OAK RIDGE NATIONAL LABORATORY

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ORNL
FOREIGN TRIP REPORT

ORNL/FTR-3640

ORNL/FTR--3640

DE90 012743

DATE: June 18, 1990

SUBJECT: Report of Foreign Travel of Roy H. Cooper, Program Manager, Space and Defense Programs, Metals and Ceramics Division

TO: Alvin W. Trivelpiece

FROM: Roy H. Cooper, Jr.

PURPOSE: To present a paper on fuels and materials used for the U.S. space nuclear power systems and to learn about the status of fuels and materials technology used on Soviet and French space nuclear power systems.

SITES VISITED:

05/15/90	Ministry of Atomic Power Engineering and Industry Obninsk, USSR
05/16/90	Scientific Industrial Association "Lutch" Podolsk, USSR
05/17-20/90	Ministry of Atomic Power Engineering and Industry Obninsk, USSR
05/30/90	Commissariat A L'Energie Atomique Paris, France

ABSTRACT: The principal purpose of this trip was to participate in the Anniversary Specialist Conference on Nuclear Power Engineering in Space hosted by the USSR Ministry of Atomic Power Engineering and Industry. The conference was held in Obninsk, USSR. A secondary purpose of the trip was to meet with the French Commissariat A L'Energie Atomique in Paris regarding the status of their space power program.

DISCLAIMER

COMPREHENSIVE TRIP REPORT

1. INTRODUCTION

The principal purpose of this trip was to participate in the Anniversary Specialist Conference on Nuclear Power Engineering in Space hosted by the USSR Ministry of Atomic Power Engineering and Industry. The conference was held in Obninsk, USSR. Attendance of this conference provided an excellent opportunity for the United States to review the technical status of the Soviet space nuclear power program and to meet the individual engineers and scientists that support this program. From the Soviet perspective, this conference was clearly an opportunity to attempt to "sell" their space power technology to the United States.

The conference was attended by ~450 people of which about 50 were from the United States and 10 were from France. No other countries were represented at the conference. In general, the first day of the conference, May 15, 1990, was a plenary session oriented to overviews of the Soviet, United States, and French space power programs. The second day, May 16, included tours of specific Soviet research centers. The third and fourth days, May 17 and 18, were technical sessions with nine concurrent sessions. In general, my interest was directed toward the high-temperature fuel and structural materials session.

As indicated previously, a secondary purpose of this trip was to receive a briefing from the French regarding the direction and approach of the their space power program. This briefing was held in Paris.

2. DETAILED REPORT OF TRAVELER'S ACTIVITIES

2.1 Conference – Nuclear Power Engineering in Space - May 15, 1990 – Plenary Session

Obninsk is a city of ~100,000 people located 100 km southwest of Moscow. Obninsk is thought to have many similarities with Oak Ridge, as the principal business of the city appeared to be oriented toward scientific and engineering activities. Other members of the U.S. delegation were of the opinion that the city had been closed to both Soviet and foreign visitors until 5 to 10 years ago and had only recently been open to foreign visitors.

Before discussing technical details associated with the conference and the site visits, some time should be invested in discussing the apparent motivation of the Soviets in hosting this meeting. In general, the Soviets made it very clear that they were anxious to show us their "good" technology in hopes that the United States would be interested in purchasing components, hardware, and/or rights to the use of selected technologies. What we heard from our newly acquired Soviet colleagues was that the Soviet administration has set goals for the scientific institutes and ministries for obtaining an increased fraction of their funding from outside and independent sources. Specifically, they expect their budget to decrease in the coming years and they desire access to more foreign currency. In response to these desires, the Soviets were extremely responsive to any expression of interest in a specific technology. The first three Soviet speakers in the first plenary session reinforced this point (N. N. Ponomarve-Stepnoy, First Deputy Director, Kurchatov Institute of Atomic Energy; A. G. Meshkov, Deputy Minister, Atomic Power Engineering and Industrial; and V. Y. Pupko, Institute of Physic and Power Engineering).

Three Soviet talks presented in the second plenary session discussed the Topaz thermionic reactor, nuclear propulsion, and radioisotopic power systems, respectively. A review of these presentations follows.

Topaz Reactor. G. M. Gryaznov of the Science Production Corporation provided the talk on the Topaz program. Gryaznov's talk was highlighted by the fact that the Soviets provided a full-size mock-up of the Topaz reactor in the lobby of the conference hall. Many members of the U.S. delegation photographed this mock-up in detail. Major technical features of the Topaz reactor were (1) it is designed to deliver 7 kW(e) by generating ~152 kW(t) at the beginning of life and 160 kW(t) at the end of life for a net efficiency of ~4.6%; (2) reactor outlet temperature to the radiators is ~408°C; (3) Topaz design activities were initiated in 1976 and proceeded through four major design changes (10 electrically heated mock-ups were tested during this period to confirm a 1000-h lifetime); and (4) at this point the program has succeeded in the successful deployment in space of two thermionic reactors, Comos 1818 and 1867. These reactors successfully demonstrated the reactor system for operational times of 200 and 300 days, respectively, and demonstrated the effectiveness of the alkali metal pump, radiator, and radiation shield as well as confirmed the performance model for the integrated system.

