:

1. Migration Area: M_x^2 , M_y^2 , M_z^2
2. Control rod strength data
3. Back-check on critical size

3.1.2.2 Instrumentation and Equipment

Identical with Measurement #1, except no foils or pins are required.

3.1.2.3 Estimated Time Requirement: 36 - 60 hours

Responsibilities: Operational Physics, NPR Operations

3.1.2.4 Summary of Measurement - Method

1. Begin with the supercritical size loading of Measurement #1. (This loading may not be a completed rectangle, but will definitely have two completed sides; i.e., there will be no "gaps" in the uppermost row of tubes and either the extreme near or extreme far column of tubes.)
2. With rods inserted, add the final element to each of the ~ 200 short-charged tubes used for the critical test; carefully withdraw rods and establish new base reactivity (~ 0.5 milli-k increase will result from the added elements).
3. Insert rods; discharge designated pairs of tubes from horizontal row 24, taking reactivity measurements after each tube discharge. Continue discharging tube pairs until unit is slightly subcritical (supercritical data points will be used to extrapolate to determine subcritical multiplication after discharging is complete). The count rates here will be used as the normalizing points for subcritical multiplication determination.
4. Continue discharging fuel in designated tube pairs until horizontal row 24 is completely discharged.
5. Start charging production quality fuel into the vertical column designated by the responsible physicist (e.g., vertical columns 50, 65, or 66). Take multiplication data after each tube is charged and plot $1/n$.
6. Continue charging until the vertical column is complete; control rod compensation will be made if necessary.

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3.1.3 Single Column Reactivity Measurements

3.1.3.1 Desired Results:

1. Reactivity equivalent of selected single columns
2. k_{∞} of dry primary fuel
3. Ball column local strength information

3.1.3.2 Instrumentation and Equipment:

Normal pile instrumentation, two special proportional counters, lubricant for dry charging, and procedure for removing water from central columns.

3.1.3.3 Estimated Time Requirement: 48-80 hours

Responsibilities: Operational Physics, NPR Operations

3.1.3.4 Summary of Measurement Procedure:

1. Begin with the small supercritical loading at the conclusion of the migration area measurement; the array has ~ 100 tubes and an excess of $\sim 2-3$ milli-k.
2. With $\geq$ four rods inserted, remove the special proportional counter chamber from channel 1758 and replace in 1849; introduce full flow into channel 1758.
3. If the reactor period will be limiting as indicated by the initial reactivity, discharge fuel from the corners of the loading (e.g., tubes 1350 and 1364) to lower the reactivity to an allowable quantity (period ≥ 10 seconds, rods removed).
4. Carefully establish base reactivity of selected configuration; excess should be no more than ~ 3 mk (rising period ≥ 10 seconds). Insert several rods.
5. Replace contents of 1758* sequentially with following test materials and measure resulting pile reactivity:
 - a. Water column
 - b. Air column
 - c. Dry 0.947 per cent uranium (lubricant required)
 - d. Dry natural uranium
 - e. Wet natural uranium
 - f. Wet natural uranium plus boron spaine
 - g. Lead cadmium column (charge in quarter-column steps)

*If there are restrictions on the number of times a single tube may be charged during the test program, channels 1757, 1857, and 1858 may be used alternately with 1758.

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- h. Dummy aluminum
- i. Any other anticipated fuel or flattening column
- 6. After above measurements are complete, recharge central column with primary fuel. Recheck reactivity base point to determine and evaluate any reactivity drift; insert four or more rods.
- 7. Fill ball channel #50 with boron steel balls.
- 8. Withdraw rods and check for rising period; if pile is supercritical, insert rods and remove balls; if pile is not critical, add fuel as necessary to bottom of loading to establish critical point; insert same rods as step 6 and remove balls.
- 9. Replace boron steel balls with ceramic balls; withdraw rods to check for critical. Charge additional fuel as required, adding to bottom of loading.
- 10. After new critical point has been established and evaluated, insert rods and remove balls.

3.1.4 Lattice Temperature vs. Reactivity; Small Pile

3.1.4.1 Desired Results:

- 1. Reactivity versus uniform lattice temperature.
- 2. Graphite temperature coefficient of reactivity and relaxation period, and metal and water temperature coefficients of reactivity.
- 3. Rod strength-versus-temperature data.

3.1.4.2 Instrumentation and Equipment:

All instrumentation of previous tests, plus special thermocouple probes inserted into graphite and metal within the loaded core, and spline or wire for special flux traverse.

3.1.4.3 Estimated Time Requirement: 96 - 128 hours

Responsibilities: Operational Physics, NPR Operations

Remarks: Data will be strictly applicable only to a uniformly heated lattice, which will not occur in practice; however, the data will be extremely useful as a basis for theoretical calculations applying to the operating temperature distribution, and is directly applicable to the pre-startup heating-pressurizing transient.

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3.1.4.4 Summary of Measurement Procedure

A. Heating Process

1. This test begins at the conclusion of the single column substitution tests. The total excess reactivity of the unit will be 2-3 milli-k.
2. Adjust the total excess as necessary to ≤ 2.0 milli-k, using partial charges if necessary.
3. Accurately establish this base reactivity by measuring the rising period with all rods out; it must be ≥ 10 seconds.
4. Insert horizontal rods 45 and 55.
5. Carefully withdraw rods 45 and 55, as a mated pair, to establish critical once more, monitoring the inverse count rate on all chambers during the approach.
6. Calibrate the inserted portion of rods 45 and 55 by withdrawing simultaneously in steps, and measuring the rising period at each step. Insert four or more rods after each step to reduce the flux to a tractable level.
7. After the two rods are completely withdrawn (and thus completely calibrated), insert four or more rods.
8. Heat the unit up to ambient temperature ($\sim 20^\circ\text{C}$) plus 10 degrees, using techniques of ATP 2405.* Slowly withdraw all rods and check for criticality; no more than 2 mk will be withdrawn in any three minute period. Insert four or more central rods.
9. Heat up an additional 10C; slowly withdraw all rods and check for criticality. Insert four or more central rods.
10. Repeat step #9, in increments of 10C, until unit is only slightly supercritical (0-0.25 mk excess) with all rods withdrawn.
11. Insert calibrated 1 milli-k of rod; record stable count rate; insert additional 1 milli-k of rod; record stable count rate. Temperature is held as nearly constant as possible throughout this step.

*ATP 2405 is an acceptance test which converts pumping power to sensible reactor heat; see Appendix III.

