beginning professionals would hesitate to include it on their bookshelves.

Fifty articles and discussions–one in French, two in Spanish, and the remainder in English–make up the contents of this book. It is divided, unevenly, into six sections: "Exploration Policy," 1 paper; "Exploration Techniques," 28 papers; "Case Histories of Recent Exploration," 9 papers; "Preliminary Evaluation Techniques," 3 papers; "Research and Development of Exploration Techniques," 4 papers; and "Reports of Working Groups," 5 papers.

The first paper, the only one in the section titled "Exploration Policy," is slightly more than a listing of current and potential exploration techniques. It deals little, if at all, with matters of exploration policy. Nonetheless, it includes some interesting facts and figures.

The next section, "Exploration Techniques," is separated into four sections: "Gamma-Ray," ten papers; "Radon and Geochemical Surveys," nine papers; "Non-Radiometric Geophysical Methods," four papers; and "Exploration Drilling and Logging," five papers. These 28 papers vary widely in the significance of their technical content. Students and professionals not acquainted with the field will find this a good exposition of the scope of uranium exploration techniques. Experienced professionals will find themselves criticizing many of the articles that deal with subjects in which they are expert.

The nine "Case Histories of Recent Exploration," two in Spanish, constitute the most significant section in the book. Here one can compare large-scale (or should I say small-scale?) exploration programs throughout the world with the propitious newer discoveries in northern Australia.

The two sections on "Preliminary Evaluation Techniques" and "Research and Development of Exploration Techniques" are the most interesting parts of the book. Terms such as resource evaluation, equilibrium analysis, geostatistical study, labile uranium, remote sensing, and pulsed neutrons convey the breadth of subject matters and the timeliness of the content of these sections. Unfortunately, little mention is made of uranium-isotopic variations in the hydrologic cycle. Stuckless comes closest in his article on labile uranium.

A comprehensive technical review of this volume would be beyond the abilities of most professionals, for the subject matter varies widely. Prospective purchasers should look at the contents of the papers of their interest before buying the book. As a reference, it would be nice to have it available in someone else's library, but this reviewer would not pay the price to place it on his own bookshelves. Much of this information and some much better is or soon will be available in appropriate journals.

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Advanced LMFBR Fuels

(Proceedings of a Topical Meeting)

Publisher	The University of Arizona, Tucson (distributed by The American Nuclear Society, La Grange Park, Illinois) (1977)
Pages	694
Price	Soft, \$17.00; Hardbound, \$20.00
Reviewer	Donald R. Olander

The purpose of this volume, and the conference on which it is based, is to provide a forum for exchanging technical information and for summarizing national programs pertaining to advanced fuels for liquid-metal fast breeder reactors (LMFBRs). The efforts of seven countries are represented by 45 papers, which can be subdivided into categories representing:

1. national program descriptions (8 papers, nos. 1-7, 28)
2. properties of advanced fuels (9 papers, nos. 14-20, 31, 35)
3. irradiation testing of advanced fuels (15 papers, nos. 8-13, 21-27, 33, 44)
4. advanced fuel system studies, covering analytical work on fuel element modeling, core design, and safety (13 papers, nos. 29, 30, 32, 34, 36-43, 45).

For the purpose of this review, the numbering of the papers follows the table of contents of the proceedings; papers presented but not published are not counted. The breakdown given above follows closely but not exactly the subdivisions of the editors of the proceedings. Categories 1 and 2 emphasize the fuel material, and a final paper summarizing the complementary cladding and structural material aspects of LMFBR development from the recent Scottsdale Conference on Radiation Effects in Breeder Reactor Structural Materials completes the present volume.

The term "advanced fuels" means not only carbides and nitrides (sodium or helium bonded) but oxides as well. In the latter case, it is not the fuel *per se* that is advanced, but its configuration in the core; in the American and British programs, an advanced oxide fuel is one that can provide a doubling time of less than 15 years at higher linear power, burnup, and core fuel fraction than current oxide fuels for LMFBR use. Practically, development of advanced oxide fuel elements is a matter of increasing fuel pin diameter, increasing fuel smear density, and reducing cladding thickness. French advanced oxide fuel elements are ones in which fertile material (UO_2) is located at the axial center of the pin, surrounded above and below by mixed-oxide fuel.

