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PACER Program
FY-1974 LASL Activity

by

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ABSTRACT

PACER is a power program designed to meet the present energy crisis and the future world energy problem. The idea is to use clean, thermonuclear explosives to heat steam contained in a large underground cavity and to use the steam to operate a conventional electric power plant. The program is based upon a proposal made by R&D Associates to the AEC in October of 1972. As a consequence, the AEC funded the program in FY 74 for one-half million dollars with RDA as the prime contractor and LASL as the contract manager. The LASL effort during FY 74 is reported herein. RDA work is reviewed in other reports.

PACER PROGRAM

FY-1974 LASL ACTIVITY

by

R. G. Shreer and R. E. Roush

I. DESCRIPTION OF PACER PROGRAM

PACER is a power program designed to solve present U.S. energy problems and to avoid future energy crises by using the energy from clean fusion devices to heat steam in a large, spherical, underground cavity and then using the steam to operate a modern, conventional electric power plant. This concept is primarily attractive because it takes advantage of enormous reserves of low-cost energy that can be released by the nuclear fusion of heavy hydrogen (deuterium). Perhaps equally important for the short term, the burning of deuterium releases neutrons we can use to provide a plentiful source of reactor fuel. Unlike other programs to harness fusion energy (magnetic confinement and laser fusion), PACER involves technology that has been proven in both the AEC weapon-development and Plowshare programs. Almost all the basic technology of the power-production scheme is available; only engineering development is required, supplemented by a very modest scientific research program.

Figure 1 shows how a specific version of the PACER system might operate to contain a 210-TJ (50-kt) fusion explosion within a salt-dome cavity of 300-m diameter. This process would take place about twice a day to supply the energy for a 2000-MW power plant.

Figure 2 is an artist's conception of the surface installation, including the device injection system, the pipes that transmit working fluid to and from the surface, the heat exchangers, the debris scrubbers, and the containment vessel. The turbines, the cooling tower, and the transmission system are readily procured items that are common to almost all power plants.

II. HISTORY OF PACER

The PACER concept is not new. It was put forward--rather unsuccessfully--by Brobeck in 1957. In October 1972, R&D Associates (RDA), on the basis of their experience with nuclear decoupling experiments, proposed to the AEC that the system be reconsidered with the containment cavity in a salt dome.[1] As a consequence, RDA received FY-74 funding at $250,000; LASL was appointed the project manager and received $200,000.

III. ORGANIZATION OF PACER EFFORT

The PACER Program is organized in three phases:

Phase 1. Theoretical and Laboratory Studies.

Phase 2. Reduced-Scale Field Experiments.

Phase 3. Prototype System.

Only Phase 1 has received significant attention. It has been broken down into nine projects[2] that are listed in Table I along with the FY-74 funding and the proposed total funding. Section III.B of this report lists the supporting laboratory experiments and their costs.

The following text summarizes the LASL FY-74 effort on these projects and experiments. Although all tasks in the program received some attention, only those that received concentrated effort are reviewed.

RDA FY-74 effort on this program is summarized in a number of documents.[3,4]

A. Phase 1 Projects

1. Project 1: Fusion-Device Development

Development of an appropriate fusion device is essential to program success. To restrict the design, a list of constraints[5] was agreed upon after considering such factors as device security and safety, use of natural resources, influence of breeding and cost,

TABLE I

FY-74 AND PROPOSED TOTAL FUNDING FOR

PHASE 1 PROJECTS

Project	Organization & Funding Period		Men/year		Cost ($1000)		
			SM	GR	S&I	U.C.	Total
1. Fusion-Device Development	LASL:	FY 74	0.4	0.1	7.2	4.0	11.2
		Total	4.7	0.3	173.2	27.0	200.0
	RDA:	FY 74	0.1				7.0
		Total	0.3				21.0
2. Cavity Phenomenology	LASL:	FY 74	2.2		79.0	30.2	109.2
		Total	6.8		250.0	76.0	326.0
	RDA:	FY 74	1.25	0.05			112.0
		Total	4.15	1.50			365.5
3. Engineering	LASL:	FY 74	1.1		37.5	1.6	39.1
		Total	28.0	10.0	1663.0	215.0	1878.0
	RDA:	FY 74	0.7				49.0
		Total	9.0	4.0			830.0
4. Economics	LASL:	FY 74	0.1		5.0		5.0
		Total	0.3		15.0		15.0
	RDA:	FY 74	0.05				3.5
		Total	0.3				21.0
5. Safety & Environmental Considerations	LASL:	FY 74	0.1		5.0		5.0
		Total	4.2		195.0	15.0	210.0
	RDA	FY 74	0.4				28.0
		Total	2.1				147.0
6. Fuel Recovery and Processing	LASL:	FY 74					
		Total	13.5		611.0	80.0	691.0
	RDA:	FY 74	0.1				7.0
		Total	7.1	1.0			547.0
7. Geology, Site Definition & Selection, Cavity Constr.	LASL:	FY 74	0.2		6.7	1.2	7.9
		Total	4.8	2.0	293.0	26.0	319.0
	RDA	FY 74	0.15				10.5
		Total	2.3				161.0
8. Nuclear Test & Effects Facility	LASL:	FY 74					
		Total	13.2	0.5	680.0	139.0	819.0
	RDA:	FY 74					
		Total	4.7				329.0
9. System Analysis, Coordination, & Planning	LASL:	FY 74	0.2		10.0		10.0
		Total	2.0		110.0	10.0	120.0
	RDA:	FY 74	0.5				35.0
		Total	3.0				210.0
Project Totals	LASL	FY 74	4.2	0.1	150.4	37.0	187.4
		Total	77.5	12.8	3990.0	588.0	4578.0
	RDA	FY 74	3.25	0.05			252.0
		Total	33.0	6.5			2632.0