12. Heat additional 25C; record count rate; withdraw 1 milli-k of rod and record stable count rate; withdraw additional 1 milli-k and record stable count rate.
13. Heat additional 25C; record count rate. Insert calibrated 1 mk of rod; record count rate; insert remaining 1 mk of rod and record stable count rate.
14. Continue sequence of steps 12 and 13 until unit is at $\sim 200\text{C}$. Hold temperature constant to establish stable count rate.

B. Cooling Process

1. Begin with unit at 200C; if calibrated rods are inserted, withdraw sufficiently to establish base (hot) count rate.
2. Reduce water temperature, at rate of 5F per minute, by 20C (or 36F); take and record graphite temperature and count rate during water cooling period and at two-minute intervals thereafter for a total of 30 minutes.
3. Repeat step #2 until count rate indicates a k_{eff} of $\approx .998$ at any point in the cooling cycle (probably after three cooling steps of 20 degrees each).
4. Insert 1 mk of calibrated rod while holding water temperature constant at above (step 3) level; take count rates for ~ 5 minutes.
5. Insert additional 1 mk of calibrated rod; take count rate (and graphite temperature) for 5 minutes.
6. Continue recording graphite temperatures; reduce water temperature by 20C as sharply as possible (10-15F per minute would be desirable). Record count rate and graphite temperature at two-minute intervals until temperature change rate is $\leq 1\text{C}/5$ minutes.
7. Insert four or more rods and allow unit to cool normally.

C. The Processes in Tabular Form

The heating and cooling, and expected reactivity and count rate variations for a typical case are presented in tabular form.

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SMALL PILE HEATING PROCESS

Step No.	Procedure	Water Temperature	Graphite Temperature	k _{eff}	Normalized* Count Rate
0	Start with small loading, 2 milli-k excess	20C	20C	1.0020	
1	Calibrate 2 mk rod; insert	20C	20C	1.0000	
2	Heat up by 10C	30C	30C	.9999	1.0000
3	Withdraw rods	30C	30C	1.0019	
4	Insert rods	30C	30C	.9999	
5	Heat up by additional 10C	40C	40C	.9997	.333
6	Withdraw rods	40C	40C	1.0017	
7	Insert rods	40C	40C	.9997	.333
8	Heat up by additional 10C	50C	50C	.9994	.167
9	Withdraw rods	50C	50C	1.0014	
10	Insert rods	50C	50C	.9994	.167
11	Heat up (in steps)	75C	75C	.9984	.063
12	Withdraw rods	75C	75C	1.0004	
13	Insert rods	75C	75C	.9984	.063
14	Heat up by 25C	100C	100C	.9971	.034
15	Withdraw calibrated 1 mk	100C	100C	.9981	.092
16	Withdraw additional 1 mk	100C	100C	.9991	.111
17	Insert rods; heat 25C	125C	125C	.9956	.023
18	Withdraw rods	125C	125C	.9976	.042
19	Insert rods; heat 25C	150C	150C	.9939	.016
20	Withdraw rods	150C	150C	.9959	.024
21	Insert rods; heat 25C	175C	175C	.9920	.013
22	Withdraw rods	175C	175C	.9940	.017
23	Insert rods; heat 25C	200C	200C	.9941	.010
24	Withdraw rods	200C	200C	.9921	.013

*Temperature-sensitivity corrections may be required on observed count rates.

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SMALL FILE COOLING PROCESS

Δt Minutes	Step No.	Procedure	T_W	T_G	k	n
0	0	Start; rods out	200	200	.9921	.013
7	1	Cool water	180	200	.9943	.018
30	2	Cool graphite	180	192	.9940	.017
37	3	Cool water	160	192	.9964	.028
60	4	Cool graphite	160	180	.9959	.024
67	5	Cool water	140	180	.9985	.067
80	6	Cool graphite	140	172	.9980	.050
90	7	Insert rods	140	164	.9958	.024
93	8	Cool water <u>sharply</u>	120	164	.9987*	.077
120	9	Cool graphite	120	147	.9979	.048
240	10	Cool graphite	120	120	.9961	.026

*Indicated period = 30-60 seconds

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3.1.5 Block Reactivity Measurements3.1.5.1 Desired Results:

1. Lattice multiplication for natural uranium (plus E-N loading if applicable)
2. Poison effect of water columns
3. Poison effect of air columns
4. Lattice multiplication for dry enriched uranium
5. Rod strength data for theoretical calculation bases

3.1.5.2 Instrumentation and Equipment:

1. Twenty-four charges of reject natural uranium
2. Standard pile instrumentation plus special proportional counters
3. Foils and/or chambers for 3-dimensional flux distribution measurements
4. Equipment for blocking flow from and drying 24 process channels
5. Special lubricant for dry-charging 24 process tubes

3.1.5.3 Estimated Time Requirement: 48-80 hours (96-128 hours if E-N loading checked)

Responsibilities:

Operational Physics - Accomplishment of test in safe and proper manner.

NPR Operations - Operation of reactor and provision for dry channels.

Process Design - Provision for dry channels.

3.1.5.4 Summary of Measurement Procedure:

1. Begin with the supercritical loading at the conclusion of Measurement #4; the unit has an excess of 2-3 mk, held subcritical by inserted control rods.

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2. Build up total potential reactivity to ~ 1 milli-k (calculated) by charging fuel as necessary in a symmetric pattern; e.g., see Figure XI.
3. Position rods to allow a reactivity of ~ 1.5 milli-k; measure period and insert several rods.
4. Discharge reject metal from process channel 1755; measure period with configuration used in step 3, then re-insert four or more rods to reduce to subcritical.
5. Recharge tube 1755 with natural uranium; withdraw rods to position calibrated in step 3 and measure period. Insert four or more rods.
6. Repeat steps 3, 4, and 5 for the following tubes in the order shown in increments of one or more tubes per step:

1) 1755	7) 1557	13) 1958	19) 1957
2) 1860	8) 2058	14) 1657	20) 1859
3) 1760	9) 1959	15) 1856	21) 1757
4) 1855	10) 1656	16) 1759	22) 1758
5) 2057	11) 1659	17) 1658	23) 1858
6) 1558	12) 1956	18) 1756	24) 1857
7. After all 24 tubes have been charged with natural uranium, establish a rising period of 20 seconds and record configuration; insert and calibrate rod #57 over range of available reactivity. Raise to a nominal level (≤ 10 kilowatts) and obtain flux distributions in two radial dimensions (utilizing wire or splines in central ball 3X channel and graphite cooling channel #1890). Insert four or more rods.
8. Uncap front and rear rods, and divert flow from twenty-four central tubes by proper valving. Allow water to drain; take count rate data continuously. Withdraw rods to point corresponding to 20-second period in wet array) and measure period if any.
9. If subcritical, charge additional fuel as recommended by the responsible physicist to re-establish the critical condition. Measure reactivity, then insert four or more rods.
10. Discharge natural uranium from process channel 1857; return to "20-second" rod configuration calibrated in step #7 and measure rising period; calibrate a few rods over a range of 0-2 milli-k, record configurations and insert four or more rods.

