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UCRL-50249

SUMMARY REPORT OF THE NTH COUNTRY EXPERIMENT - EXTRACT

(Title: Unclassified)

Edited by W. J. Frank

March 1967

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ATOMIC WEAPON DATA CATEGORY SIGMA 1

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Lawrence Radiation Laboratory
UNIVERSITY OF CALIFORNIA
LIVERMORE

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CONTENTS

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PREFACE

W. J. FRANK

This report summarizes the LRL Nth Country Experiment. It contains a description of the final design (omitting the physics justification), a critique of its performance by two LRL physicists, and a series of short articles on the technology available in the unclassified literature (Appendices F thru L). The full physics description and history of the Nth Country design, completed by the three Nth Country physicists on December 14, 1966, has been published separately (UCRL-50239). The correspondence between the Nth Country designers and the LRL support committee is published in UCRL-50248.

Two major technical problems face a nation wishing to acquire a small stockpile of nuclear weapons. The first concerns the manufacture of the source material – probably with a plutonium production reactor. The second problem concerns the effort required to design a nuclear weapon. [redacted]

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LRL started its Nth Country Experiment in May 1964, to see if a few capable physicists, unfamiliar with nuclear weapons and with access only to the unclassified technology, could produce a credible weapon design. They were to receive such unclassified computer and technical support as might be required. The duration of the Experiment was to be one year, since the physicists who agreed to work half-time on the Experiment (D. A. Dobson and D. N. Pipkorn) were post-graduate students at the Laboratory on a one-year appointment. They were subsequently appointed for a second year, and in March 1965, R. W. Selden, an LRL Army Research Associate, joined the design team. The designers' backgrounds and a brief chronology of the Experiment are given in Appendices B and C.

There was only one contact, A. J. Hudgins, to provide good security control and avoid contact with Laboratory personnel familiar with weapon design. Some security aspects of the Experiment, as experienced by the designers themselves, are described in Appendix D. All technical questions were handled via written documents coordinated by W. J. Frank. The day-to-day problems and progress of the design were kept in classified notebooks by the physicists. The operating rules for the Nth Country Project are given in Appendix A.

Several comments can be made about the manner in which the Experiment was conducted. It proceeded on a relatively low-key basis (in all, only three man-years of effort were spent over the two-and-a-half year period of the Experiment). While the three designers had technical support, they were not allowed to interact or discuss their ideas with these people (except through written documents); they thus lacked the vital feedback process of explaining and defending their work in the context of a larger group of interested, equally talented but differently oriented technical staff members.

The Experiment was formally ended on April 10, 1967.

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A short follow-on Experiment is now underway: the designers were given the results of the test and asked several questions about their current design, its possible extensions, and alternative design approaches. A report will be issued later describing these postshot activities.

I would summarize the conclusions of the Experiment in two statements:

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Appendix L considers the costs of building and running a small weapon laboratory and production facility. These data, plus a typical estimate for a plutonium production reactor, give a third conclusion:

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THE NTH COUNTRY FISSION WEAPON DESIGN

D. A. DOBSON, D. N. PIPKORN AND R. W. SELDEN

(December 14, 1966)

I. BASIC CONCEPTS

The basic concept of how a bomb works, preliminary design considerations, and our first complete design were significant stages in the evolution of our understanding about nuclear explosives. We present the basic concepts as we understood them early in the Experiment and not from our current knowledge.

1. A nuclear fission explosion results when a supercritical mass of fissile material is assembled and held together long enough for the chain reaction to take place.
2. Critical mass numbers are readily available from the literature (Paxton, Los Alamos Critical-Mass Data and Paxton, Critical Dimensions of Systems Containing U^{235}, Pu^{239}, and U^{233}.

Fissile material	Critical mass (kg)	
	Bare sphere	Sphere surrounded by 4-cm-thick U reflector
U^{235} (93.5%), U^{238} (6.5%)	48.0	26.0
U^{233}	14.5	8.5
α phase Pu^{239} (density 19.8 g/cc)	9.5	6.2
δ phase Pu^{239} (density 15.6 g/cc)[a]	15.5	8.0

[a] containing 1 wt % gallium

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4. The time for the chain reaction to take place can be estimated. The neutron multiplication time, α^{-1}, is the mean time a neutron spends in a supercritical fissile assembly before producing a fission.

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The uranium in the example above is both a neutron reflector and an inertial material. This is the so-called tamper surrounding the fissile core as they are popularly described.

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6. There are two general techniques for assembling a supercritical mass described in the literature: the gun method where subcritical masses are "shot" together, and the implosion method where a subcritical mass is made supercritical by compression.

For a gun assembly, suppose that

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the fissile hemispheres become critical and the time they meet.

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For an implosion assembly, suppose that

It appears that the implosion method can be made to give faster assembly times than the gun method.

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7. The most important feature of the assembly times calculated in subsection (6) above is that they are more than 10 times the total fission chain reaction time. This means that it is essential for the fissile material to be neutron free during the assembly or the reaction will take place prematurely. If the fissile material is neutron free, then it is necessary to "turn on" neutrons to initiate the chain reaction at the desired time. This is the role of the so-called initiator. DOE b(1)

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II. EARLY DESIGN

A. PRELIMINARY DESIGN CONSIDERATIONS

Early in the Experiment it was decided that a choice had to be made about a fissile material and a method of assembly because of the time and effort it would take to develop more than one type of explosive. This section outlines the important considerations which influenced our decision as to how to proceed, and describes those features of the explosive which were recognized at the time the decision was made.

