WHC-SA-1067-S

Advancing Liquid Metal Reactor Technology With Nitride Fuels

W. F. Lyon
R. B. Baker
R. D. Leggett
Westinghouse Hanford Company

R. B. Matthews
Los Alamos National Laboratory

Date Published
December 1990

To be presented at
International Conference
on Fast Reactors and
Related Fuel Cycles
Kyoto, Japan
October 28 - November 1, 1991

Prepared for the U.S. Department of Energy
Assistant Secretary for Nuclear Energy

Westinghouse Hanford Company
P.O. Box 1970
Richland, Washington 99352

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

Printed in the United States of America

DISCLM-2.CHP (10-90)

ADVANCING LIQUID METAL REACTOR TECHNOLOGY WITH NITRIDE FUELS

W. F. Lyon, R. B. Baker, and R. D. Leggett
Westinghouse Hanford Company
P. O. Box 1970 MSIN L5-02
Richland, WA 99352
(509) 376-8869

R. B. Matthews
Los Alamos National Laboratory
P. O. Box 1663 MS E505
Los Alamos, NM 87545
(505) 667-2358

1.0 INTRODUCTION

This paper has the following purposes.

- Summarize the past experiences and the present activities related to the use of mixed nitride [(U,Pu)N] fuel in liquid metal reactors (LMRs).
- Identify key performance issues.
- Recommend specific design criteria for nitride fuel and blanket pins.

This study is prompted by a renewed interest in alternative fuel designs for advanced LMRs that emphasize enhanced performance and passive safety. Current fuel development programs encompass a wide spectrum of fuel types and designs; however, a concensus has gradually evolved that nitride fuels offer the best option for future development. The excellent thermal conductivity, complete compatibility with sodium, attractive safety features, and other characteristics such as favorable neutronic, physical, and mechanical properties suggest that nitride fuels offer significant advantages over other fuel types.

2.0 NITRIDE FUELS DEVELOPMENT

The interest in nitride fuels has manifested itself in development programs throughout the world. The U.S. Department of Energy, along with the Department of Defense and the National Aeronautics and Space Administration, is conducting irradiation tests with uranium mononitride (UN) fuels in support of its space reactor program in both the Fast Flux Test Facility (FFTF) and the Experimental Breeder Reactor-II (Matthews 1990). The European community has designated (U,Pu)N as its alternate liquid metal fast breeder reactor (LMFBR) fuel system and is testing nitride fuels in the Phénix reactor (Prunier et al. 1990). In conjunction with this activity, fabrication studies are also being supported by the French Commissariat à l'Energie Atomique, the Paul-Sherrer-Institute in Switzerland, and the Institute for Transuranium Elements in Germany. The Soviet Union has irradiated an entire core load of UN in the BR-10 reactor (Troyanov and Rineysky 1989). Although no fuel tests have been conducted to date, Japan has shown an interest in the fabrication of (U,Pu)N fuel. These programs indicate that the development of nitride fuels is broad-based within the international LMR scientific community and is proceeding at an aggressive pace.

3.0 NITRIDE PERFORMANCE ISSUES

The properties of nitride fuels can translate into a variety of advantages when integrated into an advanced reactor design. The results of recent studies by Westinghouse Hanford Company predict that a (U,Pu)N fuel system will provide larger operating margins for fuel, blanket, and cladding peak temperatures and cladding strain than the reference ternary metal fuel system during steady state operation in an advanced LMR (Lyon et al. 1990). Other analyses predicting the transient performance of several fuel types in the FFTF indicate that a (U,Pu)N fuel system would have the best overall performance compared to oxide, mixed oxide, and binary metal fuel core designs (Padilla et al. 1990). The enhanced performance of nitride fuel systems stem from the inherent properties of nitride fuels and their effects on reactor systems. A summary of the characteristics of nitride fuels and their impacts on reactor design and operation is illustrated in Table 1.

Table 1. Nitride Fuel Characteristics.

Characteristic	System Impact
High thermal conductivity	Higher power density, enhanced thermal performance, large passive safety margins
Fuel, cladding, and coolant compatibility	Postbreach operation possible, zero FCCI,[a] allows use of sodium bond
Low sodium void coefficient and favorable Doppler coefficient	Enhanced safety performance because of higher margins to failure in power transients, excellent tolerance for loss of flow and transient overpower without SCRAM[b]
Low fission gas release and fuel swelling	Smaller plenum and pins, lower cladding stresses, longer pin lifetime, and better economics
Ease of fabrication and reprocessing	Compatibility with conventional oxide fabrication and reprocessing and, potentially, pyro-reprocessing technology

[a]FCCI = fuel/cladding chemical interaction
[b]SCRAM = rapid reactor shutdown

Issues concerning nitride fuels include fabricability, steady state and transient performance, high-temperature dissociation, and reprocessing. Uranium nitride fabrication by carbothermic reduction, nitriding, cold pressing, and sintering has been established by the pilot plant production of UN fuel pellets for the SP-100 ground test (Matthews 1990). Mixed nitride can be fabricated with a nearly identical process (Aria et al. 1989). The steady state irradiation behavior of UN has been characterized for space power reactor programs (Hales et al. 1989; Matthews et al. 1988), and several (U,Pu)N irradiation tests were conducted as part of the advanced LMFBR fuel development program (Bauer 1972). The steady state and transient irradiation performance of carbides has been well established (Matthews and Herbst 1983; Matzke and Blank 1989), and because of similar properties and characteristics, the carbide database can be used to establish performance trends for nitride fuels. Swelling rates of approximately 0.5% ΔD per at.% burnup and fission gas release rates of approximately 1% per at.% burnup, and burnups greater than 20 at.% should be readily achievable for nitride fuels.