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Horizontal Tube Number

Block Substitution Test

Block Substitution Test

Notes:

1. Charging order indicated by numerals in center.
2. Zone 1 is approximate critical size.
3. Zone 2 is approximate addition for lattice temperature test.
4. Zone 3 is approximate addition for block test.
5. Dashed arrows represent rod compensation; all rods in horizontal rows 3-7 should be inserted symmetrically as gangs to compensate for excess reactivity of core.

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11. Discharge natural uranium from process channels 1757, 1858, and 1958; slowly withdraw calibrated rods to determine critical point and establish change in reactivity.
12. Calibrate rods over the range 0-2.0 milli-k; discharge natural uranium from process channels 1756, 1759, 1856, and 1959; withdraw calibrated rods to establish critical point.
13. Repeat step 12 and discharge remaining natural uranium columns in groups of four tubes; check for criticality at each point. In the event that the pile will be subcritical prior to completion of the discharge, charge additional reject quality .95 per cent material symmetrically on the periphery of the loading, measuring periods after each three tubes, until excess of 2 milli-k is available.
14. Calibrate rods over range 0-2 milli-k, again permitting rods to barely graze loaded core; insert several rods.
15. Slowly withdraw rods down to configuration of zero reactivity determined in step #14; measure period and record; insert rods to the same configuration held in step 1.
16. Recharge the 24 tubes with primary fuel; measure reactivity before water flow is restored; insert four or more rods.
17. Restore water; measure reactivity at position of rods in step #14.
18. Insert four or more rods.

3.1.6 Control Rod Local Strength

3.1.6.1 Desired Results:

1. Horizontal rod local strength
2. Rod coolant loss and strength relationship

3.1.6.2 Instrumentation and Equipment:

Same as 3.1.5.2

3.1.6.3 Estimated Time Requirement: 36 - 60 hours

Responsibilities: Operational Physics, NPR Operations

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3.1.6.4 Summary of Measurement Procedure

1. Begin with the small supercritical loading at the conclusion of the natural uranium block tests; the loading has a potential reactivity of ~ 12 milli-k, held subcritical by rods. (See Figure X)
2. Withdraw near side rods to establish reactivity base point of 2 milli-k; insert rods 53, 54, 55, 56, and 57 as a gang sufficiently far to reduce reactivity to 0-0.25 milli-k.
3. Repeat step #2 until the reactor is 0-2.0 milli-k supercritical with all rods out except numbers 53-57.
4. If the gang will be fully inserted prior to the desired reactivity state, discharge additional fuel from the near side of the loading (e.g., vertical column #48) as instructed by the responsible physicist. If the gang falls short of full insertion, charge production quality fuel into designated tube in vertical column #48. In the event of additional charging or discharging, establish a rising period with a given rod configuration, charge or discharge three tubes of fuel, and measure the rising period at the previously calibrated position to account for reactivity changes.
5. The loading is to conclude with a critical or slightly supercritical (0-0.5 mk) assembly with the rod gang inserted completely across the reactor.
6. Insert rod #52 and measure period with only rods 52-57 in the pile. If little or no change is observed, insert rods 51, 58 and 59 and check for reactivity change. Add fuel if necessary to return to 0-0.5 mk excess reactivity with rods 51-59 fully inserted.
7. Take a longitudinal flux traverse in process channel #2758 (or appropriate substitute, perhaps the TWPM #5) and vertically down Ball 3X channel #60, using splines or wire.
8. Insert all rods in vertical rows 40 and 60 (i.e., rod numbers 41-49 and 61-69) and withdraw rods 51-59; (shut off rod water flow and evacuate cooling water from rods 51-59); re-insert as a gang.
9. Withdraw rods 41-49; check for rising period; if none, slowly withdraw rods 61-65 and again check for period.

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10. If no period occurs in step #9, withdraw rods 66-69 one at a time, checking for rising period after each half of a rod withdrawal (i.e., take count rate data at 50 per cent and 100 per cent withdrawal of each rod). Continue until reactivity is 1.5-2.0 milli-k or rod 69 is withdrawn, whichever occurs first.
11. Insert rods 41-49 and 61-69, withdraw rods 51-59 and restore rod coolant flow, and re-insert.
12. Withdraw rods 41-49 and 61-69 and measure rising period; re-insert.
13. Proceed to Ball 3X test.

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FIGURE XII
ROD

LOCAL STRENGTH TEST

Notes:

1. Vertical numbers along center line are rod numbers.
2. Numbers at left are for orienting rods with fuel charges; e.g., rods 41, 51, and 61 are just beneath tube row 02; and rods 47, 57, and 67 are between rows 25 and 26.
3. Flux traverses will be taken in ball channel 60 and traverse opening 5.

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3.1.7 Local Ball 3X Strength

3.1.7.1 Desired Results:

1. Local Ball 3X strength
2. Ball strength versus location
3. Ball strength versus control rod strength

3.1.7.2 Instrumentation and Equipment:

Identical with 3.1.5.2, with additional requirement of splines or wire for flux analysis.