Fissile Material Considerations

Economic and Political Considerations – U^{233} was eliminated because of the prohibitive cost of production (thorium breeder reactor). U^{235} and Pu^{239} cost about the same to manufacture, but we were informed by the "Nth Country Treasury Department" that only one or the other could be produced. The production of Pu^{239} has a long range economic advantage over U^{235} because it requires the development of reactor technology.

Physics Considerations – Pu^{239} has the advantage of a lower critical mass and a low density phase (δ phase) with a greater compressibility, both of which lead to a shorter chain reaction time. U^{235} has the advantage of a low neutron background, while the Pu^{240} impurity produced in the Pu^{239} has a relatively high spontaneous fission rate.

Method of Assembly Considerations

The gun method appeared easier to accomplish because it involved familiar technology. The long assembly times and the Pu^{240} impurity in Pu^{239} rule out the use of plutonium with this method.

The implosion method appeared more difficult because of its unfamiliar technology, but it seemed to have a greater potential for future development and more efficiency because the 1945 implosion bombs gave greater yields. The development of the implosion method seemed to be a more sophisticated, challenging, and hence appealing problem.

Preliminary Decisions

It was decided to design a spherically symmetric plutonium implosion explosive which would be compressed by a spherically converging detonation wave. Figure 1 shows our concept of this explosive. The features of this drawing are:

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B. THE INFLUENCE OF LITERATURE

A number of articles and books give some aspects of the basic concepts of bomb design in a variety of contexts. We refer to these publications as the "general bomb literature."

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C. THE EARLY DESIGN

This section is an historically accurate description of our first complete plutonium implosion design, which had evolved by December 1965.

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Explosive Lenses

DOE (3)

Detonators

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DOE (3)

Tamper

The tamper was :

Core

The core was. DOE (b)(3)

DOE (3)

The following neutronics calculations were performed to establish the core parameters:

1. The critical mass of a

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b)(3)

2. For the tamper and core specified above,

Initiator

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The initiator was designed to produce

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D. ASSESSMENT

Three Phases of the Experiment

The evolution of our knowledge of nuclear explosives during the Experiment seems to fall naturally into three principal levels of understanding. Thus the course of the Experiment is divided into three phases, each representing the attainment of a principal level of understanding. The phases are not completely distinct in time.

Phase I — Phase I represents our understanding of the basic concepts and the design considerations described in Section A. This level of understanding was achieved by Davidon, et al. (Davidon, Hohenemser, and Kalkstein, "The Nth Country Problem").

Phase II — Phase II was the extension of the basic concepts to a more quantitative form by making neutronics calculations involving rudimentary compression numbers, and engineering converging wave lenses, detonators, and an initiator. Quantitative values for core mass and hole size, tamper thickness, and explosive thickness were chosen. The Early Design described in Section C represents Phase II.

Phase III — Phase III was the extension of Phase II which involved doing meaningful implosion and iterative fission expansion calculations on plutonium-implosion designs derived from the Early Design. The sections on the Final Design and Test and the Continuing Program were a result of our Phase III level of understanding.

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Assessment of Early Design

It is useful at this point to evaluate the Early Design in the light of our current knowledge. It should be pointed out that if a Phase II design had been submitted as a final design, it might not have been exactly the Early Design. We believe that the Early Design is representative of our Phase II understanding. There were no sound reasons for changing any of the parameters.

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Phase III provides the understanding necessary to make this assessment.

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III. BOMB PHYSICS

This section of UCRL-50239 has been omitted. It discusses in detail the implosion process, the neutronics before and after initiation, the expansion of the core as fission proceeds,

IV. THE FINAL DESIGN

The Final Design describes a

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The primary objective of a test would be to obtain as much information as possible about the factors affecting

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A. DESIGN

The Final Design is a spherical implosion design with a

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These changes were incorporated in this report on March 1, 1967 — after the report had been written and the Final Design submitted, but before the Experiment had formally ended and this report published.

The important specifications and the basis for the choice of the specifications are discussed below. (The design drawings are contained in UCRL-50239.)

Detonators and Lenses

The detonators and lenses are essentially those described in the Early Design. There are two minor changes in the lens design.

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1. The test of the Early Design lens showed that the shock wave

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Fig. 2. A cross-section sketch of the Final Design.

The baratol-Comp B interface then obeys the equation,

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2. The Comp B

obeys the equation,

up to the top of the lens where the shell is modified to accept the detonator.

The detonator simultaneity requirement and explosive tolerances have been specified so that the total timing error that can be

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DOE
(b)(3)

Tamper

DOE
b)(3)

Core

The core is

DOE
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The assembled device is calculated to be
This value is to be checked by measurement.

Doe
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Doe
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Initiator

The polonium-beryllium initiator is

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V. TEST

This section of the report (UCRL-50239) describes the diagnostics measurements to be made before and during a test of the Final Design.

VI. THE CONTINUING PROGRAM

The development of a nuclear explosive is an evolutionary process. Ideas for future investigation have been a continuous part of the Experiment. These ideas both affect and are affected by whatever current work is being done, and new ideas for future work are constantly generated. An important part of our understanding of nuclear explosives is involved in our ideas for future investigation, both in the extent to which a particular idea has been developed and in our judgment about the importance and difficulty of the investigation.

The purpose of the Experiment was not to establish a long range development program, and we have not attempted to do this. A real Nth Country would establish a program (perhaps they would only build five copies of our Final Design) which would strongly influence the nature of the investigations pursued. Establishment of this program would be influenced by judgments of the designers about feasible future developments. Four general applications of future investigations which could serve as objectives in the Nth Country's nuclear explosive development program are:

1. Light, compact, low yield tactical weapons.
2. High yield fission weapons.
3. Thermonuclear explosives.
4. Peaceful applications.