The tendency of UN to dissociate to free uranium and N_2 at high temperatures can be suppressed by controlling stoichiometry and operating temperatures below 1,650 K. Nitride reprocessing is compatible with the head end of the PUREX (plutonium/uranium extraction) process, and high temperature processes to convert (U,Pu)N to metal for pyro-reprocessing are conceivable. The production of ^{14}C from (n-p) reactions with ^{14}N will impose design restrictions on reprocessing facilities; however, effluent CO_2 streams could be readily trapped and the reprocessing of nitride fuels is not considered to be an insurmountable problem (Blank 1988).

4.0 RECOMMENDATIONS FOR DESIGN CRITERIA

After a thorough review of the available information, the following design criteria are recommended for a nitride fuel system for an advanced LMR.

- Restrict the peak fuel temperature to less than 1,200 °C.
- Maintain the steady-state, peak cladding temperature below 1,000 °C.
- Use zero for fuel/cladding chemical interaction.
- Use a value of 0.5% ΔD (or 1.5% ΔV) per at.% burnup for fuel pellet swelling.
- Use 10% fission gas release.
- Select either a sodium or helium bond.
- With a sodium bond, a shroud is acceptable but may not be required for all designs.
- Assume fuel swelling is inexorable.
- Select either significant fuel/cladding contact or a cladding strain limit (2% for HT9) as end-of-life.
- Select a smeared density consistent with the desired lifetime.

It is judged that applying these criteria will result in a rugged fuel pin design capable of very high burnup in an advanced LMR.

5.0 CONCLUSIONS

Although historically nitride fuels have received less attention than other advanced fuels, it should be evident from the programs that are currently underway that this is no longer the case. The development of nitride fuel systems is continuing with programs supporting irradiation testing for both space reactor systems and proposed advanced LMRs in many countries throughout the world. Nitride fuels combine many of the favorable properties of other fuels systems such as having high thermal conductivity similar to metal fuels with a high melting temperature typical of ceramic fuels. This combination of operational and safety characteristics can provide reactor systems with both design flexibility and enhanced performance.

6.0 REFERENCES

Aria, Y., S. Fukushima, K. Shiozawa, and M. Handa, 1989, "Fabrication of (U,Pu)N Fuel Pellets," *J. Nuc. Mater.* 168, pp. 280-289. Amsterdam, The Netherlands.

Bauer, A. A., "Nitride Fuels: Properties and Potentials," 1972, *Reactor Technology* 15 (2), pp. 87-104, Washington, D.C.

Blank, H., 1988, "Specification and Characterization of Dense Fuels for Liquid Metal Cooled Fast Breeder Reactors," *J. Nuc. Mater.* 153, pp. 171-177, Amsterdam, The Netherlands.

Hales J. W., B. J. Makenas, and D. S. Dutt, 1989, "SP-100 Fuel Pin Irradiation Testing," *Trans. Sixth Symposium on Space Nuclear Power Systems*, p. 136, Albuquerque, New Mexico.

Lyon, W. F., R. B. Baker, and R. D. Leggett, 1990, "Performance Analysis of a Mixed Nitride Fuel System for an Advanced Liquid Metal Reactor," *Transactions of the ANS Winter Meeting*, Washington, D.C.

Matthews, R. B., 1990, "Overview of SP-100 Fuel Development Activities," *Trans. of the Seventh Symposium on Space Nuclear Power Systems*, CONF-900109, pp. 883-888, Albuquerque, New Mexico.

Matthews, R. B., K. M. Chidester, C. W. Hoth, R. E. Mason, and R. L. Petty, 1988," Fabrication and Testing of Nitride Fuel for Space Power Reactors," *J. Nuc. Mater.* 151, p. 334, Amsterdam, The Netherlands.

Matthews, R. B., and R. J. Herbst, 1983, "Uranium-Plutonium Carbide Fuel for Fast Breeder Reactors, "*Nuclear Technology* 163, pp. 9-22, LaGrange Park, Illinois.

Matzke, Hj. and H. Blank, 1989, "Fuel Research and Basic Aspects of Fuel In-Pile Performance," *J. Nuc. Mater.* 166, pp. 120-131, Amsterdam, The Netherlands.

Padilla, A., S. F. Kessler, K. D. Dobbin, and A. E. Waltar, 1990, "Fuel Aspects of Beyond Design Basis Event Analyses for the Fast Flux Test Facility," *Transactions of the 1990 International Fast Reactor Safety Meeting*, Snowbird, Utah.

Prunier, C., P. Bardelle, K. Richter, R. W. Stratton, and G. Ledergerber, 1990," European Collaboration on Mixed Nitride Fuel, "*Transactions of the ANS Winter Meeting*, Washington, D.C.

Troyanov, M. F. and A. A. Rineysky, 1989, "The State of Work on Fast Reactors in the USSR," presentation made at the *22nd Session of the International Fast Reactor Working Group*, Vienna, Austria.

DISTRIBUTION

Number of Copies

OFFSITE

1	Los Alamos National Laboratory	
	R. B. Matthews Los Alamos National Laboratory P. O. Box 1663, MS E505 Los Alamos, New Mexico 87545	

ONSITE

5	U.S. Department of Energy Richland Operations Office	
	R. A. Almquist	A6-55
14	Westinghouse Hanford Company	
	R. B. Baker	L5-05
	D. S. Dutt	L5-60
	E. W. Gerber	L5-62
	J. W. Hales	L5-02
	R. D. Leggett	H0-32
	W. F. Lyon III (3)	L5-02
	D. J. Newland	N1-35
	R. P. Omberg	H0-40
	A. E. Waltar	H0-32
	Central Files	L8-04
	EDMC	H4-22
	Publication Services (3)	L8-07