Definitions:

GP Organizational group at LASL
SM Staff member
GR Graded series or technicians
S&I Salary and indirect cost
U.C. Usual cost. This includes costs for shop services, computing, and other outside expenditures.

Fig. 1. Concept of 2000-MW power plant - PACER.

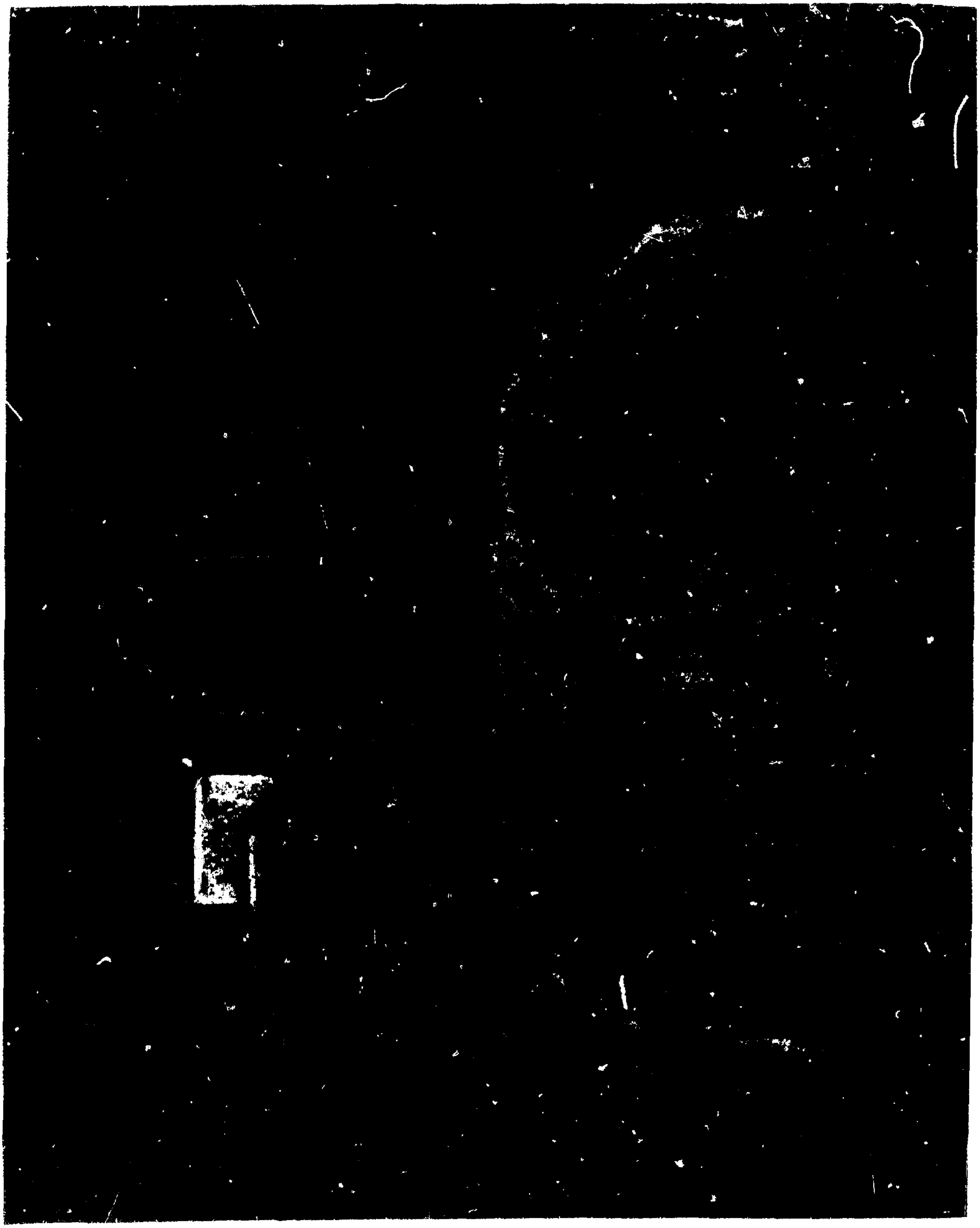
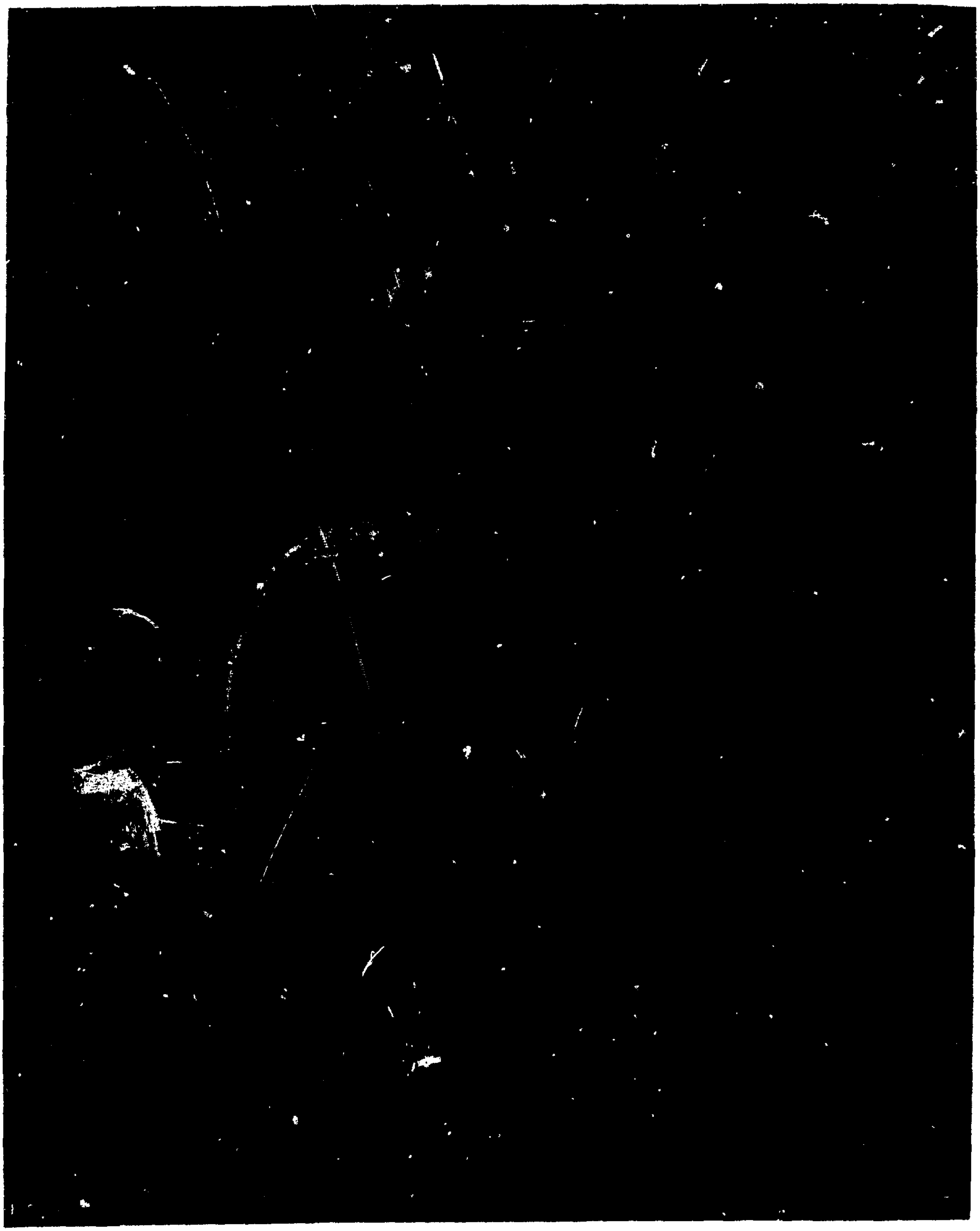


Fig. 2. Artist's conception of surface installation.



and appropriate yield range. The device characteristics then developed under these constraints were:

a. Maximum yield of 420 TJ (100 kt).
b. Deuterium for thermonuclear fuel.
c. Minimized tritium, lithium, plutonium, fission products, and induced activity.
d. No size or weight restriction, within reason.
e. Highest priority on security and safety.
f. Minimum cost consistent with constraints.

