Part II
MOLTEN-SALT REACTORS

H. G. MacPherson, Editor
Oak Ridge National Laboratory

CONTRIBUTORS

L. G. Alexander
J. W. Allen
E. S. Bettis
F. F. Blankenship
W. F. Boudreau
E. J. Breeding
W. G. Cobb
W. H. Cook
D. R. Cuneo
J. H. DeVann
D. A. Douglas
W. K. Ergen
W. R. Grimes
H. Inouye
D. H. Jansen
G. W. Keilholtz
B. W. Kinyon
M. E. Lackey
H. G. MacPherson
W. D. Manly
L. A. Mann
W. B. McDonald
H. J. Metz
P. Patriarca
H. F. Poppendiek
J. T. Roberts
M. T. Robinson
T. K. Roche
H. W. Savage
G. M. Slaughter
E. Storto
A. Taboada
G. M. Tolson
F. C. Vonderlage
G. D. Whitman
J. Zasler

PREFACE

The Oak Ridge National Laboratory, under the sponsorship of the U. S. Atomic Energy Commission, has engaged in research on molten salts as materials for use in high-temperature reactors for a number of years. The technology developed by this work was incorporated in the Aircraft Reactor Experiment and made available for purposes of civilian application. This earlier technology and the new information found in the civilian power reactor effort is summarized in this part.

So many present and former members of the Laboratory staff have contributed directly or indirectly to the molten salt work that it should be regarded as a contribution from the entire Laboratory. The technical direction of the work was provided by A. M. Weinberg, R. C. Briant, W. H. Jordan, and S. J. Cromer. In addition to the contributors listed for the various chapters, the editor would like to acknowledge the efforts of the following people who are currently engaged in the work reported: R. G. Affel, J. C. Amos, C. J. Barton, C. C. Beusman, W. E. Browning, S. Cantor, D. O. Campbell, G. I. Cathers, B. H. Clampitt, J. A. Conlin, M. H. Cooper, J. L. Crowley, J. Y. Estabrook, H. A. Friedman, P. A. Gnadt, A. G. Grindell, H. W. Hoffman, H. Insley, S. Langer, R. E. MacPherson, R. E. Moore, G. J. Nessle, R. F. Newton, W. R. Osborn, F. E. Romie, C. F. Sales, J. H. Shaffer, G. P. Smith, N. V. Smith, P. G. Smith, W. L. Snapp, W. K. Stair, R. A. Strehlow, C. D. Susano, R. E. Thoma, D. B. Trauger, J. J. Tudor, W. T. Ward, G. M. Watson, J. C. White, and H. C. Young.

The technical reviews at Argonne National Laboratory and Westinghouse Electric Corporation aided in achieving clarity.

The editor and contributors of this part wish to express their appreciation to A. W. Savolainen for her assistance in preparing the text in its final form.

Oak Ridge, Tennessee
June 1958

H. G. MacPherson, *Editor*

CHAPTER 11

INTRODUCTION*

The potential utility of a fluid-fueled reactor that can operate at a high temperature but with a low-pressure system has been recognized for a long time. Some years ago, R. C. Briant of the Oak Ridge National Laboratory suggested the use of the molten mixture of UF_4 and ThF_4, together with the fluorides of the alkali metals and beryllium or zirconium, as the fluid fuel. Laboratory work with such mixtures led to the operation, in 1954, of an experimental reactor, which was designated the Aircraft Reactor Experiment (ARE).

Fluoride-salt mixtures suitable for use in power reactors have melting points in the temperature range 850 to 950°F and are sufficiently compatible with certain nickel-base alloys to assure long life for reactor components at temperatures up to 1300°F. Thus the natural, optimum operating temperature for a molten-salt-fueled reactor is such that the molten salt is a suitable heat source for a modern steam power plant. The principal advantages of the molten-salt system, other than high temperature, in comparison with one or more of the other fluid-fuel systems are (1) low-pressure operation, (2) stability of the liquid under radiation, (3) high solubility of uranium and thorium (as fluorides) in molten-salt mixtures, and (4) resistance to corrosion of the structural materials that does not depend on oxide or other film formation.

The molten-salt system has the usual benefits attributed to fluid-fuel systems. The principal advantages over solid-fuel-element systems are (1) a high negative temperature coefficient of reactivity, (2) a lack of radiation damage that can limit fuel burnup, (3) the possibility of continuous fission-product removal, (4) the avoidance of the expense of fabricating new fuel elements, and (5) the possibility of adding makeup fuel as needed, which precludes the need for providing excess reactivity. The high negative temperature coefficient and the lack of excess reactivity make possible a reactor, without control rods, which automatically adjusts its power in response to changes of the electrical load. The lack of excess reactivity also leads to a reactor that is not endangered by nuclear power excursions.

One of the attractive features of the molten-salt system is the variety of reactor types that can be considered to cover a range of applications. The present state of the technology suggests that homogeneous reactors which use a molten salt composed of BeF_2 and either Li^7F or NaF, with UF_4 for fuel and ThF_4 for a fertile material, are most suitable for early construction.

*By H. G. MacPherson.

These reactors can be either one or two region and, depending on the size of the reactor core and the thorium fluoride concentration, can cover a wide range of fuel inventories, breeding ratios, and fuel reprocessing schedules. The chief virtues of this class of molten-salt reactor are that the design is based on a well-developed technology and that the use of a simple fuel cycle contributes to reduced costs.

With further development, the same base salt, that is, the mixture of BeF_2 and Li^7F, can be combined with a graphite moderator in a heterogeneous arrangement to provide a self-contained Th–U^{233} system with a breeding ratio of one. The chief advantage of the molten-salt system over other liquid systems in pursuing this objective is that it is the only system in which a soluble thorium compound can be used, and thus the problem of slurry handling is avoided. The possibility of placing thorium in the core obviates the necessity of using graphite as a core-shell material.

Plutonium is being investigated as an alternate fuel for the molten-salt reactor. Although it is too early to describe a plutonium-fueled reactor in detail, it is highly probable that a suitable PuF_3-fueled reactor can be constructed and operated.

The high melting temperature of the fluoride salts is the principal difficulty in their use. Steps must be taken to preheat equipment and to keep the equipment above the melting point of the salt at all times. In addition, there is more parasitic neutron capture in the salts of the molten-salt reactor than there is in the heavy water of the heavy-water-moderated reactors, and thus the breeding ratios are lower. The poorer moderating ability of the salts requires larger critical masses for molten-salt reactors than for the aqueous systems. Finally, the molten-salt reactor shares with all fluid-fuel reactors the problems of certain containment of the fuel, the reliability of components, and the necessity for techniques of making repairs remotely. The low pressure of the molten-salt fuel system should be beneficial with regard to these engineering problems, but to evaluate them properly will require operating experience with experimental reactors.