The national programs are presented in a bewildering variety of detail, ranging from a discussion of the global ecological consequences of advanced breeder reactors complete with drawing of dinosaurs and a map of the world with its population distribution (paper no. 3) to a chart showing each item of equipment, down to ball mills and analytic balances, in the glove boxes of the Japanese fuel research laboratory (paper no. 5). The French presentation is no-nonsense and brief, perhaps too brief. (This is true of the entire French contributions, with 4 papers totaling 31 pages, compared with 23 U.S. papers totaling 362 pages.) The best balanced and most readable of the national program synopses are the American and British papers (nos. 1 and 2, respectively). The American effort in advanced fuel development is obviously a late-starter, with detailed irradiation information yet to come. From what can be gleaned from these state summaries, the Germans are most deeply committed to carbide LMFBR cores, the Americans are noncommittal, and the English and the French are somewhat skeptical of the overall competitiveness of carbide cores, particularly concerning spent fuel reprocessing.

What is left unsaid in these introductory papers can be surmised from the emphasis placed by the contributions in the remaining three categories. Of the nine papers devoted to fundamental fuel properties, six are from the U.S. and three are from Germany (including the EURATOM Transuranium Institute at Karlsruhe). This distribution is probably not representative of the actual advanced fuel research efforts in the various national programs, and the papers of the two countries that are represented in this category reveal dramatic differences. The German contributions, represented by papers 14, 18, and 35, summarize what is obviously a substantial effort to obtain fundamental understanding of the most important features of carbide and nitride fuel behavior. Laboratory and in-pile experiments have been designed to investigate phenomena such as carbon, actinide, and fission product transport in a temperature gradient, point defect and atomic mobilities in the fuel, restructuring, and particularly fuel swelling. The American effort, with the exception of Singh's measurement of creep in mixed carbides (paper no. 20), appears to deal with peripheral problems and to lack focus.

The core of the volume is devoted to reports of irradiation testing programs. Owing to the length of such testing, some of the papers cover irradiations that were initiated over a decade ago, and some can only report the objectives of a still in-pile irradiation campaign. As noted by Kummerer (paper no. 24), the carbide irradiation program is roughly two decades behind the oxide programs, and as a result, very few general trends have been sorted out. As an example of an unresolved problem, the Los Alamos Scientific Laboratory (LASL) paper (no. 21) states that 10% sesquicarbide (M_2C_3) is acceptable in production fuel, whereas the Swiss paper (no. 26) reports that sesquicarbide contents in excess of 5% promote cladding carburization. This difference in corrosion susceptibilities may, however, be due more to oxygen impurities in the fuel than to the carbon-to-heavy-metal ratio; oxygen levels in excess of ~1000 ppm appear to permit carbon transport to the cladding in the form of carbon monoxide. There is, on the other hand, general agreement on several important items: Cladding corrosion by the fuel is not as severe in carbides as it is in oxides; the distinct restructuring (central void and columnar grain formation) that occurs in oxide fuels at a linear power of ~400 W/cm does not appear in carbides until a practically unattainable rating of ~2000 W/cm; again, in contrast to oxide fuels, the carbides exhibit virtually no plasticity under irradiation, owing to the lower operating temperature and the near absence of irradiation creep. A corollary of this fact is that carbide fuel cannot be restrained by the cladding, and internal porosity in the form of low smear density must be provided to accommodate fuel swelling.

Considerable effort is devoted to comparison of the sodium-bonded fuel pin concept with the standard helium-filled fuel element. The main advantage of a sodium-bonded pin is the elimination of the gap conductance and the possibility of operating at acceptable power levels with temperatures low enough to ensure manageable fission gas swelling of the fuel. Bagley et al. (paper no. 23) identify wedging of fuel fragments against the cladding and development of a fission gas bubble blanket as the principal problems associated with sodium-bonded pins. However, the LASL study (paper no. 44) provides evidence that a thin, perforated shroud tube separating the fuel from the cladding effectively holds the broken fuel together, and the French experiment (paper no. 33) suggests that blowout of the sodium bond does not lead to rapid fuel failure.

The current American emphasis on computation and analysis utilizing computer codes is evidenced by the papers in the fourth category; of the 13 papers devoted to fuel modeling, core design, and safety, 11 are from U.S. organizations. These papers all suffer from lack of a firm set of materials property data and irradiation performance information. For example, in the Argonne National Laboratory contribution (paper no. 37), the source of the thermal conductivity of the carbide fuel is cited as a personal communication, the coefficient of thermal expansion is of 1965 vintage, the fuel thermal creep properties are a factor of 5 different from the measurements reported by Singh at this conference, and irradiation creep has been estimated "indirectly" from mixed-oxide data. Nayak et al. (paper no. 38) note that their fuel modeling calculations for carbide elements are "preliminary" owing to the less developed data base compared with oxide fuels. The same caveat is offered by Barthold et al. (paper no. 41). Finally, the computations of Madell et al. are based on materials properties information that is simply referenced as "unpublished."