This project was divided into three tasks: design, price, and safety and security. During FY 74, the following work was performed:

a. TD-3 designed an advanced 420-TJ (100-kt) fusion device to meet the above characteristics. This design included no detailed engineering.
b. Meetings were held with ALO to determine the price of the device.[6] Preliminary cost estimates are being made on the unengineered device as a first step in defining the pricing problem. The goal is to reduce the current AEC PNE price tenfold by applying the results of exhaustive nuclear testing, careful engineering, and quantity production techniques (more than 100 000 devices per year).
c. The specific classification rules that apply to PACER were considered.[7,8]
d. Preparation of a document on PACER fusion-device development was started.[9]

2. Project 2: Cavity Phenomenology

a. Task 2.2: Nuclear-Explosive Investigation ($t < 1$ sec)

We studied the explosion of the nuclear device and the subsequent behavior of the working fluid in the cavity up to the time its behavior ceases to be one dimensional (< 1 sec). During FY 74 the following work was performed:

a. J-10, T-4, CNC-4, and RDA have held numerous discussions to decide on the proper theoretical and experimental inputs for this exercise.[10,11,12] As a result, J-10 performed an initial calculation (RADFLO) with dry air as the working fluid.[13] Somewhat later, a program was defined.[14]

b. Further RADFLO calculations will be made when the equation of state of water has been properly defined and the opacity data for a steam-air-salt system have been generated, at which time we will write a report. There is little question about the general characteristics of the nuclear explosion while $t < 1$ sec. Complete determination is largely a matter of detail, and we are reluctant to do further calculations until the proper inputs are available.

c. A considerable debate took place as to whether we should perform experiments to determine the opacity of a steam-air-salt system to support the theoretical calculations.[15,16,17,18,19] For the present, these experiments have been set aside.

b. Task 2.3: Calculation of Absorbing Fluid ($t > 1$ sec)

After the fusion device explodes and the fireball has stabilized at a radius about one-quarter the cavity radius, the fireball rises to the top of the cavity. The heat ultimately disseminates more or less uniformly throughout the cavity and is removed by the primary loop of the heat exchanger. We did a number of things to try to describe this phenomenon:

a. J-10, using the YAQUI code, computed the behavior of the fireball in dry air as it rises to the top of the cavity.[20]
b. T-3 developed a code (CIRCO) to describe the total problem; in its current state, however, the code will handle only an incompressible fluid. This capability is all we need to describe the circulation of the cavity working fluid as influenced by the working fluid that leaves and reenters the cavity through the primary loop. If necessary, we can later extend the code to cover a compressible fluid and perform a more complete study of the fireball rise and dissipation. The abstract for a report[21] describing the code is included as Appendix A.

c. Task 2.4: Cavity Integrity - Creep Effects

The PACER cavity is formed in a salt dome that consists of halite with anhydrite inclusions. The cavity is filled with steam n.m.n. at 550°C and 20 MPa (200 bars). The stability of the cavity over periods exceeding 20 years must be certified under these conditions. In particular, we must determine the following related information:

a. Optimum pressure and temperature of the working fluid.

b. Long-term creep of the cavity walls.

c. Effects of wall geometric imperfections.

d. Effects of inclusions in the halite.

To address this subject, the CSAAS code has been developed as a variant of a weapons code (TSASS). A report[22] is being prepared; an abstract and an introduction are included as Appendix B.

3. Project 3: Engineering

This project covers all engineering aspects of the proposed power-generation concept, from the cavity-piping interface to the turbine-generator output. The injection system for the explosive device is also included. The study of problems associated with startup, emergency, and final-shutdown operations will be pertinent to the engineering project. The study and solution of these problems will interact with other project considerations in such areas as choice of working fluid, cavity-wall stability and environment, safety, and economics. The project will require considerable interaction with laboratory experiments, especially those specifically designed to provide engineering design information. The engineering goal in Phase 1 is to complete all engineering concepts, criteria calculations, and associated design drawings for the Phase 2 scale experiments and the Phase 3 prototype development of the primary loop and the device injection system. To achieve this goal, the engineering project is divided into five tasks: trade studies and engineering project coordination, primary loop, materials, containment, and device injection.

The LASL Engineering Department has performed a wide variety of tasks in close cooperation with RDA, and this work has been summarized.[23] In addition, a number of conceptional drawings have been made (e.g., see Figs. 1 and 2).