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A wide range of ideas is discussed in this section ranging from detailed proposals for improvements on our yield calculation to, the design of a thermonuclear explosive. We have attempted to assess the difficulty and importance of pursuing each idea. (The importance in most cases has to be decided in terms of a long range development program.) General nondirected research into areas such as explosives, hydrodynamics, metallurgy, and nuclear physics is not included. Although such research is an essential part of a comprehensive long range program for a country desiring to be at the forefront of new advances as they are made, an Nth Country could be content to use results as they become available and allow others to bear nearly all the expense of maintaining research programs.

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(The remainder of this section of UCRL-50239 has been omitted from this report. It included possible improvements in

fission weapon designs; and the design of thermonuclear explosives.)

VII. CONCLUSIONS

We hope that the Nth Country Experiment is useful in assessing the difficulty for an Nth Country to develop a nuclear explosives capability. Such an assessment is clearly outside the scope of our part of the Experiment. This section contains a discussion of some nontechnical aspects and some comments on the results which we believe are an essential part of the Experiment and should be considered in extending the results to an Nth Country.

It is inevitable that the Experiment will be compared with the early years at Los Alamos. We are not in a position to make any valid comparison of the technical developments. The people at Los Alamos had advantages of manpower and experience (including the presence of some of the world's outstanding physicists) and the motivational climate in which they worked. We had the advantages of knowing that a bomb could be built and of having access to a large quantity of literature on shock waves, explosives, nuclear physics and reactor technology which has been published since 1945.

A. FACTORS AFFECTING THE PROGRESS OF THE EXPERIMENT

The course of the Experiment falls naturally into two time periods:

The Early Period was the first year and a half (May 1964-December 1965). Phases I and II were completed during this period.

The Late Period was the last year (1966). Phase III was completed, the Final Design established, and several drafts of the Nth Country Report written (including the one submitted in UCRL-50239) during this period.

The goal of the Experiment was to design a credible nuclear explosive, but the time and the state of development at which the Experiment would end was left up to the experimenters (see Appendix A). It was assumed by the experimenters that a test would be the end of the Experiment rather than a step in the development.

A total of three man-years has been spent on the Experiment, divided as follows:

1. Early Period: Dobson 1/4 time, Pipkorn 1/2 time, Selden full time for last half year.
2. Late Period: Dobson 1/2 time, Selden full time.

The informal structure and part time nature of the experiment resulted in a lack of continuity during the Early Period. (The periods of maximum effort were put in when the committee wanted to see the notebooks.) We tended to work individually, resulting in some duplication of effort. In the Late Period continuity was provided; also, we worked together.

Since the Experiment was carried out inside a nuclear explosive design laboratory, it was necessary to insure that we received no classified information including any hints about our technical progress from anyone involved in the Experiment. Aside from documents generated within the Experiment, we have never been exposed to any classified information. (See Appendix D.)

In line with security requirements, all our communications with the committee have been in writing. Such communications were essential since the committee simulated the support groups who would have carried out experiments and some computations in the Nth Country. Written communication provides a complete record of information exchange but has some serious disadvantages. Expression is inevitably incomplete and some degree of misunderstanding results. A great deal of time is consumed deciding on the wording of requests and answers and trying to interpret them. Other aspects of communication peculiar to this experiment result from the fact that our "support groups" are actually Laboratory senior staff members.

1. In the Early Period we were overly conscious of our lack of knowledge and were reluctant to appear more foolish than necessary. This resulted in postponement of some requests and the omission of others.
2. In the Late Period we spent a good deal of time preparing requests which presented enough information about our understanding of what was being requested so that a suitable reply could be obtained.

The transition from Phase II to Phase III of the Experiment occurred during the fall of 1965. At that time we felt that the completion of certain calculations was essential, but we did not know that this would lead us to a completely new level of understanding. (Recall that the phases were identified much later during the writing of this report.) No decision was made to embark on a new or different course of action, and none of us ever proposed submitting a final design based on our understanding at that time. There were several factors influencing the course of the Experiment during the transition period:

- We felt that the design submitted had to work since the challenge was to design a credible explosive.

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- Our confidence in our ability to understand implosion

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- We believed that we could make satisfactory calculations in "a month or two" to be able to submit a final design. If we had known how long it would really take to attain our current understanding we would have submitted a Phase II design.

There were several factors which affected the duration of the Late Period.

We felt increasingly concerned about drawing the Experiment to a close, but we continued to greatly underestimate the time required to finish the Experiment to our satisfaction throughout the Late Period. One consequence was that, in order to try to finish sooner, we did not request

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and ended up spending considerably more time satisfying ourselves that our estimates were adequate.

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Preparing this comprehensive report of our understanding of nuclear explosives has taken about four months or half a man year during the last half of the Late Period. This time cannot be entirely subtracted from the time necessary to arrive at the Final Design, however, because the clarification of ideas associated with report writing has improved our understanding of nuclear explosives.

There is a sense in which submitting our Final Design was more difficult than it would be to prepare a final design for a test in which we were participating. We would receive feedback during construction and preparation of the test, and have the option of making changes based on this information.

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B. SOME COMMENTS ABOUT THE EXPERIMENT

We could have designed a U^{235} gun explosive. Such a design would have been submitted as a final design much sooner than our implosion design. There are two main reasons:

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2. A test of the U^{235} gun mentioned above would likely play a similar role to a test of the Early Design.