To the reader who has the stamina to plow through this nearly 700-page volume and who attempts to reach a judgment on the state of the carbide fuel program, the following message should be evident: The foundation of fuel property and irradiation behavior data is weak, and the calculations are not to be trusted; notwithstanding statements that we now understand the reasons for the high failure rates in early carbide fuel pin irradiation, reliable high-performance advanced fuel elements for the LMFBR are not yet a reality.

The mechanics of the production of this volume are generally good; its appearance within weeks following the conference is especially laudatory. However, the costs of speedy publication are occasionally evident: The list of references in paper no. 18 is missing; in the same paper, it is not possible to tell which spots on the graphs are data points and which are fly specks. Some of the line drawings, graphs, and tables in other papers have been reduced so much that a magnifying glass becomes a desirable reading aid. The nonuniform typescripts from which the volume was assembled occasionally result in gaps in lettering or overly heavy reproduction of line drawings.

Although not consistent with speedy publication, the organizers of the conference could have used a bit more editorial clout in rejecting the few papers that are only marginally concerned with the theme of the conference and in curbing some of the excesses of bland generalities and stultifying detail that appear in some contributions. With all of its warts, however, this volume is a valuable compilation of the world-wide efforts in developing an advanced LMFBR fuel element. It reveals, in the words of the organizers, that "much remains to be done," but it also points to the proper direction for the future effort.

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Migration of Uranium and Thorium—Exploration Significance

Author	John W. Gableman
Publisher	The American Association of Petroleum Geologists, Tulsa (1976)
Pages	168
Price	$15.00
Reviewer	William C. Peters

One of a series of monographs otherwise devoted to the geology of oil and gas resources, this volume reflects the widening scope of the American Association of Petroleum Geologists to include all energy minerals. The author's viewpoint—that the world is not faced with an early depletion of usable uranium—is of interest to the entire nuclear community. The book is, however, written for geologists involved in the search for uranium ore deposits rather than for scientists and engineers concerned with the broader aspects of uranium and thorium resources. The treatment is heavily geologic and related entirely to the natural processes of uranium and thorium concentration that can be expected to result in orebodies. Thorium deposits are considered, but the emphasis is on uranium. There is no coverage of the specific locations and characteristics of individual uranium and thorium deposits.

Gableman, a long-time participant in uranium exploration for the federal government and for private industry, introduces his study in a chapter dealing with the low discovery-efficiency index (success related to effort) experienced during recent years. He considers the lack of success a result of narrow geologic concepts rather than the results of an exhaustion in discoverable deposits. In the remainder of the volume, the author discusses relevant geologic observations and develops a detailed argument for giving broader limits to the geologic and geographic setting of potential deposits than those now used in exploration efforts.

Early chapters deal with the global distribution and geochemistry of uranium and thorium. Later chapters deal with the mechanisms of transfer from the earth's mantle to the crust and the migration of radioelements within the crust. Special consideration is given to the geologic history of continental margins, sites in the pattern of plate tectonics where many concentrations of ore minerals are born. In several chapters, the additional processes of mobilization, redistribution, and fixation—processes that can lead to the formation of uranium and thorium orebodies—are discussed.

Gableman's most emphatic geologic argument is for the derivation of sandstone-type uranium deposits from concentrated thermal brines of possible mantle affiliation rather than from dilute groundwater acting over longer periods of time. He cites abundant evidence, but a great many geologists who do not share his view will find the evidence equivocal. A specific weakness in the development of Gableman's proposition for broader conceptual models of uranium deposits is his minimization of ample and widely accepted evidence supporting the transport of uranium in meteoric groundwater systems.

In one respect, the volume is poorly balanced; the scale of observation changes between global and local several times in successive chapters. Another shortcoming is the uneven treatment of uranium and thorium geochemistry under several headings. Still, Gableman's book is a unique and scholarly review of the broader aspects of uranium and thorium deposits. His purpose, to stimulate exploration in new terrain, is achieved.

The book is not for the general reader, but it is strongly recommended to all uranium exploration geologists. The collective decline in their discovery-efficiency index may well have its roots in their need to appreciate the underemphasized processes of mineralization discussed by Gableman.

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