3.1.7.3 Estimated Time Requirement: 48-80 hours

Responsibilities: Operational Physics, NPR Operations

3.1.7.4 Summary of Measurement Procedure

1. Begin with the loading at the conclusion of test #6; the unit will be at room temperature, with a potential excess of ~ 15 milli-k controlled by an inserted bank of rods.
2. Withdraw a small increment of the rod bank to establish a base point rising period (~ 30 seconds); re-insert several rods to restore to subcritical.
3. Trip Ball 3X Hopper #48 and fill the associated channel; withdraw rods to the base point established in step 2 and check for supercriticality. If subcritical, continue withdrawing bank ($\sim 1/2$ milli-k/minute) until the pile is supercritical by ~ 2.0 milli-k; record position and shut down by inserting several rods.
4. Repeat steps 2 and 3 for ball channels 58, 38, 68, 78, 28, 18, and 88 in order indicated.
5. If the strength of ball columns is such that the rod bank will be removed and the pile should be subcritical before the above sequence is completed, insert several rods and charge one-half of the number of columns (calculated on-the-spot from test data by the responsible physicist) required to allow completion of the sequence; tubes will be charged on the near-side of the loading only. Continue in sequence of step #4 above until rods are out once more. Charge 50 per cent of newly calculated requirement to complete sequence. Continue withdrawal; charge remainder of calculated requirement when sequence is at the next appropriate point. Test should

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be programmed to terminate with full row of ball columns filled and a measured excess of 0.5-1.5 milli-k with all rods withdrawn.

7. If the rod bank is stronger than the Ball 3X row (i.e., it will remain partially inserted when the column sequence is complete) discharge fuel on a program similar to step #6; intended termination point is identical.
8. Raise power to ~10 kilowatts, and take flux traverses as follows:
 - a. Utilizing incore-monitor station #5, record the front-to-rear flux distribution as indicated by the five individual chambers.
 - b. Utilizing the travelling-wire flux monitor at the same location, obtain the continuous front-to-rear flux distribution.
 - c. Insert flux traversing splines or some convenient wire (e.g., manganese-copper encased in plastic) into graphite-cross-cooling channels 1799, 1794, and 1790. The flux monitoring equipment should be arranged to obtain a continuous thermal flux distribution completely across the reactor (i.e., side-to-side).
9. Shut down by inserting the previously inserted rod gang plus several additional rods and proceed with ball removal operation.

3.1.8 Lattice Fine-Structure Measurements

3.1.8.1 Desired Results:

1. Disadvantage factors, enriched and natural uranium.
2. Four-factor multiplication data ($k_{\infty} = \eta \epsilon p f$) for natural and enriched uranium.
3. Conversion efficiency, natural and enriched (cold).
4. Neutron energy distribution, cadmium ratios, etc.

3.1.8.2 Instrumentation and Equipment:

1. Standard reactor instrumentation.
2. Foils and/or pins of various target materials.

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3. Specially fabricated receptacle fuel element(s).
4. Counting equipment, including spectrometer, photomultiplier tube (RCA 6342 or similar), etc. (or substitute instruments as recommended by HLO).
5. Special retrieving equipment for securing special receptacle slugs.

3.1.8.3 Estimated Time Requirements: None

Responsibilities: Operational Physics, NPR Operations, HLO

Remarks: Details will be worked out by HLO and Operational Physics

3.1.8.4 Summary of Measurement Procedure:

1. In a selected slug position near the maximum flux but away from the utilized rod bank and process channel, insert specially designed element(s) containing detector pins and/or foils of a chosen material; in addition, detectors will be placed in cross-cooling channels.
2. Raise power to some nominal level (a few hundred watts to a few kilowatts) and irradiate for a prescribed length of time.
3. Shut down and discharge tube contents, recovering the detector-containing element(s).

3.1.9 Completion of Reactor Loading, Preliminary Control Rod Calibrations, and Determination of Safety System Strength

3.1.9.1 Desired Results:

1. Safe completion of loading.
2. Reactor statistical weight function in control rod plane.
3. Partial calibration of control rod system.
4. Minimum number of rods to hold unit subcritical.
5. Minimum number of ball channels to hold unit subcritical.
6. Penetration time and speed of control for rods, balls.

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7. Flux distributions, rod strength data for complete calibration by theoretical methods.

3.1.9.2 Instrumentation and Equipment (Parts b,c,d.):

1. All standard pile instrumentation
2. High speed recorder and timer for speed of control measurements.

3.1.9.3 Estimated Time Requirement: 144-240 hours

Responsibilities: Operational Physics, NPR Operations

3.1.9.4 Summary of Measurement Procedure

3.1.9.4.1 Completion of Loading

1. Beginning with the small loading at the conclusion of the Ball 3X local strength measurement (Test #7), return to the configuration of Step #2 of Test #5 (i.e., ~15 mk potential excess); this may involve recharging a few tubes of material if they were discharged for the Ball 3X measurement. Check the reactivity of this base loading with the rod configuration of Step 2, Test 5, by period measurements; it will be approximately 2 mk.
2. Insert several additional rods to hold the unit subcritical.
3. Discharge fuel from process channel 1758.
4. Start charging lead-cadmium elements, whose poison strength has been determined in the preceding "danger coefficient" measurements, into process channel 1758; charge one-quarter of the total poison length. Return to the configuration of Step 1, which has been calibrated, and measure the period.
5. Continue charging poison in steps of one-quarter charge until process channel 1758 is completely charged or the loading is ≥ 0.25 mk supercritical, whichever occurs first. Determine the period after each quarter charge is completed.
6. Repeat process in channels 1257, 1852, 2357, and 1863; each time the reactivity is reduced

to 0.25 mk, halt the loading procedure and withdraw rod gang (Step 1 above) to establish new base point ~ 2 mk supercritical.

7. Charge poison into channels 1252, 1263, 2352, and 2363 on a one-half tube basis (i.e., one-half tube, measure reactivity, establish 2 mk base point as required). If unit is not subcritical with all rods out after these nine tubes are charged with lead-cadmium, charge additional poison as instructed by the responsible physicist.
8. Insert all rods and complete the primary loading. Temporary poison is to be charged in the following locations (subject to amendment by the physicist if indicated by Step 7 above):

0652	1246	2369	2963
0658	1269	2846	
0663	1746	2869	
0746	1769	2952	
0769	2346	2958	

9. Charge additional poison as required to adjust pile reactivity to ~ 0.25 mk with all rods withdrawn except Nos. 54, 55, and 56.
10. Withdraw rods 54, 55, and 56 as a gang to point where period is 15-20 seconds; record position. Insert several additional rods to reduce to subcritical state.
11. Charge additional poison into tubes at configuration with rods 54, 55, and 56 at position of Step #10 after each quarter charge of poison, until reactivity is reduced to ~ 0.25 mk, compensating by poison, etc., until rods are completely out; the end point will be the fully charged reactor containing fuel and poison, exhibiting a small excess reactivity (≤ 2 mk) with all rods out.