Nuclear Propulsion. This talk (delivered by V. P. Smetannikov from the Research and Design Institute of Power Engineering) discussed the status of gas-cooled reactor systems for both high electrical power generation and thermal propulsion applications. The electrical power systems would utilize a Brayton cycle for power conversion. On the basis of this talk, it would appear that the reactor utilizes a UC fuel, ZrC structure, and He or He/Xe mixed coolant. The propulsion system appears to also use UC fuel but with hydrogen as the coolant. For both applications fuels assemblies have been fabricated and tested in the appropriate coolant as test assemblies in an existing reactor.

Radioisotopic Power. This talk (given by V. A. Checchurov of the All-Union Research Institute of Technical Physics and Automation) implied that there is an increased demand for radioisotopic power systems. To date the Soviets have used Sr-90 fuel for small power levels. They are considering using Pu-238 fueled system coupled to Stirling engines for power levels to 1 kW(e).

In the third plenary session, excellent talks were given by Earl Wahlquist of DOE-HQ on the status of the U.S. space nuclear program and Dick Verga (SDI program) and Jim Turi (DOE-HQ) on the U.S. radioisotopic space power program. These talks are not described in this report.

2.2 Conference – Nuclear Power Engineering in Space - May 16, 1990 – Tour of Scientific Industrial Association "Lutch", Podolsk, USSR

On the morning of May 16, 1990, a group about of 35 people from the French and U.S. delegations were bused to the site of the Scientific Industrial Association located in Podolsk. The short name for this site is "Lutch" which I am told translates to "beam" in English. Podolsk is a town of 100,000 to 200,000 people located about 40 km south of Moscow. The actual site, Lutch, appeared to be a large materials processing and fabrication facility. Although the Soviets declined to give any exact information on the size of the facility or the number of employees, the site appeared to be at least as big EG&G Mound Applied Technologies, Inc., and possibly as big as the Oak Ridge Y-12 Plant.

Our principal hosts for this tour were the Director and Deputy Directors of Lutch (Ivan Ivanovich and Yury Vyacheslavovich, respectively). The site tour was initiated in the Director's office where he gave an overview of Lutch. The Director indicated that Lutch is oriented toward technology development and limited production of successful technologies. In all cases, these technologies are oriented toward nuclear applications. In reviewing my notes on this visit, I found information was provided indicating the following materials have been or are currently being worked on at Lutch: (1) high-temperature structural ceramics and metals systems including W, Mo, and Nb alloys; (2) high-temperature reactor fuels including UO_2, USC, UC, and UC+Zr; (3) electrical insulators for thermionic applications including Al_2O_3, Si_2O_3, and Y_2O_3; (4) zirconium hydride moderator for reactor applications; and (5) beryllium for reactor reflector applications.

The first stop on our tour was to a moderate-sized laboratory set up to display a variety of hardware. A large number of Lutch staff members were there to support subsequent discussions. During this portion of the tour we were shown large single crystals of Al_2O_3 grown in both rectangular and tubular shapes. I would guess that one of the Al_2O_3 single-crystal tubes to have been about 10 in. long by 1 in. diam with a 0.3-in. wall. We were also shown a large number of single-crystal molybdenum and tungsten alloy tubes that are for thermionic emitter use. The reference emitter material at this time appears to be the molybdenum alloy. Both the molybdenum and tungsten tubes are solution alloy hardened to improve the creep strength over that of unalloyed single-crystal material and polycrystalline material. Our hosts also indicated that the single-crystal material had improved compatibility with the UO_2 fuel. There was also some discussion of the ZrH moderate material. It appears Lutch fabricates large shapes having a Zr to H ratio of about 1.85.

Following the more formal presentations at this first stop, we were given the opportunity to talk with the various staff members. I found people working on refractory alloys and was also able to locate people who had worked on the Soviet equivalent of PWC-11 (Nb-1Zr-0.1C). Although the translator help at this point was rather poor, I am of the impression that the Soviets have a significant mechanical property and compatibility data base for this alloy. They have characterized the aging phenomena in the alloy and have characterized the compatibility of a mixed Nb-1Zr/PWC-11 loop in flowing lithium; my contact was Igor Karetnikov.