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It is not surprising that China has progressed so rapidly, and we believe they may test a thermonuclear explosive within about a year if the news reports about their tests are accurate.

From our present understanding of nuclear explosives, we believe that our Final Design is credible without a test, but we see no way to design a credible thermonuclear explosive without testing. However, our position on thermonuclear design is very similar to our position on fission design in the Early Period, so it is possible that further study of the thermonuclear problem would change our outlook.

CRITIQUE OF THE NTH COUNTRY WEAPON DESIGN

F. S. EBY AND L. S. GERMAIN

1. (The analysis of the Nth Country weapon lens system in this section was written about an early version of the Final Design.

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As the reader will discover below, the detailed LRL design calculations, using codes unavailable to the Nth Country physicists, disagree with both of these numbers.

4. The LRL calculations on the Nth Country Weapon followed the usual sequence.

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5. It was impossible for us to detail the Nth Country predictions from the data given in the sections on Final Design and Test of the Nth Country Experiment report

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They give no estimate of the magnitude of the latter effect on final yield and, in fact, do not really cite reasons for their belief that alpha decreases too rapidly.

They correctly observe that they have very little firm information about the criticality of their system.

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In light of this extreme sensitivity, it would seem that confidence in the expected yield is unwarranted.

6. Another point which would appear to call for conservatism in the prediction of the yield of the test device is

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7. In summary, the Nth Country designers arrived The authors do not give any detailed reasons for the discrepancy.

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9. There are two areas in which the direction of the Nth Country program may well have been modified by the tastes of the experimenters. On page 7 (of UCRL-50239), it would seem that one of the reasons for undertaking the study of an implosion system is that it is "a more sophisticated, challenging and hence appealing problem." While this value judgment is certainly a logical one for a scientist to make, the administration of the Nth Country may be less concerned with a scientifically appealing problem and more concerned with quick results. Also on page 7, the statement is made "the production of Pu^{239} has a long range economic advantage over U^{235} because it requires the development of reactor technology." While this is certainly true, it is doubtful that the weapon scientists would be called upon to make decisions concerning the overall economy of the nation. Thus, it may be that they have directed themselves to plutonium implosion systems for reasons which are not completely valid in the context of the study.

APPENDIX A

THE OPERATING RULES FOR THE NTH COUNTRY PROJECT

A. J. HUDGINS

(Editor's note: The following set of rules was given to the experimenters in memorandum form at the beginning of the Nth Country Experiment.)

1. The purpose of the so-called "Nth Country Experiment" is to find out if a credible nuclear explosive can be designed, with a modest effort, by a few well trained people without contact with classified information. The goal of the participants should be to design an explosive with a militarily significant yield. A working context for the experiment might be that the participants have been asked to design a nuclear explosive which, if built in small numbers, would give a small nation a significant effect on their foreign relations.

2. An informal committee has been chosen to monitor this experiment. In order to provide maximum assurance that the committee does not, in fact, perturb the experiment in a casual or unrecorded manner, all communications regarding the substance of the experiment will be in writing. The men doing the experiment are expected to avoid conscientiously any contact with classified information in order to maintain the integrity of the primary assumption. They may request further guidance or specific information from the committee through A. J. Hudgins.

3. The experimenters are expected to use any means available to obtain as much unclassified information as they believe to be pertinent. The experiment will have to be conducted in such a way that all sources of unclassified information can be explicitly identified. It is important that as much as possible of the progress of the experiment be put in writing. Secretarial help will be available.

4. It is not expected that the experimenters do all of the routine work involved in the design themselves. Help in computation or in other mechanics such as information search should be requested only through the committee. In each case there must be a specific request detailing the result desired. In other words, the experimenters must state the problem and their boundary conditions for its solution. The committee will see to it that the best response possible is obtained in a timely fashion.

5. Even though this experiment will be based upon the use of information from unclassified sources, the Atomic Energy Act and AEC Regulations require that any design efforts related to nuclear explosives be given proper security protection. This requires that the work books and any elaboration or deduction from unclassified

information be classified properly and that all such information be protected in accord with the Laboratory Security Manual.

6. For the purposes of this experiment it should be assumed explicitly that any material may be fabricated in any shape. The purpose of this assumption is to remove fabrication and procurement problems from the area of the experiment.

APPENDIX B

BIOGRAPHICAL SKETCHES

DAVID A. DOBSON

David A. Dobson was born in 1937 in Oakland, California, and attended elementary and high school in Alameda, California. He received a B. S. degree in chemistry (1959) and a PhD. in physics (1964) from the University of California, Berkeley, California. Dobson worked in experimental atomic physics; his thesis was entitled, The Beta-Decay Asymmetry and Nuclear Magnetic Moment of Ne^{19}. (See UCRL-11169, Lawrence Radiation Laboratory, Berkeley, California (1963).) In 1964 he came to LRL, Livermore, on a post-doctoral research appointment and became a regular staff member in 1966. In addition to participating in the Nth Country Experiment, Dobson has continued his work on beta-decay experiments.

DAVID N. PIPKORN

David N. Pipkorn was born in 1936 in Milwaukee, Wisconsin, and attended elementary school in Thiensville, Wisconsin, and high school in Shorewood, Wisconsin. He received a B. S. E. degree in electrical engineering (1958) from Princeton University and M. S. (1960) and PhD. (1964) degrees in physics from the University of Illinois, Urbana, Illinois. Pipkorn worked in experimental solid state physics, and his thesis was entitled, Mössbauer Effect in Iron Under Very High Pressure. (See Phys. Rev. 135, A1604 (1964).) He came to LRL, Livermore, in 1964 on a two year post-doctoral research appointment and became a regular staff member in 1966. In addition to participating in the Nth Country Experiment he has continued to do research on the Mössbauer effect.