3.1.9.4.2 Rod System Calibration

1. Insert four or more control rods. Place all subcritical and intermediate level instrumentation on-line, and remove any remaining temporary nuclear chambers and charge any uncharged process tubes. Withdraw rods slowly to observe proper instrumentation response. Check that the reactor safety circuit is properly made up, with any bypassed trip or setback mechanisms noted and brought to the attention of the responsible physicist.

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TEMPORARY POISON LOCATIONS (Tentative)

(Poison in Blackened Locations)

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2. Accurately determine rising period with all rods out; modify to a $\approx$ 20 second rising period, after observing sensitivity of intermediate level instrumentation, and record rod positions. Shut down by inserting rods 44, 46, 64, and 66.
3. Set period trips at 20 seconds (or at "calibrated period" of Step 2 above); determine flux level corresponding to $\sim$ 5 kilowatts, (or at least 2 decades above intermediate level instrumentation sensitivity), and set level trip at 10 kilowatts (or a factor of $\approx$ 200 above intermediate level sensitivity).
4. Start reactor up on a 30-second period, gradually decreasing toward the trip period (Step 3 above) so as to reach it at about 5 kilowatts reactor power.
5. Allow level to increase to trip point, causing a scram (scram manually if level exceeds the set trip point). System response will be recorded by oscilloscope and high speed camera, receiving signal from a subcritical range chamber.
6. Measure the reactivity with individual rods (as per the following list) by withdrawing all but the designated rod and evaluating the rising period:

(1) 25	(5) 56	(9) 46
(2) 35	(6) 57	(10) 37
(3) 45	(7) 58	(11) 28
(4) 55	(8) 59	
7. After each individual rod measurement, shut down by inserting four or more rods, until rod #28 has been measured. At that point, raise power to a nominal level (10 kw) and irradiate splines or other suitable flux detectors inserted into Ball Channel #50, graphite cross cooling channel #1689, and process channel #1958.
8. Set level trip at the level of Step #7 + 10%. Introduce a small positive reactivity (0-.1 milli-k) and allow LX circuit to trip. Record system response as in Step 5 above.
9. Re-establish reactivity of system with no controls inserted; k excess should be 1.5-2.0 milli-k.

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10. Insert sufficient of rod pair 45 and 56 to reduce the reactivity by 0.25 milli-k; record position. Insert additional rod (as a pair) in steps of 0.25 milli-k, recording position, until pile excess is ~ 0.5 milli-k. Then discharge sufficient poison from 1758 to increase k to 1.5-2.0 milli-k excess.
11. Repeat Step #10 until all rod pairs in the following list are inserted, discharging poison as noted when available excess is 0-0.25 milli-k:

<u>Pair No.</u>	<u>Rods</u>	<u>Octant for Poison Discharge*</u>	<u>Poison Tubes (Probable Nos.)</u>
1	45,46	1	1852
2	54,65	5	1269
3	25,34	3	2963
4	76,85	7	1252
5	59,68	2	2357
6	52,51	6	1263
7	62,74	4	2369
8	36,48	8	1246
9	88,97	1	2846
10	82,93	5	0769
11	13,22	3	2958
12	17,28	7	0652
13	46,57	2	2952
14	53,64	6	0663
15	66,75	4	2969
16	35,44	8	0646
17	94,105	1	2346
18	05,16	5	1769
		3	2363
		7	1257
			2352
			1863
			0658
			1746

*See Figure XIII

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12. Continue calibration on a single rod basis, utilizing the following order, and again discharging poison when the available excess reactivity declines to 0-0.25 milli-k:

<u>Rod No.</u>	<u>Rod No.</u>	<u>Rod No.</u>
43	38	07
67	72	103
47	33	21
63	77	89
55*	37	29
52	73	81
58	15	41
23	96	69
87	14	49
27	95	61
83	12	31
26	98	79
84	18	39
86	92	71
32	03	04
78	107	106
		104

*Stop and proceed to step 13.

This procedure will be uninterrupted until rod #55 is inserted. At that time, proceed to step #13, complete step 13, and then return to the insertion order at rod #52. Complete as much of the system as allowed by the available reactivity, and then insert all remaining rods, and proceed to the next test (3.1.9.4.3, step 1).

13. After rod #55 has been calibrated, insert rods 52, 58, 23, and 87; withdraw rod #55.
14. Replace the tip of rod #55 with "isotope producing material" (see HW-63460, Isotope Producing Control Rods, D.E. Simpson, 12-21-59). Re-insert rod #55.
15. Slowly withdraw rods 58, 23, and 87, observing the subcritical count rate; after withdrawal, wait three minutes and check for criticality.
16. If reactor is subcritical, withdraw 25 per cent of rod #52; check for criticality after a three-minute wait.

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17. Continue withdrawing rod #52 in increments of 25 per cent and checking for criticality with a three-minute wait after each incremental withdrawal.
18. If reactor will be no more than 2.0 milli-k supercritical with rod 52 all out, it should be withdrawn; at any rate, establish a condition of ≤ 2.0 milli-k excess with rod 52 either withdrawn or partially inserted.
19. Insert rods 52, 58, 23, and 87.
20. Withdraw rod #55 and replace isotope producing tip with standard control rod tip; reinsert and return to step #12 at rod #52 in the charging order.

3.1.9.4.3 Minimum Number of Rods Required to Hold Cold Clean Reactor Subcritical

1. Start withdrawing rods, one at a time, to establish critical, utilizing the following sequence and waiting two minutes after each rod is withdrawn before proceeding to the next rod: (sequence down and to right)

07	05	97	15	59	25
18	17	105	27	78	37
29	39	93	49	96	58
89	88	71	69	94	77
98	106	22	87	72	85
107	104	04	95	51	73
103	82		83	32	52
92	31		61	14	33
81	13		41		26
21	06		23		48
12	28		16		68
03	79		38		86

2. After the minimum number of central rods required for subcriticality is determined, insert the next available full ring of rods (see Figure XIV); i.e., pick the next ring that is completely outside the above array; this will be ring "n".
3. Withdraw rods in ring "n-1" (Figure XIV) one at a time, with two-minute waits, to reestablish critical; proceed to ring "n" if required.