The next stop on the tour was a mechanical properties testing laboratory. The purpose of this stop was to show us data on the creep properties of the molybdenum and tungsten alloy single crystals. Little or no information was given about the creep test systems in terms of vacuum capability or the method by which strain was measured in the test specimen.

We were also shown an electron-beam (EB) welding laboratory where single-crystal molybdenum and tungsten alloy emitters are welded to the rest of the thermionic fuel element assembly. Our Soviet welding experts claimed that they could weld the single crystal and maintain a single crystal structure in the weld metal. Although they showed us some photomicrographs, the photos seemed inadequate to prove the point. The Soviets were extremely confident about their ability to maintain good ductility in the tungsten and molybdenum weld metal. They indicated this required stringent control of the chemistry of the base metal and a high-purity vacuum environment. In this case, their EB welder was ion pumped. The same welders indicated that they had made niobium to Fe-Ni-Cr alloy joints that had performed well for 30,000 h at 600°C. Their solution to this problem was considered proprietary, and they would provide no information regarding this joint.

The last stop on the tour was to a laboratory where we received a briefing on fuel for a gas-cooled reactor. The Soviets are looking at a gas-cooled reactor for high electrical power needs and propulsion. It remains unclear to me if this design is bimodal or two separate reactor systems. The structural material for the systems appears to be ZrC. They also indicated that fuel assemblies have been tested in a reactor. The hydrogen cooled propulsion system has operated at 3100 K for a total of 4000 s in four runs of about 500 s each. The Brayton cycle fuel system has been operated at 2000 K for 5000 h. It is unclear if this was an uninterrupted run or not.

The wrap-up meeting of the tour of Lutch was led by the Director and Deputy Director of the facility. They made it very clear that they were interested in selling some components to the United States.

2.3 Conference – Nuclear Power Engineering in Space - May 17 & 18, 1990 – Technical Sessions

Rather than discuss the numerous technical papers presented, the remainder of this section will highlight the response to the paper I presented and private technical discussions with Soviet engineers on LiH fabrication and coatings for oxidation protection of niobium alloys.

Technical Paper. On May 17, 1990, I co-chaired the session on High Temperature Fuels and Structural Materials and also presented a paper on fuel, cladding, and structural alloy development for space power reactors. This paper was prepared by Bruce Matthews of Los Alamos National Laboratory, with contributions from Dale Dutt of Westinghouse Hanford Company, Gene Hoffman of DOE-ORO, and me. Because Bruce was not able to make the trip, I presented the paper. The Soviets asked many questions on how we monitored and/or controlled weepage of lithium through the niobium alloy structure of the SP-100 system. They appeared to be familiar with the need to control the oxygen content of the alloy, postweld heat treatments, and control of oxygen level in the test environment. Successful applications of these measures appears to have created some problems for them in the past.

Lithium Hydride. Some interesting capabilities in the fabrication of complex shapes of Li, Zr, and U hydrides were on display at the conference. These materials were shown for radiation shielding applications. A lead engineer for fabricating these materials is K. J. Tkack from the Research and Development Institute of Power Engineering. Dr. Tkack and I discussed the Soviet LiH fabrication technology at some length. The Soviets appear to fabricate their LiH components by a casting process. The resulting material is about 2 to 3% rich in lithium and has a final density of 0.72 to 0.73 g/cm^3. They felt comfortable in casting shapes up to 800 mm long by 1100 mm in diameter. The shapes could be complex configurations, including numerous penetrations. According to Dr. Tkack, the Institute would be very interested in making some LiH components for us; it was unclear if they were interested in selling the casting technology to us.

Oxidation Protection Coatings for Niobium-Based Alloys. During the course of the meeting I met Dr. A. G. Arakelov who has done a great deal of work on refractory alloy/alkali metal compatibility. In our discussion, Dr. Arakelov described a coating the Soviets developed to provide oxidation protection for niobium-based alloys. In particular, the coating has been used for the operation of niobium alloy/alkali metal loop systems in test environments having a high oxygen partial pressure, protection of niobium alloys from atomic oxygen exposure when used in low earth orbit, and coating the niobium-alloy structural skin used in the Soviet space shuttle. The coating is a multilayer plasma-sprayed coating which relies ultimately on a silicon-rich outer layer for the oxygen protection. Dr. Arakelov indicated that the coating can tolerate about a 3% deformation of the substrate without failing. Further, a coated niobium alloy was exposed to a oxygen partial pressure of 10E-2 atm for 6000 h at 1100°C. Oxygen uptake of the base materials was less 100 ppm. Coated niobium alloys have also been exposed to several thousand thermal cycles from –198 to 1600°C, with no delamination or degradation of the coating. Dr. Arakelov indicates that the Institute would be particularly interested in coating some specimens for us to evaluate the process and to sell us rights to the coatings technology. This technology, if it is indeed as effective as described, would be extremely valuable for the SP-100 Nuclear Assembly Test (NAT), as it would allow us to significantly reduce the vacuum vessel and pumping requirements.