ROBERT W. SELDEN

Robert W. Selden was born in 1936 in Phoenix, Arizona, and attended elementary and high school there. He received a B. A. degree in physics (1958) from Pomona College, Claremont, California. Selden received M. S. (1960) and PhD. (1964) degrees in physics from the University of Wisconsin, Madison, Wisconsin, where he was an Edward John Noble Foundation Fellow for four years. He worked in experimental low temperature physics with liquid helium and his thesis was entitled, He-II Film Transfer Rates Under Various Conditions. (See Phys. Rev. 138, A1363 and A1371 (1965).) He was commissioned a 2nd Lt. in the U.S. Army Reserve in 1958 from the ROTC at Pomona College. He began a three-year tour of active duty in 1964 as a 1st Lt. in the U.S. Army Ordnance Corps at Aberdeen Proving Ground, Maryland. Selden was assigned to LRL, Livermore, as an Army Research Associate, and promoted to Captain in 1965. He has worked full time on the Nth Country Experiment since March 1965.

APPENDIX C

A BRIEF CHRONOLOGY OF THE EXPERIMENT

Apr 1964 – The ground rules are formulated for the Experiment.

May 1964 – D. Dobson and D. Pipkorn are selected as participants; they begin working half-time on the Experiment.

Dec 1964 – The decision is made to design a plutonium implosion explosive...

Feb 1965 –

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Mar 1965 – R. Selden becomes the third participant.

May 1965 – The first HE lens design test is proposed.

Jul 1965 – The first initiator experiment is proposed.

Oct 1965 –

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Nov 1965 – The second HE lens design is tested (hypothetically) and adopted with small changes.

Dec 1965 – The first implosion design is documented

DOE (b)(3)

Dec 1965 –

Jan 1966 –

Jan 1966 –

Feb 1966 –

Apr 1966 –

Apr 1966 – The first version of the final design is produced.

Jun 1966 – The first outline of the final report is completed.

Sep 1966 – The second April 1966 design is submitted as final.

Dec 1966 – The complete draft of final report is submitted.

Mar 1967 – The final preshot corrections are made to the design and report.

Apr 1967 – The tape-recorded discussions are completed.

Apr 1967 – The Nth Country device is tested (hypothetically).

APPENDIX D

SECURITY ASPECTS OF THE EXPERIMENT

As part of the documentation of the Nth Country Experiment before their design was tested, the Design Physicist

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I. STATE OF KNOWLEDGE BEFORE THE EXPERIMENT.

1. DD . . . My wife worked at LRL from 1957 to 1961 as a Laboratory Technician in Chemistry. I can think of only two things having a possible influence on the Experiment that I learned because she worked here. First, since the chemists worked late in the night during a test series, I was aware that they were analyzing bomb debris. I recall having the idea that sometimes they added materials to these tests deliberately to tell something from the isotopes produced, but I had no idea of what isotopes were used, or what they learned. I also was aware that her group made large quantities of elements above plutonium in the periodic table and studied their properties, but I still have no idea of the quantities produced – whether they are in milligrams or kilograms.

2. DD . . . With regard to my knowledge of the areas of physics pertinent to this experiment, I have never taken or attended regularly a course in nuclear physics or hydrodynamics. I have picked up quite a bit of nuclear physics studying on my own in connection with my thesis research, but only in the areas of beta decay and the structure of light nuclei. I was aware that shock waves existed and that they were nonlinear as compared to sound waves but I had never heard of the Hugoniot equations. I had heard about the application of shock waves to the study of equations of state at a

one-hour lecture, probably 10 or 11 years ago, given by Professor Jura of the Chemistry Department (Berkeley).

I understood the general idea that fission involved the breaking up of a large nucleus into a couple of fragments, with neutrons and gammas being given off. I had seen an exhibit with a model of a chain reaction made up of mouse traps and ping pong balls.

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I was aware that the basic idea of a fission explosive was to throw together enough fissile material to have a super-critical mass, and that there were two ways to do this: either shooting two pieces together with a gun, or putting explosives all around some material and blowing it together from all sides.

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I was aware that both uranium and plutonium had been used in bombs, but I was not familiar with heavy isotopes and did not know which isotope numbers were relevant. I had not seen the pictures in "Life Magazine" showing the external appearance of the first U.S. bombs. I have never at any time thought seriously about how a bomb might be built. I am not sure why, because now it seems interesting

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3. RS . . . Most of my time before coming to LRL was spent going to school. I went to Pomona College and then to the University of Wisconsin where my thesis research was in experimental low-temperature physics on the superfluid properties of liquid helium. While at Wisconsin I took a one-semester course in experimental nuclear physics, taught by Professor Henry Barshall who had been at Los Alamos during the War. A small part of this course was concerned with nuclear fission and a small part of this dealt with criticality and reactors. He devoted part of one hour to some "Lansing Lamont" type reminiscences about Los Alamos – how it was to be at Los Alamos and the kind of things that happened there. He mentioned the gun-type assembly and the requirement of a super-critical mass, but not in any detailed way. After leaving Wisconsin I went on active duty in the Army to fulfill my ROTC commitment and was assigned to Aberdeen Proving Ground and the Ordnance Officer's basic training course. Part of the course was a three-hour presentation on the effects of nuclear weapons (such topics as radiation, blast waves, radioactivity, and the fact that nuclear artillery existed.). This presentation was primarily to make Army Officers aware that nuclear weapons existed and that their effects were quite different from those of conventional explosives. No technical details were given about the weapons themselves.