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FIGURE XIV

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4. As an example of steps 2 and 3, assume that, for simplicity, rods 44, 45, 46, 54, 55, 56, 64, 65, and 66 are required to hold the unit subcritical. Step 2 required insertion of ring #2, composed of rods 34, 35, 36, 43, 47, 53, 57, 63, 67, 74, 75, and 76; step 3 requires withdrawal of rods 44, 45, 46, 54, 55, 56, 64, 65 and 66, or enough of them to restore critical.
5. Insert all remaining rods to reduce to subcritical.
6. Start withdrawing rods in pairs (except for rod #55, withdrawn alone). Pull no more than one pair of rods in any three-minute period; record neutron count rate after each pair is withdrawn. Use the following sequence for withdrawal:

<u>Pair</u> <u>No.</u>	<u>Rod</u> <u>Nos.</u>	<u>Pair</u> <u>No.</u>	<u>Rod</u> <u>Nos.</u>
1	55	12	42,68
2	46,64	13	62,48
3	44,66	14	04,06
4	35,75	15	104,106
5	53,57	16	39,79
6	33,77	17	31,71
7	37,73	18	13,22
8	15,95	19	88,97
9	51,59	20	17,28
10	86,24	21	82,93
11	26,84		

7. A continuous plot of inverse multiplication versus number of rods withdrawn will be maintained; rods may be pulled at the rate of three minutes per pair until the inverse count rate indicates criticality within 5 rod pairs; a more conservative rate of five-minutes per pair will then be adopted.
8. Rod withdrawal will continue as per the above schedule until the critical condition is established; in the unlikely event that criticality is not attained by the time all of the above rods are withdrawn, the responsible physicist will designate the withdrawal order for additional rods.
9. After criticality is established and checked by withdrawal to a supercritical state (rising period $\geq$ 15 seconds) insert all control rods.

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10. Start withdrawing rods again by pairs, at a rate no greater than 2 rods per three-minute period, in the following order, recording neutron count rate and estimating critical as in steps #6 and #7 above:

<u>Pair No.</u>	<u>Rod Nos.</u>	<u>Pair No.</u>	<u>Rod Nos.</u>
1	05,15	12	35 (alone)
2	03,07	13	34,36
3	04,06	14	33,37
4	14,16	15	32,38
5	13,17	16	31,39
6	12,18	17	45 (alone)
7	25 (alone)	18	44,46
8	24,26	19	43,47
9	23,27	20	42,48
10	22,28	21	41,39
11	21,29		

11. Discontinue above schedule when reactor is slightly supercritical ($\beta_k = 0-0.5$ mk) and insert all rods after establishing reactivity.
12. Repeat steps 10 and 11 for the following schedule:

<u>Pair No.</u>	<u>Rod Nos.</u>	<u>Pair No.</u>	<u>Rod Nos.</u>
1	55 (alone)	9	34,76
2	45,54	10	47,63
3	56,65	11	67,43
4	46,64	12	25,85
5	44,66	13	52,58
6	53,57	14	37,73
7	35,75	15	33,77
8	36,74		

13. Insert all rods.

3.1.9.4.4 Ball 3X System Effectiveness

1. Withdraw rods to critical configuration determined in step #1 of 3.1.9.4.2 above; measure period.
2. Trip ball hoppers 49, 50, 59 and 60 (Group 1); measure penetration period.
3. Withdraw rods in reverse order of initial insertion (step #1, 3.1.9.4.2), one at a time,

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4. Trip ball hoppers 38, 39, 40, 41, 48, 51, 61, 68, 69, 70, and 71 (Group 2); withdraw additional rods by the reverse of the insertion order, as in step #3 above, to re-establish critical point.
5. Continue process of tripping ball hoppers, withdrawing rods, and establishing critical as above, in groupings of ball channels in the following order:

28	18	9	4
29	20	12	8
30	32	35	23
31	36	44	86
37	53	65	101
42	56	74	105
47	73	97	
52	77	100	1
57	89		6
62	91	10	15
67		22	24
72	19	26	85
78	21	54	94
79	27	53	103
80	43	83	108
81	46	87	
	63	99	7
	66		14
	82	11	102
	88	17	95
	90	33	
		45	
		64	
		76	
		92	
		98	
		2	
		5	
		25	
		34	
		75	
		84	
		104	
		107	
		3	
		13	
		16	
		93	
		96	
		106	

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FIGURE XV

BALL SYSTEM GEOMETRY

When it becomes apparent that all rods will be removed when the next group of balls is inserted, continue on a single column basis (i.e., fill a single column, compensate by rods, establish critical) until all rods are removed, and the unit is 0.5-1.5 milli-k supercritical.

6. Establish a rising period (≥ 20 seconds) and trip next ball hopper on schedule; measure penetration time and record flux decay transient.
7. Insert rods and proceed to ball removal operation.

3.1.9.4.5 Speed of Control

Safety system response times (speed of control) are actually measured during the calibration procedure above. The procedure is covered in the following sections:

Flux Response to Period Trip of Rod System . . .
. . . . 3.1.9.4.2 (Steps 1-5)

Flux Response to Level Trip of Rod System . . .
. . . . 3.1.9.4.2 (Step 7)

Flux Response to Trip Signal of a Ball Column .
. . . . 3.1.9.4.4 (Steps 2 and 6)

3.1.10 Full Pile Temperature - Reactivity Transients

3.1.10.1 Desired Results:

1. Uniform lattice temperature coefficient of reactivity in fully loaded reactor.
2. Graphite temperature coefficient.
3. Graphite temperature falling period.
4. Possibly sufficient data to separate metal and water temperature coefficients.
5. System temperature, flow, pressure, etc., feedback effects.

3.1.10.2 Instrumentation and Equipment:

All standard pile instrumentation, plus thermocouple probes for insertion in cross cooling channels, and special thermocouples for monitoring specified uranium temperatures if practical.

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3.1.10.3 Time Requirements: 96-128 hours

Responsibilities: Operational Physics,
NPR Operations, HLO

3.1.10.4 Summary of Measurement Procedure

1. Start with the fully loaded reactor; return to the "uniform distribution" rod configuration established at step 8 of Section 3.1.9.4.3, "Minimum Number of Rods Required to Hold Cold Clean Reactor Subcritical." (This configuration, designated as "configuration one," is the minimum number of rods, uniformly distributed, which will hold the room-temperature, green reactor subcritical or just critical.)
2. Slowly withdraw a pair of rods (probably #45 and #55) in concert to establish excess reactivity of 1 milli-k (60 second rising period) and record position (configuration 2); insert four or more rods.
3. Withdraw rods inserted in step #2, and continue withdrawing selected pair to establish excess reactivity of 2 milli-k (configuration 3). Insert four or more rods.
4. Heat entire reactor by technique of ATP 2405, using following schedule and taking reactivity and count rate data as indicated on the following table.

