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OAK RIDGE NATIONAL LABORATORY
Operated By
CARBIDE AND CARBON CHEMICALS COMPANY

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POST OFFICE BOX P
OAK RIDGE, TENNESSEE

CF 52-11-164

DATE: November 21, 1952
SUBJECT: SCOPE OF P.B.R. STUDY
TO: Listed Distribution
FROM: P. C. Zmola

COPY NO. 7

Photostat Price \$ 1.80

Microfilm Price \$ 1.80

Available from the
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SCOPE OF P.B.R. STUDY

The stated purpose of the PBR study has been to help evaluate, clarify, and possibly uncover problems which would arise if an actual boiling reactor were designed for some specific economic objective. In this memorandum a more specific outline of the study is presented.

The results of a PBR study should display the relation between two somewhat diverse areas of activity. In the direction of economic evaluation, the study should extend at least to the point where the specific unit chosen can be evaluated on the same basis that Lane, et al, have evaluated various aqueous homogeneous units in ORNL-1096. In the complementary direction of aqueous homogeneous reactor research and development, effort is being directed toward investigating problems of nuclear behavior, corrosion and solution stability, power production, breeding or conversion, etc. This study should provide the means of synthesizing the results of these investigations as applied to a specific unit. It is hoped that the results of this synthesis will help clarify the aims and problems of the research and development groups that provide the information upon which this study must feed.

At present the approach which appears most fruitful is to choose a specific purpose for which a boiling reactor is to be designed. The distinction between PBR design and the design of a reactor for actual construction is that in the former the luxury of an arbitrary decision is permitted if it is clear that the information on which a discriminating decision could be made is unobtainable. That is, in the PBR the emphasis is placed on establishing and clarifying the problems which would have to be solved if an actual boiling reactor were to be constructed. At any point in the design about which insufficient information is available, the existing information should be reviewed, the problem concisely outlined, and a clear postulation made based on the "best" information available.

A list of general problems which must be reviewed in the PBR design is presented in the appendix. It is clear that the problems are so extensive and so intimately related that even a modest investigation of each before deciding upon a specific reactor design would require an effort far beyond that intended for this study. The philosophy to be followed, then, will be to specify in the beginning and on a somewhat arbitrary basis, a sufficient number of the key features of the unit that parts of the study can be conducted with some measure of independence. Greater effort should be devoted to those features of the system which are unique to boiling reactors. If after preliminary studies it becomes clear that some of the initial decisions were poor ones, corresponding changes can be made. It is hoped that this process will bare at least the less subtle features influencing an optimum design.

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The most perfunctory examination of an aqueous boiling system reveals that attainable power densities are appreciably lower than those for circulating systems. This points to large, low enrichment units. Initially the PBR will be a power and plutonium producer. The following are design conditions:

1. Power	1000 MW
2. Cylindrical Core	
diameter	20 ft
active height	20 ft
volume	6280 ft ³ (178,000 l)
3. Power Density	5.63 KW/l
4. Fuel	UO ₂ SO ₄
5. Moderator	D ₂ O
6. Maximum Temperature	250 C (482 F)
7. Design Pressure	580 psia
8. Intermediate heat exchanger	
will be used	
9. Secondary coolant and working fluid	H ₂ O
10. Natural convection boiling	
in core	

It is not intended that these conditions constrain the investigation of the individual problems but rather provide a starting point.

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APPENDIX

The following is a list of general problems which must be reviewed in the design of the PBR. The arrangement of the outline is for convenience only (division into problems of operation, construction, and economics); it is clear that problems in the various categories are intimately related.

I. OPERATION

- A. Choice of Fuel - Examination of the several possible solutions and slurries. Evaluation should be based on the fuel and corresponding retaining material combination.
  - 1. Chemical Stability
  - 2. Radiation Stability
  - 3. Corrosion
- B. Nuclear Requirements for Steady State Operation
  - 1. Influence of density distribution
    - a. On enrichment requirements
    - b. On fuel moderator ratio for optimum conversion
  - 2. Effect of fission product poisoning
  - 3. Conversion ratio (see Section III-C)
- C. Dynamic Behavior of the Reactor System - The objective is to establish the limits of acceptable operation. Of course, the limits themselves must be defined in some operational manner.
  - 1. Nuclear Kinetics
  - 2. Control Properties of Reactor System
    - a. Conditions under which a nuclear power plant may be self regulating
    - b. Start up procedure
    - c. Need for fast acting external control system

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C. (Continued)

3. Flexibility of unit under conditions of changing load.

D. Power Removal

1. Dependence of specific power on density distribution and density decrement
  - a. Evaluation of density distribution
  - b. Method of vapor separation from vapor-liquid mixtures
2. Core Hydrodynamics
  - a. Comparison of natural and forced circulation systems
  - b. Evaluation of circulation resistance
3. Control or elimination of foaming - (possibly an influencing factor in the choice of fuel salt.)
4. Practicability of cooling coils within the reacting core.