4. Project 5: Safety and Environmental Considerations

a. Government Safety Regulations

This task consists of surveying the various governmental safety and environmental regulations as they apply to PACER. J.J. Koelling has written a survey paper on this subject.[24]

b. Task 5.4: PACER Promotion

This task has two goals: (1) to present the PACER program to the people responsible for approving and funding the activity and (2) to present the subject to the public.

The following actions were taken:

a. A number of meetings were held in Germantown, several general review meetings were held at LASL, and many meetings were held between RDA and LASL.

b. RDA and LASL wrote monthly progress reports.

c. Numerous attempts were made to write press releases. A better approach to this problem would probably be to maintain a well-written unclassified review of the subject from which press releases can be written.[2,3,4,25] Some attention was also given to developing a plan for public presentation.[26]

d. It is appropriate to list a number of references (30, 31, 34, 35, 37, 39, 40).

5. Project 7: Geology, Site Definition and Selection, and Cavity Construction

The purpose of this project is (1) to define and assess potential U.S. sites and to indicate generally the worldwide sites potentially suitable for the PACER concept; (2) to develop site selection criteria based on technical, engineering, economic, and environmental trade-offs; (3) to select prime site candidates for the scaled field test and for the prototype full-scale plant; (4) to define site exploration methods and requirements; (5) to assess the status of cavity construction technology and coordinate the planning of field experiments; and (6) to complete all aspects of site selection prior to required site confirmation drilling.

LASL progress to date is covered in Appendix C.

6. Project 8: Feasibility Study for Nuclear Test and Effects Facility

Principles and techniques developed in the PACER program could be applied to develop a nuclear test and effects site that, once proven feasible, might have certain advantages. For that reason, the following actions were taken:

a. We wrote a document[27] for DMA describing the potential association of PACER with the nuclear-weapons program. One association was the possibility of developing a nuclear test and effects site. Several letters were exchanged.[28,29] DNA was acquainted with the potential of such a test site.[30,31]

b. A work statement for the RDA FY-75 contract was written that emphasized work on this particular PACER project.[32] During FY 75, LASL will concentrate its effort on supporting the contract. In particular, we will define the device cassette and will stipulate the measurements to be made in an exploding device.

7. Project 9: Systems Analysis, Coordination, and Planning

The complexity of PACER requires continuing system analysis as new ideas or designs are incorporated. This activity is necessary to ensure the compatibility, not only of system elements, but of operational procedures as well. The entire system, from manufacture and assembly of explosive to waste disposal, requires comprehensive planning and integration. Achieving this goal requires careful coordination and management of all activities.

References 1, 2, 3, 4, 25, 33, 36, 37, 38, and 40 document pertinent FY-74 activity. Numerous trip reports and agenda document meetings at AEC Headquarters, ALO, RDA, and LASL. There are also internal laboratory administrative memoranda.

B. Phase 1 Experiments

Table II lists the laboratory experiments in support of Phase 1, along with their estimated cost. Reference 2 describes these experiments. The list has fluctuated over FY 74 but now appears realistic, though one or two experiments might be deleted or added. Experiments 1, 2, 7, 9, and 10 have been sufficiently defined to permit ordering of materials. Experiments 3, 4, 5, 6, and 8, the more expensive ones, require much closer scrutiny; only then will we have a better defined program and a more realistic cost. Only on Experiment 1 has there been laboratory work.

TABLE II

PACER EXPERIMENTAL PROGRAM

Experiment	Experiment Name	Total Cost ($1000)
1	Material Selection	217
2	Halite Creep-Rupture Experiments	77
3	Primary-Loop Mockup	918
4	Shaft Sealing	728
5	Device Injection	678
6	Dynamic Loading of Access Piping	703
7	Steam Cavity-Wall Interaction	81
8	Laboratory Cavity Experiment	835
9	Anhydrite Creep Experiment	77
10	Radiation Deposition in Salt	100
	Total	$ 4414

Refer to LA-5764-MS (to be published) for information on Refs. 2-5, 10-12, 14-19, 23, 24, and 27-40.

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19. "PACER Experiments," R. Shreffler to L. Jones, April 5, 1974.

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21. "A Numerical Method for Studying the Circulation Patterns of a Fluid," Linda Stephani, LA--MS (to be published).

22. "Analysis of Cavity Stability by Finite-Element Method," C. A. Anderson (see Appendix B).

23. "Contribution to PACER Program Summary Document--Project 3 - Engineering," T. J. Merson, ENG-6-370, August 30, 1974.

24. "Environmental Review - PACER," J. J. Koelling, ENG-7-2829, February 7, 1974.

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26. Earl Voss memorandum to R. Shreffler, July 6, 1973. Private Communication.

27. "The Association of the PACER Program and the Nuclear Weapons Program," DOS-1-82, November 29, 1973, H. Hubbard and R. Shreffler.