4. RS . . . There is an interesting story in connection with my application for an assignment as a Research Associate at LRL. I was interviewed in Washington, D. C., by Glenn Werth. I was aware, of course, that I knew very little about nuclear physics, so I tried very hard to come up with every bit of information I could on the subject. Dr. Werth was not concerned about how little I knew about nuclear physics and nuclear weapons, and I felt at the time that there was something very strange about the interview. It wasn't until later, here at LRL when I learned about the Experiment, that I realized what had been going on.

5. RS . . . With regard to explosive design, I was aware that nuclear weapons existed. I understood the nature of the fission process and I knew that U^{235} and Pu^{239} were fissile materials. I had a general idea of criticality in terms of sustaining a chain reaction in a reactor, including the advantages of reflecting escaping neutrons back into the fissile material. I also knew that the fission cross section was higher for thermal neutrons. I knew of the gun-method of assembling a critical mass to produce an explosion.

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should add that I never seriously considered how a bomb would be designed other than these considerations which I have just stated. I was not aware of the implosion method of assembly at all, as far as I can remember. The only thing I knew about shock-waves was that they existed, as everyone who has felt an earthquake or heard thunder knows. I knew absolutely nothing about explosives (except than that TNT was the name of an explosive).

6. RS . . . Perhaps the most important factor involving the knowledge that I had before starting with the Experiment is that I believed that designing a nuclear explosive

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DD . . . That applied to me too.

7. RS . . . Dave Pipkorn told me that he also had no experience directly related to nuclear explosive design before going into the Experiment.

II. THE EFFECTS OF VISITING LRL "OPEN HOUSE" EVENTS.

8. DD . . . All three of us on several occasions have visited the open houses at LRL (which are not open to people who are not employees or members of employee's families). On several earlier occasions, when my wife was working here, I came to see the LPTR (Livermore Pool-Type Reactor) and the opening of Building 112 before

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there was any furniture in it. At the 1964 Open House I visited buildings 102 and 114, but they were pretty austere. I also went out to Site 300 and saw a test pad for shock wave experiments and the Helac x-ray machine. They were interesting machines, but didn't give me hints as to how things might be done. At the 1966 Open House, I saw the lasers in Building 154 and also the Labs in 174B, but again I didn't get any ideas from anything that I saw there. This, perhaps, speaks pretty well for the people who classify things.

9. RS . . . Dave Pipkorn has told me that he went to the Laboratory Open House and Site 300 Open House in 1964, but he also didn't learn anything that was really useful to our project.

10. RS . . . I went to the Site 300 Open House in May 1966 and did not see anything that I had not already believed had to be there. I did see the explosives machine shop

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At the September 1966 Open House I visited my office, the Computer Building, the Chemistry Building, and the Plowshare exhibit. By the time I went to both of these open houses, our knowledge was advanced enough so that any hints would have to be rather specific and have to do with physics to be really useful.

This general background information about what kind of research is going on, what kind of technology and capability there is, etc., is interesting, but not very useful to the design itself. This kind of information would be available to anyone interested in pursuing it carefully and certainly a real Nth Country would likely do a much better job of finding out what is going on at Livermore than we did!

11. RS . . . In December 1965, we all attended the family lecture series talk on the Laboratory weapons program by Carl Haussmann. He certainly didn't say anything that could be used on the project. (In fact, he announced early in his talk that he was going to try not to say anything that might be useful to any Nth Country that might be listening.)

Here are some comments I wrote in my notebook about this lecture. "We attended the weapons lecture by Carl Haussmann. The talk itself did not give us anything useful to the project, but it was interesting to know something of the weapons systems developed at LRL.

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Looking at the warhead has really gotten our curiosity up about how such a device could be designed. This is a challenging problem that deserves some thought."

III. LRL BUILDINGS VISITING DURING THE EXPERIMENT.

12. DD . . . One of the questions that might naturally be asked of us is: What buildings have you been in within the "Q" cleared area? The best way to answer this is simply to list them. My offices were in Building 152 at first and are now in 155. I went to Building 109 on two occasions to pick up some prints of my apparatus, but at no time did I see any pink paper. I went to Building 110 on one occasion to see Stew Bloom's set up at the van de Graaff Accelerator when it was set up down there. I have simply gone into, or walked through to deal with one particular person or something that had to do with my E Division experiments – Buildings 101, 111, 120, 122, 151, 161 (the mailroom only), and Trailer 33. I have been to Building 112 on numerous occasions, but only to Dr. Hudgins' office and the library. I have been in the Mech. Engr. Library in Building 170. Once I returned a gaussmeter that I had borrowed to Building 173A. I have made three trips to the Glass Shop (Building 114A) regarding the repair of some apparatus. In March or April 1966, I talked to the hydroform die operator in Building 114A about making parts for my LPTR irradiation capsule. In September 1966 I went to the Sheet Metal Shop, Building 140B, to have the lid welded on my reactor capsule. I can say, certainly, that at no time (in these shop areas that we are talking about) did I see or hear anything that even remotely suggested anything applicable to the Experiment.

13. RS . . . When Dave Pipkorn was still working actively on the Experiment, he visited the following Buildings: 101, 102 to visit Harold Stromberg (he saw more at the Open House than he observed then), 110 – the van de Graaff part, 111, 112, the sheet metal rack outside 114, 120, 151, 152, 155, 161, 162, 170 (to the libraries and to visit people about germanium detectors and coincidence circuits), and 173B. He said he never got any hints useful to the Experiment.