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REACTIVITY-COUNT RATE TABULATION

Heating Process

Step	Event	Water Temperature	Graphite Temperature	k _{eff}	Relative Count Rate
0	Start	20 C	20 C	1.0020	
1	Calibrate & insert 2 mk of rod	20	20	1.0000	
2	Insert additional rods	20	20	1	
3	Heat to 50 C	50	50	1	
4	Withdraw to "configuration 3"	50	50	1.0008	
5	Insert to "configuration 1"	50	50	.9988	1.000
6	Heat to 100 C	100	100	.9962	.316
7	Withdraw to "configuration 3"	100	100	.9982	.667
8	Heat to 150 C	150	150	.9953	.255
9	Insert to "configuration 1"	150	150	.9933	.179
10	Heat to 200 C	200	200	.9902	.122
11	Withdraw to "configuration 3"	200	200	.9922	.154
12	Heat to 260 C	260	260	.9880	.100
13	Insert to "configuration 2"	260	260	.9870	.092
14	Insert to "configuration 1"	260	260	.9860	.086

Note: Configuration 1 = 0 mk excess at room temperature
 Configuration 2 = 1 mk
 Configuration 3 = 2 mk

Cooling Process

Step	ΔT, Min.	Event	T _W	T _G	k	n
1	0-15	Cool water 40 C	220	254	.9900	.120
2	15-60	Withdraw to Config. 1, Cool Graphite	220	233	.9910	.133
3	60-75	Cool water 40 C	180	225	.9958	.286
4	75-120	Cool graphite	180	197	.9942	.207
5	120-135	Cool water 40 C	140	189	.9990	1.200
6	135-138	Insert to configuration 1	140	188	.9970	.400
7	138-180	Cool graphite	140	158	.9946	.222
8	180-187	Cool water 20 C	120	156	.9976	.500
9	187-210	Cool graphite	120	140	.9962	.316
10	210-217	Cool water 20 C	100	139	.9992	1.500
11	217-240	Cool graphite	100	121	.9977	.522

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3.1.11 Power Ascension and Operating Power Tests; "Feedback"

3.1.11.1 Desired Results:

1. Data for calculating transfer function $\frac{\delta P(s)}{\delta k(s)}$.
2. Experimental verification of analog studies on system responses to driving functions of reactivity and temperature variations.
3. Transport delay lags and time constants between inlet and outlet and between reactor and heat exchangers.

3.1.11.2 Instrumentation and Equipment:

1. Standard reactor and loop instrumentation.
2. Temperature monitoring devices and fast recorders, at:
 - a. Reactor inlet
 - b. Reactor outlet
 - c. Heat exchanger inlets
 - d. Heat exchanger outlets
 - e. Standard flow and pressure measuring points.
3. Fast recording system to be used in conjunction with in-reactor flux chambers.
4. (Possibly) pile oscillator system.

3.1.11.3 Estimated Time Requirements: Open

3.1.11.4 Summary of Measurement Procedure

(Note: This test requires considerable fission power and is thus not properly classed with the previously described zero level tests. Details for this particular experiment will be worked out after considerable production has been logged. A preliminary and cursory description of the visualized procedure is presented here for early consideration.)

3.1.11.4.1 Reactivity in Rods as a Driving Function

1. In the operating reactor just prior to shut-down, have provisions for the monitoring and fast recording of reactor and heat exchanger temperatures, reactor flux level, and rate-of-rise.
2. Ascertain that the stable reactor level is at least 10 per cent below current operating limits; set power level trips at ~5 per cent below operating limit.

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3. Referring to current rod calibration curves, insert exactly one milli-k of a rod designated by the responsible physicist, at maximum speed.
4. Without changing rod configuration, allow power level to drop and stabilize at new lower level. Record power level and reactor temperatures as accurately and completely as possible. Also, monitor and record system flows and pressures during the power transient.
5. After system has reached quasi-stability, select two rods as designated by the responsible physicist, choosing one entering from the left and one entering from the right in near proximity of each other.
6. Ascertain the insertion required for 0.2 milli-k of excess reactivity; insert the pair of selected rods to this extent, and then withdraw them to their original position at the same rate. In other words, there will be a near-triangular waveform of reactivity input; the period of oscillation should be ~20 seconds.
7. Continue inserting and withdrawing the selected increment of rod, with a complete cycle every 20 seconds.
8. Record reactor flux level and process variables as a function of time for 3-5 minutes.
9. Insert all remaining rods for normal shutdown.

3.1.11.4.2 Primary Coolant Temperature as a Driving Function

1. At subsequent period of steady-state operation, ascertain that the reactor is in the condition of steps #1 and 2 of 3.1.10.4.1 above.
2. Using manual control, operate the secondary steam pressure control to increase primary coolant temperature at the inlet by 10 F. Allow the system to reach stability at the higher temperature.
3. Determine the secondary control action necessary to result in a ± 5 F change in reactor inlet.
4. Ascertain that the reactor is operating at least 15 per cent below power level limits.

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5. On a periodic basis (~20 seconds per cycle) first decrease and then increase the primary inlet temperature by appropriate secondary steam pressure manipulation.
6. Continue for 3-5 minutes, or until maximum power level is within 5 per cent of limits, continuously recording reactor level and process variables.
7. Insert all rods for normal shutdown.

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APPENDIX II

Procedure for Measuring Reactor Period

Since the determination of the reactor rising period is an integral part of most of the individual tests, it is appropriate to describe the procedure separately and in detail.

In general, no period shorter than 10 seconds will be permitted, and at least three separate instruments will be included in the safety circuit to scram the unit in case of excessive level. This trip function will be provided by three thermal-neutron-sensitive ion chambers connected directly into the safety circuit via the normal High Level Nuclear Instrumentation system. There is one important difference from the operating case: normally, the chambers for this system are located in vertical ports at the top of the reactor; for extra sensitivity during startup, substitute chambers will be located in horizontal traverse openings 4 and 5, or possibly in designated rod channels. They will be repositioned as necessary as the loading progresses. Trips will be set by mutual agreement between Operational Physics and N Reactor Operations; in no event will rising pile periods shorter than 10 second or individual tube powers greater than 10 watts be allowed in the small pile loadings. (Higher tube powers may be required in the full pile tests, but the full complement of normal operational instrumentation will have been calibrated and will then be operational.)