28. Letter, Feb. 7, 1974, F. Gilbert to H. Agnew.

29. Letter, Feb. 15, 1974, R. Shreffler to F. Gilbert, DOS-1-93.

30. Letter, R.Shreffler to Lt.Gen. W. D. Johnson, May 31, 1974.

31. Letter, Lt. Gen. W. D. Johnson to R. Shreffler, June 27, 1974.

32. Appendix D, Statement of Work, Contract No. AT(29-2)-3324.

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34. Letter, R. Shreffler to Michael Daly, Senator Montoya's Staff, Feb. 26, 1974, DOS-1-94.

35. Letter, Maj. Gen. Graves to R. Shreffler, PACER, April 18, 1974.

36. "Proposed Objectives and Budget for FY-75," DOS-1-107, April 25, 1974.

37. Letter, H. Agnew to Maj. Gen. E. Graves, PACER, April 26, 1974.

38. "PACER, Proposed Objectives and Budget for FY-75," DOS-1-111, May 7, 1974.

39. PACER Presentation for JCS Delegate to SALT and Members of the Verification Panel Working Group, DOS-1-118, August 1, 1974.

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APPENDIX A

A NUMERICAL METHOD FOR STUDYING CIRCULATION PATTERNS OF A FLUID. LA---MS (To be Published)

(Abstract)

This report presents a description of a numerical method designed to study the circulation patterns of a fluid in a cavity. The method incorporates three circulation-inducing mechanisms: 1) buoyancy induced by nonuniform initial distribution of heat throughout the fluid, 2) buoyancy induced by removal of heat from the fluid, and 3) forced convection induced by withdrawal of heated fluid and return of cooled fluid back to the system. A two-dimensional computer program, CIRCØ, based on the Marker-and-Cell (MAC) technique, is used to study the circulation patterns. This report discusses the code, and its capabilities are illustrated by examples from studies conducted for the PACER project, which investigates the concept of producing electrical power from energy released by thermonuclear explosions in a salt dome. Efficient engineering for the withdrawal of energy from the cavity requires an understanding of the circulation patterns of the heated fluid. The CIRCØ studies provide some of this information in the form of computer generated plots.

APPENDIX B

ANALYSIS OF CAVITY STABILITY BY THE FINITE ELEMENT METHOD

C. A. Anderson

Abstract

Long-term steady-state creep and creep rupture of underground structures are problems of increasing importance by virtue of the implications to storage of radioactive waste materials and to energy extraction methods which employ underground structures or cavities. This paper describes the axisymmetric finite element code CSAAS which has been developed at the Los Alamos Scientific Laboratory in order to look at these problems. Special attention is directed to the "nearly incompressible" element formulation in CSAAS and to the stable method of time stepping which is used to obtain an estimate of the incompressible steady creep state from an initial elastic solution. Applications are made to thermal creep problems involving pure halite which posesses a well documented creep law of the Weertman's form; the flow rule for axisymmetric stress states is based on the Prandtl-Reuss law of metal plasticity. The resulting discretized equations are highly nonlinear.

Comparison of the numerical results from CSAAS with the few known analytical solutions to one-dimensional steady creep problems indicates a high degree of accuracy for this finite element method. When applied to the examination of the long-term stability of a spherical cavity in halite, various steady motions of the cavity (such as buoyancy or slumping) can be observed, depending on the temperature field and the internal pressurization of the cavity.

Introduction

At sufficiently high temperatures metals and certain other crystalline materials show progressive plastic deformation, called creep, when loaded under a constant, nonhydrostatic state of stress. The situation becomes exaggerated when either temperature or the stress level is raised. Three stages of creep are often distinguished; these are termed primary, secondary, and tertiary creep during which the creep strain-rate is decreasing, constant, and increasing with time, respectively. It is the secondary creep stage with which we will be mainly concerned in this report.

A nonmetallic substance where steady-state creep behavior has been thoroughly characterized is halite (NaCl). The steady-state creep behavior or isotropic polycrystalline aggregates of this substance has been determined in the temperature range from 20°C to over 500°C and at confining (hydrostatic) pressures of zero and two kilobars. The steady creep behavior of halite has been found to be well described by Weertman's formula which is based on dislocation climb mechanisms,

$$\dot{\varepsilon} = A\, e^{-E/RT} \sigma^N \qquad (1)$$

where σ, $\dot{\varepsilon}$, and T are the stress, creep strain-rate, and absolute temperature, respectively, and where A, E, and N are material constants and R is the universal gas constant. Considering that N usually ranges from 3 to 7 for most crystalline materials ($N \approx 5.5$ for halite), it is clear from Eq. (1) that the steady creep problem is highly nonlinear, and recourse to numerical techniques must be undertaken in order to solve real problems.