14. RS . . . I have walked through or been briefly in Buildings 101, 111, 120, 122, 151, 161, Trailer 105, Trailer 112, Building 112 (to the library, Hudgins' office and Harlan Zodtner's office), the 170 Elec. Engr. Library on two occasions, and Building 155 where my office is.

IV. POSSIBLE SECURITY LEAKS INSIDE THE LABORATORY.

15. RS . . . There is some classified material around Building 155; it is usually always locked up and we are always very careful about not seeing it. On several occasions I saw that people did have classified documents but I never saw anything more than that these documents were classified. In other words, they had the word "Secret" or were marked with red. There was an interesting discovery in Building 155 in the Summer of 1965, which isn't classified but which we will record in the spirit of recording everything. Marv Williamson (whose office was just down the hall from us) kept an interesting paperweight on his desk. [redacted] We still have no idea of what it really is because we don't want to ask! It was probably because we found it here in the Laboratory that we were led to speculate about it in the first place.

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16. RS . . . We have been asked where we got the word "tamper" and the symbol "α" for the neutron multiplication constant. [redacted]

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17. DD . . . The other class of interactions within the laboratory were conversations with people. It is interesting to note that none of this information (which we will describe) would be considered a possible leak if it had been obtained outside the laboratory from somebody we knew to be ignorant of weapon design. It is because we know that the people in the Laboratory do have such knowledge that we considered the implications of what they said. The first one occurred to me back in 1963. One day I asked Hans Mark why the Astron Building was as big as it is. He told me that it used to contain a high current deuteron Linac, which didn't mean anything to me at the time. Later it led me to speculate that maybe they tried to make fissile materials at one time using (d,n) reactions – something like maybe Np^{236} for example– but it looks like it didn't turn out too well.

18. DD . . . The second time was just after I got an office in Building 152 and was beginning to work on the Nth Country Experiment. I was talking to Lou Eccles and he said to me – "Well, now that you are over here, you are going to learn how nuclear explosives work." I tried to put him off by saying; "Well, I guess so eventually." He

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replied, "Well, the most surprising thing that I have found about thermonuclear weapons was the importance of radiation." At this point, I cut him off very rapidly and left. This wasn't really a serious leak because books like Glasstone tell us that radiation is an important part of fusion reactions.

19. DD . . . One day Floyd Stoutamore told me that they had been running electron beams in the van de Graaff accelerator. I asked him why they were doing that – something that I have since learned not to do around here.

ever, this didn't really tell us anything since we know lithium deuteride is used in fusion weapons (UCRL-7870, Characteristics of Nuclear Explosives).

20. DD . . . One night, when I was working down at the LPTR, an L Division Physicist told me that he was working on Compton detectors for high-flux gamma ray measurements. This suggested to me a somewhat different idea than I had before as to how you might measure the gamma flux.

21. RS . . . In the Fall of 1965, Charlie Bowman gave an E Division Seminar on some work that he had been doing at the Linear Accelerator on Am^{242}. We became aware of it when there was some commotion and Doris Hine (the department secretary) rushed around collecting all of these notices because they were apparently distributed before they were declassified. This clearly indicated to us that Am^{242} was important to the Laboratory. At the time that this occurred, we already had been looking at a and had an idea of what kinds of higher isotopes would be useful and would have the right kind of properties for fissionable materials.

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22. RS . . . In May 1966 when our first set of drawings of the final design was complete

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23. RS . . . In July 1966 I was working at my desk with a large pile of printouts from the Mark III calculation lying around. Jerry Wesolowski looked into the office,

saw all of those printouts, and asked if I was writing a new code. I answered, "Why not? I like to write codes."

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24. RS . . . Also in July 1966, John Anderson came into Jack McClure and Bert Pohl's office (which is next door to mine) and began describing a new problem (or something) that they were going to be working on. I heard some drawing on the blackboard and the word detonation, and decided that I had better get out of here. Later that day I stopped by John's office and told him about the nature of the project that we were working on (that is, that we were designing a nuclear explosive without any access to classified literature) and added that if he were going to discuss classified things next door, particularly how a bomb is built, that I would appreciate some warning! He readily agreed to cooperate with us, and said that if I had listened to his discussion earlier I would probably have been disqualified from the Experiment.

25. DD . . . One evening Lou Eccles had kept a classified document out to read after the secretary had gone home. He asked us to lock it up in our repository (it was enclosed in a manila envelope). We did lock it up overnight, but we don't have any idea what the document was about.

V. TWO INCIDENTS OUTSIDE THE LABORATORY.

26. RS . . . There were two outside sources of information which were not classified but which did influence the Experiment.

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not learn anything that we were not already aware of. The really important result of

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perhaps it gave me confidence that it might also be possible to be a successful impostor as a bomb designer!)

DD . . . I was certainly much encouraged by the greater level of confidence in our understanding of hydrodynamics that Bob brought back and passed on to me.

27. RS . . . The other outside incident occurred in July 1966. It was of considerably less magnitude than and again did not involve any classified information. I was invited to give a talk on liquid helium at a summer science program at Thatcher School, Ojai, California. It turned out that Richard Feynman visited the program and gave a lecture while I was there. One evening I had the privilege of discussing liquid helium and my thesis experiment with him. During the course of this discussion I asked him about Lansing Lamont's book The Day of Trinity. He said that he had actually been interviewed and he felt that Lamont had done a rather good job of relating the spirit of what he had said. He generally thought that the book was well done. Later, at an informal gathering with several others, Dr. Feynman was asked about the early days at Los Alamos. He reminisced about his encounters with the security people (giving us a short course on the theory of safe-cracking) and recalled the early Los Alamos computer (a room full of girls with desk-calculators).