E. Fission Product Removal and Disposal

1. Removal of fission products from vapor
2. Removal of fission products from fuel-moderator mixture
3. Comparison of continuous vs. periodic removal

F. Recombination of Dissociation Products - Comparison and evaluation of hydrogen - oxygen recombiners

1. Catalytic Recombiner
  - a. Poisoning by fission products
  - b. Suitable catalyst for operating temperature range
2. Flame Recombiner
3. Recombination by fuel solution-additives

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F. (Continued)

4. Desirable location of recombiner in piping circuit
5. Problems associated with reactor start up and low load operation
6. Methods of utilizing recombiner energy most effectively

II. CONSTRUCTION

A. Layout of Physical Plant (see Sec. III-A)

B. Design of Reactor Core Tank and Intermediate Heat Exchangers

1. Desirable shape from construction standpoint
2. Limitations on tank size and wall thickness
  - a. operating temperature
  - b. operating pressure
  - c. heat generation in walls from heating
  - d. transient loads
3. Thermal stress problems and requirements for thermal shielding - review of the system to determine points at which thermal stresses might be high and the possibility of design changes to avoid the difficulty.
4. Practicability of using liners of corrosion resistant materials with structural steel backing to withstand pressure loads.
5. What difficulties are involved in construction of a core vessel that can be opened periodically (to replace or inspect reactor internals such as steam separators, etc)?

C. Fuel Feed and Withdrawal System

1. Location and nature of fuel withdrawal point in fuel circuit based on continuous or batch processing

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C. (Continued)

2. Expected response of a fuel feed system which is to be used as primary reactivity control
3. Comparison of the problems of handling solution and slurry in a fuel feed system
4. Size of storage and dump tanks

D. Shielding and Contamination of Components

1. Shielding required for operation at design power - establish factors on which an optimum design depends
2. Arrangement of components for accessibility with attention to:
  - a. Contamination and ease of component decontamination
  - b. Need for maintenance

III. ECONOMICS

A. Size and Arrangement of the Physical Plant

1. Requirements and cost of buildings and standard facilities
  - a. Can power and production facilities be physically separate without inconvenience?
  - b. Storage space requirements (for dump tanks, fission product storage, etc.)
  - c. Can part of the system be located out of doors (little weather protection)?
2. Physical arrangement of plant components - with attention to the somewhat conflicting objectives of minimum piping and easy accessibility where necessary.
  - a. Reactor
  - b. Intermediate heat exchanger
  - c. Condenser

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2. (Continued)

d. Turbines and Generators

e. Feed and Dump Tanks

f. Auxiliaries (pumps, recombiners, fission product disposal equipment, etc.)

3. Equipment arrangement for low external holdup of fissionable material and moderator.

B. Power Equipment - Heat Exchanger, Turbine, and Generator Arrangement.

1. Comparison of using the coolant-moderator as the working fluid in direct expansion through a steam turbine with using an intermediate heat exchanger from the standpoint of:

a. Attainable operating temperature

b. Inventory of moderator required

c. Contamination of turbine and condenser and associated maintenance problems

d. If intermediate heat exchanger is used, requirements for pre-treatment turbine working fluid

2. Optimization of thermodynamic power cycle on the basis of minimum costs and ease of maintenance

a. Reheat - number of stages

b. Regenerative cycle - number of turbine bleed points for feedwater heating.

c. Physical size of heat exchangers, piping, turbines and condensers

3. Low holdup heat exchangers (condensers) for handling D₂O

4. Implications of turbine control by utilizing a variable fraction of the reactor heat output with the remaining flow going to a steam killer.

5. Optimization of heat exchange equipment (cost per unit of heat transferred based on optimum temperature difference)

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C. Production of Fissionable Material

1. Optimum fuel concentration and enrichment
2. Influence of varying power demand on production -
Based on both fixed value of fissionable material and
value only as fuel supply.
3. Permissible fission product buildup
4. Optimum reprocessing and fuel replenishing cycle -
influence of proximity to processing plants.

D. Evaluation of Equipment Life - Expected life of the major
components and their ease of replacement in the system
(amortization)

E. Operating Procedure

1. Power generation - price paid for uninterrupted power
is greater than that for interrupted power. What are
the conditions under which a reactor can produce power
at about rated level continuously?
2. Production of fissionable material
  - a. Which of the requirements for high price
electricity are consistent with high conversion?
  - b. The cost and implication of wasting a fraction
of the reactor energy to get greater production.

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