Extension of the one-dimensional observations for metallic creep are carried out to multiaxial stress states by use of the Prandtl-Reuss flow rule of plasticity; thus, the creep strain-rates are proportional to the stress deviators. This constitutive relation together with the equilibrium equations and strain-rate-velocity equations constitute a problem of steady-state creep. It is clear from these equations that the steady creep problem is not unlike the nonlinear elastic problem for incompressible materials; thus, numerical methods capable of solving the nonlinear elastic problem, such as the method of successive elastic solutions, may carry over to the steady creep problem.

Section II of this report discusses the numerical solution of basic creep equations starting from an initial elastic solution. A numerical algorithm is developed which allows the calculation of incremental creep strains, stresses, and displacements as in traditional initial strain methods; however, the method of this report uses the mid-interval value of the stress which appears to lead to a higher order of accuracy, and more importantly, to numerical stability which allows the use of very large time steps as steady-state creep is approached. On the other hand, this method requires the formation of the elastic-creep stiffness matrix at each time step. In addition, as steady creep is approached, the deformation becomes nearly incompressible; in order to accurately describe this feature of creeping flow, we have used the finite element formulation for cylindrically orthotropic and nearly incompressible materials. We believe this feature to be especially important to the numerical solution of long-term steady creep--a physical phenomena which maintains both the features of fluid flow and the deformation of solids which possess finite shear strength.

Section III briefly describes the axisymmetric creep CSAAS which incorporates the numerical methods of Section II into a working code. There also are compared the results of applying this numerical method to one-dimensional steady creep test problems for which analytical creep rates are observed.

Section IV addresses the main question of this report--the stability of cavities in massive salt bodies. Recently, there have been proposals to use cavities for storage of radioactive wastes and as a means of energy extraction from thermonuclear explosives; this has necessitated accurate prediction of the creep behavior of the <u>in situ</u> salt at geothermal and elevated temperatures. When the numerical method was applied to the examination of the long-term stability of a spherical cavity in halite, various steady motions of the cavity could be observed depending on the temperature field and the cavity pressurization. Thus, for a 200-m radius cavity at a depth of 2 km in a salt dome (see Fig. 1B for the finite element model) with

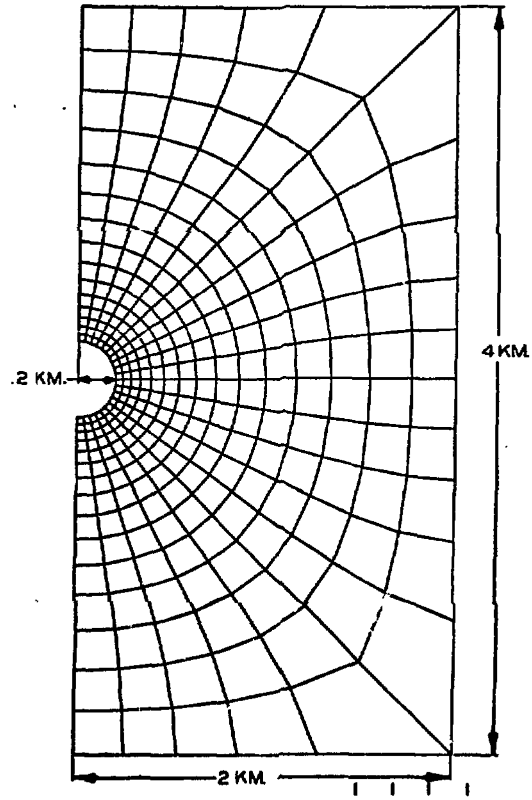

Fig. 1B. Finite Element Model of Salt Cavity.

TABLE B-I

STEADY-STATE VELOCITIES AT SELECTED LOCATIONS IN THE GEOTHERMAL SALT DOME MODEL*

Cavity Pressure (bars)	V_z at Top of Cavity	V_r at Equator of Cavity	V_z at Base of Cavity	Surface Subsidence Velocity
0	-3.6 m/yr	-11 m/yr	17 m/yr	-0.4 m/yr
110	-1.2 m/yr	- 3 m/yr	7 m/yr	-0.13 m/yr
220	-0.1 m/yr	-0.4 m/yr	0.6 m/yr	-0.015 m/yr
330	-2.6 mm/yr	-11 mm/yr	42 mm/yr	-0.6 mm/yr
440	-0.05 mm/yr	-0.002 mm/yr	0.05 mm/yr	-0.00007 mm/yr

*V_z and V_r are axial and radial velocities, respectively; positive V_z is upward and positive V_r is radially outward with respect to Fig. 1B.