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VI. A POSSIBLE SECURITY LEAK IN THE LITERATURE.

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APPENDIX E

A SELECTED BIBLIOGRAPHY

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APPENDIX F

HIGH EXPLOSIVE, DETONATOR, AND X-UNIT TECHNOLOGY

E. JAMES, JR.

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1. The Nth Country design uses.

2. The technology required to produce TNT castings and lensing systems is well known. By the end of World War II, many countries not actually engaged directly in combat (Sweden and Switzerland, for example) were selling advanced munitions. This is still true:

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7. The technology of bursting bridgewires and X-units required to activate bursting bridgewire detonators is also known in the unclassified literature.

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In these papers the subtleties of the circuit parameters are discussed in detail.

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APPENDIX G

HYDRODYNAMICS TECHNOLOGY

M. L. WILKINS

1. Two aspects of hydrodynamics technology are of interest to the Nth Country problem: the ability to compute the material motions and shocks during the implosion and explosion phases, and the equations of state for the various materials used in the explosive.

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5. The equation-of-state data for high explosives have always been in the open literature;

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APPENDIX H

NEUTRONICS TECHNOLOGY

W. C. GRAYSON

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APPENDIX I

YIELD CALCULATIONS

W. C. GRAYSON

1. The calculation of the yield of a nuclear explosive combines hydrodynamics and neutronics techniques with radiation transport. Such a "burn code" is usually the most complex calculation required for early Nth Country designs;

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APPENDIX J

INITIATORS

R. L. REMILLARD

1. The concept of mixing an alpha emitter with beryllium to form a neutron source seems relatively obvious

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APPENDIX K

WEAPON MATERIALS TECHNOLOGY

R. A. JAMES

1. Three materials in the Nth Country design (plutonium, uranium, and polonium) are often considered to require special knowledge or experience outside standard metallurgical and engineering practice.

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A team of chemical engineers would have no trouble designing and running a successful plant using any one of these processes (roughly 10-20 engineers are needed during the design and building, and only a handful for supervising the running).

3. The preparation of plutonium metal by several methods has also been described. The crystal structure and physical constants of the various allotropic modifications of plutonium metal have also appeared very extensively in the literature. Investigations of plutonium alloys and intermetallic compounds are also in the open literature.

4. Neither uranium nor polonium are newcomers to the metallurgical scene: many properties of uranium have been known for almost a century, and the Curies did the basic studies on polonium.

APPENDIX L

WEAPON FACILITY AND FABRICATION COSTS

C. R. HENRY

1. The Nth Country weapon designed by Dobson, Pipkorn, and Selden requires laboratory support facilities and a weapon production complex which includes explosive plants, component fabrication shops, and a diagnostic bunker. This appendix furnishes an estimate of the capital and operating costs of a weapon facility designed to produce 5-10 weapons per year. Any equipment, materials, or components which can be purchased on the world market were assumed to be bought so that they do not require plant investment. No estimate has been made of the time required to build such facilities – only of the time required to build the first and successive weapons.

2. The reactor and its associated fuel processing plant were considered separately. Since power as well as plutonium production might be the reason for building this facility, the actual cost and utility to an Nth Country may vary widely. A minimal estimate is given as an example, with no allowance for any power production return. Since the cost of all the plutonium and most of the uranium is attributable to the plutonium production facility, we have for simplicity assumed that all the special materials (plutonium, polonium, and uranium) costs are included in this estimate.

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4. The weapon design personnel require a laboratory/office building to house about

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6. The weapon production complex consists of about 10 buildings on 30-40 acres surrounded by a security fence. The diagnostics bunker and HE storage magazines are located in a separate, remote site. To achieve minimum cost, this relatively

small complex was assumed to be within an existing ordnance facility; utility installation costs would then include only the fenced-in area. All buildings are minimum Butler-type construction. The buildings and their arrangement are workable and safe, but do not necessarily follow U. S. and LRL safety practices in detail. The shielded operations have wooden glove boxes where possible, rather than durable but very costly stainless steel. The complex requires a staff of about 400 operating and technical personnel. Since plutonium production is expected to be the pacing process, this weapon facility would usually operate only one shift per day.

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The manpower estimate was based partly on the fact that.

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8. The major expense of the Nth Country weapon is the production of the plutonium. A 200-megawatt reactor is needed to produce about 50 kg of plutonium a year; in addition, uranium and plutonium processing plants are required. A typical estimate for such a facility is \$60M.[1] The operating costs/year would include both the salaries of several hundred people and fuel costs (~100 tons of uranium), and would run on the order of \$10M.

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[1] This estimate is based on the cost of several power reactors described in Nucleonics and a Savannah River Plant document on the production of plutonium. The Savannah River report (1964) gives \$30-45M for a 40 MW reactor and \$95-135M for a 400 MW reactor. Nucleonics (1965-1966) quotes the following "turnkey" costs for power reactors without fuel facilities (1 MW electrical requires about 3 MW thermal):

MTR (Japan)	50 MW (thermal)	\$20M
MZFR (Germany)	200 MW (thermal)	\$40M
AKB (Germany)	100 MW (electrical)	\$55M
CANDU (Pakistan)	135 MW (electrical	\$60M

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