In addition to the above safety circuit instrumentation, two to four neutron proportional counter chambers (BF_3) will be employed as a flexible system for monitoring the neutron count rate in both the sub- and supercritical ranges. In general, rising periods during individual tests will be restricted to 20 seconds or longer. These chambers will be positioned in process channels adjacent to the loading for maximum sensitivity; one will be initially located in the center of process channel #1758. At least two of these chambers shall be calibrated in the Sigma Pile, prior to the startup test program, to establish the relationship between count rate and neutron flux. For any pile size, this relationship will be used to establish trip settings on the safety circuit instrumentation.

During the pre-critical loading process, all rods will be placed in the full-out position and set to scram on a trip of the 1X safety circuit (which will be completely made up, with the exception that the process tube low flow trip will be adjusted as required by any particular test). The 3X circuit may be bypassed if the 1X circuit is properly made up (the provision for 3X manual trip must be retained).

Rising periods in the supercritical assembly will be determined as follows:

1. Withdraw specified rods to predetermined position.
2. With all other rods out of the unit, measure the rising period as seen by at least two independent proportional counter chambers.
3. After at least three twenty-second counting intervals or two decades, whichever case is more conservative, have been observed, estimate the reactor period as indicated by the two assemblies.
4. Prior to reaching established trips, reduce to a subcritical state by inserting rods 44, 46, 55, 64, 66; these rods will, in general, be reserved for this purpose. (In event of exception in any given test, the appropriate rods will be specified in the test procedures.)

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APPENDIX III

Non-Nuclear Heating for Temperature Coefficient of Reactivity Tests

As a planned part of acceptance testing, the primary loop will be heated utilizing non-nuclear techniques; it is expected that a temperature of 525F may be achieved using pumping power alone. The general procedure outlined below was prepared by H. R. Kosmata of Design Analysis, NPR Project Operation.

ATP 2405 - PRIMARY LOOP, HOT

Prerequisite

1. Primary loop intact and pressure tested.
2. Pressurizer operational.
3. House boiler operational.
4. Secondary loop intact and pressure tested.
5. Condenser cooling system operational.
6. Rod and thermal shield cooling systems operable.

Optional Arrangements

Reactor

1. Fuel and dummies not loaded.
Rods out.
Graphite cooling system drained
and gas purged.
2. Fuel and dummies charged.
Rods in.
Graphite system drained and
gas purged.

Secondary Loop

1. Heat exchangers drained and
isolated.
Dump condensers valved out
of service.
2. Heat exchangers in normal
condition.
Dump condensers in normal
condition.
Pressure control on manual.

Goals

1. Pump and flow system characteristics.
2. Reactor flow distribution.
3. Pipe movement and strain measurement, high flow vibration. (Above at equilibrium temperatures and during cooling transients.)
4. Environment temperature control.
5. Hot loop pressurizer performance.
6. Hot loop injection and spill characteristics - transient performance to compensate for expansion-contraction.

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7. Hot loop instrumentation calibration.
8. Hot dump performance.
9. Hot flow diversion system characteristics.
10. High temperature physics data.
11. Pump trip-out tests.

Procedures

Heating

The pressurizer and injection system will bring the pressure of the system to 300 psig.

Steam will be admitted to the primary pumps at the maximum possible rate.

The temperature of the primary coolant will be brought to 300 F.

The system will then be pressurized to 1500 psig.

The temperature will then be allowed to increase to a maximum of 525 F.

The temperature may be held at this or any intermediate level by throttling steam flow to the pumps.

Cooling

Procedure C-1 - The spill-inject method would be accomplished by bleeding the system to the maximum capacity of the injection pumps. The primary pumps would be cut back to a very low level. The flow rate must be maintained at a rate which will give adequate temperature distribution; however, a low rate is desired so as not to cause unnecessary system heating. The injection flow would be demineralized water. This exchange of cold for hot water will take place until the desired temperature levels are reached.

Procedure C-2 - The dump method will begin by stopping steam flow to the primary pump drive turbines. Then, the dump valves will be opened. When the system has depressurized to ~300 psia, the emergency cooling system will begin injecting water into the reactor. During actual operational use of this system, the water introduced would be raw river water. For test purposes, it would be advisable to provide demineralized water. Dump would be terminated when system temperatures had reached desired level and system would recover in same manner as from normal dump (not yet determined).

Procedure C-3 - The heat exchange method cannot be used until the primary coolant temperatures are reduced to a level where the equilibrium steam

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pressure on the secondary side is within the design limits of the secondary side piping. (The exchangers themselves are designed for 800 psia.) At this point, steam may be admitted to the dump condensers. The cooling rate will depend primarily upon the rate at which the secondary steam pressure is reduced.

In order to reduce temperatures below 250-300 F, boiling heat exchange will have to be abandoned in favor of one of the previously discussed methods or a transition to water-water cooling in the primary exchangers could be made.

This would proceed in the same manner as intended for normal operation (not yet specified). With water-water cooling, primary temperatures could be reduced close to river influent.

Preliminary Program

1. Reactor option 1, secondary loop option 1.
 - a. Heat to 300 F and hold for temperature, ΔP and flow measurements as needed.
 - b. Continue heating to 500-525 F and hold for measurements as in (a).
 - c. Measure pipe movement and strain.
 - d. Check diversion system.
 - e. Regain temperature (if necessary) and pressurize to relief point.
 - f. Reduce pressure to reseal relief valves.
 - g. Dump!
2. Reactor option 2, secondary loop option 1.
 - a. Heat to 500-525 F in steps taking physics data as needed.
 - b. Cool to ambient by injection and spill in steps taking physics data as needed.
3. Reactor option 2, secondary loop option 2.
 - a. Heat to point of relief of secondary system (~ 480 F).
 - b. Reduce level to reset relief and hold temperatures for physics data.
 - c. Manually operate secondary steam pressure control to reduce primary temperatures to 400 F at rate of $300^\circ/\text{hour}.$ *

*This method may not be satisfactory, in which case, it would be necessary to dump system to achieve rapid temperature decrease needed.

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- d. Hold for physics data.
- e. Repeat (c) to bring temperatures down in steps to 350 and 300 F.
- f. Go through transition to water-water heat exchange to bring temperature back to ambient.

(Could run pump trip-outs during the heating cycle of run #3 or this could be from separate run #4.)

Process Physics Studies
Operational Physics Sub-Section
Research and Engineering Section
IRRADIATION PROCESSING DEPARTMENT

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END