geothermal temperature field of 27.5°C/km of depth the steady creep rate ranged from about 0.1 mm/yr for full cavity pressurization which balanced the overburden pressure, up to about 10 m/yr for no cavity pressurization. In the former case the deformation mode was that of a buoyant (rising) cavity; with no cavity pressure the deformation mode was that of a collapsing cavity with the radial inward velocity a maximum and a minimum at the base and the top of the cavity, respectively. The results for other cavity pressurizations are summarized in Table B-1. On the other hand, for a localized radially symmetric "hot spot" temperature field of 500°C on the wall of the same cavity with full pressurization and with the interior temperature field that of the 20-yr transient field, the steady creep rate was calculated to be 100 mm per yr; the deformation mode was slumping off the cavity wall with salt flow down the vertical face of the cavity.

Finally, a geomechanical model for the formation of halite domes is discussed in Section IV and steady creep rates are calculated.

APPENDIX C

FIRST SUMMARY REPORT FOR PROJECT 7
SITE DEFINITION, SELECTION AND CAVITY CONSTRUCTION
FOR PACER PROGRAM.

IN TWO PARTS:

PART A - SITE DEFINITION AND CAVITY CONSTRUCTION
PART B - SITE SELECTION

by
Robert R. Sharp, Jr.

TABLE OF CONTENTS

PREFACE

The PACER concept of power production with a secondary thermoelectric circuit, by heating a primary working fluid with periodic, contained and uncoupled, underground thermonuclear explosions is not new. Yet, with the recent worldwide awakening to a real energy shortage, the importance of determining the economic and engineering feasibility or lack thereof for such a program, once and for all, becomes obvious. Consequently, whatever the outcome, it is hoped that work on the project for which this is a summary report of the first effort, will, along with the work on other PACER projects, ultimately prove collectively definitive.

In addition to the primary purposes of formulating technical site definitions, making site selections, and providing engineering criteria and methods evaluation for PACER cavity construction, the present project has a number of secondary purposes. One is to delineate the considerations, both theoretical and empirical, pertinent to PACER cavity stability. A second is to provide perspective for comparing a PACER cavity with presently existing underground openings, natural and man-made, both in hard rock and in salt. A third purpose is to present bibliographic data on geologic, mining, and geological engineering literature which deals directly with various aspects of problems related to the feasibility of PACER. The aim here is to avoid costly repetition of work brought on by failure to recognize that beneath the ground, as under the sun, there is little truly new.

A fourth secondary purpose is to review the experience with conventional and nuclear explosives in salt, again to avoid costly repetition of effort. Still another, or fifth purpose, is to review and set forth the known properties of salt and the geologic materials most commonly found with it, as well as the effects on them of temperature, pressure, and radiation. It appears to be almost tacitly assumed that only salt in large deposits can provide the properties required for cavities of the size demanded by PACER. On the other hand, it may well be ultimately proven that the properties of natural salt deposits at the high temperatures and pressures presently proposed for PACER are precisely what will prohibit their use for the program. It will, therefore, be well to critically examine all available data on the properties of rock salt.

A sixth purpose of the project is to provide a background for site definition by describing the various types of world salt deposits and salt structures. Seventh, there is the purpose of convincingly showing that all reasonably adequate sites in North America (at the present time, at least) have been considered. An eighth and last purpose is to outline the various methods that can be used to delineate and define the very best candidate sites for final selection.

The present work, representing only the fruits or the earliest stage of the project, does not pretend to meet all the purposes set forth above. However, within the constraints imposed by library research (to which the report is limited), aided perhaps by the author's background in mining, geology, and various fields of engineering, it is hoped that at least a reasonably worthwhile contribution is provided towards each of them.

As indicated above, the basic concept of PACER itself is not new. Furthermore, in addition to the fact that salt has been mined, processed, transported, and otherwise handled by industry since long before the time of Christ, both the Atomic Energy Commission (AEC) and the Advanced Research Projects Agency (ARPA) of the U.S. Government have spent many millions of dollars on research into the construction of large cavities in salt for radioactive waste storage or experiments on the seismic decoupling of nuclear explosions. Consequently, there is an immense store of literature covering previous work on the subjects at hand. In the body of this report, then, the more important works dealing with the individual topics of pertinence are indicated at the beginning of each section. Within the limits of practicality, the findings of those considered most pertinent are summarized. However, in the case of works of critical importance, such as those dealing with predicted salt cavity closure at depths below a kilometer or at ambient temperatures in excess of about 200°C, it is highly recommended that the interested reader study the original cited work in full.

Since a few of the publications of pertinence herein are somewhat obscure, the writer has seen to it that he has retained access to all of them. Consequently, requests for individual works not readily available to the reader can be directly met in one manner or another.