2.4 Commissariat A L'Energie Atomique – May 30, 1990 – Paris, France

On May 30, 1990, I met with Frank Carre of the Commissariat A L'Energie Atomique to discuss the status of the French space nuclear power program. The French program has been under way for about 7 to 8 years. During that time the emphasis had been on paper studies oriented primarily toward selecting an optimum reactor approach and to initiate some long lead technology activities. As a result of these studies, the French have selected a gas-cooled reactor using a Brayton cycle power conversion approach. The high-temperature structural alloy selected was Mo-Re alloy having a rhenium content between 7 to 40 wt %.

Apparently French government support for space nuclear power has declined, and the program was canceled early this year. Frank Carre is currently coordinating the orderly close-out of the program. Close-out activities will be completed in June and the space nuclear power program staff will be assigned to other tasks starting in July.

SUMMARY

This trip provided an excellent opportunity to assess the status of the Soviet space nuclear power program and, in my case, the status of the materials technology that supports their program. Relative to the space power program in general, at this moment it would appear the Soviets are ahead of us by virtue of the numerous Romashka and the Topaz systems they have flown. However, their future space power objectives appear no more aggressive than ours, relative to objectives and planned launch dates.

In the area of materials and fuels, it appeared that a large number of people are working on a wide variety of problems. I have the impression that the Soviets have a larger base technology program than the United States; however, the applied work associated with the building hardware and generating engineering data for future systems may be about the same.

I believe the Soviets have at least four technologies that could be of significant interest to us.

1. The coating for protection of niobium-based alloys from oxidation appears to be a well-developed system that could have significant benefit to the SP-100 Project by (a) helping to reduce the cost of the NAT vacuum and pumping system and reducing the risk of contaminated Nb-1Zr alloys structure and (b) reducing the potential degradation of the Nb-1Zr structural alloy in actual flight applications due to exposure to atomic oxygen.

2. I believe the Soviets have acquired a great deal of information on the performance of an alloy that is practically identical to PWC-11. The purchase of this information in the form of a comprehensive technical report could save the United States a significant portion of the cost necessary to confirm the feasibility and develop the preliminary engineering data base for the PWC-11 alloy.

3. The Soviet work with Li, Zr, and U hydrides is very impressive. They appear to be ahead of us in their ability to make complex configurations to near net shapes.

4. Yury Vyacheslavovich, Deputy Director of Lutch, suggested the use of molybdenum- or tungsten-alloy single-crystal tubes for fuel cladding for advanced alkali metal cooled fuel pin reactors. Although this would be a long and costly development program, the concept appears feasible and offers the potential for a significant increase in fuel operating temperature.

With regard to the French space power program, it is disappointing to see this program coming to an end. The French were doing some good work in the area of Mo-Re alloys. Their work was oriented toward obtaining some answers to questions that were identified in the early phase of the SP-100 Project when Mo-13Re was being considered as a candidate structural and fuel-clad material.

Appendix A

ITINERARY

1990	
5/11	Travel to Paris, France
5/12-5/13	Paris, France
5/14	Travel to Obninsk, USSR
5/15-5/27	Obninsk, USSR
5/28	Travel to Paris, France
5/29	Saclay, France
5/30-6/1	Paris, France
6/3	Travel to Oak Ridge, Tennessee

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Appendix B

SIGNIFICANT CONTACTS

Conference Organizer

N. N. Ponomarev-Stepnoi, First Deputy Director, I. V. Kurchatov Institute of Atomic Energy

Conference Hosts

M. F. Troyanov, Director, Institute of Physics and Power Engineering

A. V. Vorobjev, Deputy Head of Division of International Relations, Institute of Physics and Power Engineering

Site Visit to Podolsk - Scientific Industrial Association "Lutch"

F. I. Ivanovich, Director

N. Y. Vyacheslavovich, Deputy Director

L. N. Pernyakov, Head of Department on Technology of Fuel Element Materials

Individual Technical Contacts

K. G. Tkack, Institute of Inorganiz Materials (LiH Radiation Shields)

A. G. Arakelov, Science-Production Cooperation-Energiga (Coatings for Refractory Materials)

Commissariat A L'Energie Atomique

Frank Oliver Carre, Manager, Eux-Atom Program

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Appendix C

LITERATURE ACQUIRED

Conference Information

Final Program, Anniversary Specialist Conference on Nuclear Engineering in Space

Transactions, Anniversary Specialist Conference on Nuclear Engineering in Space (Abstracts of Papers of Soviet Specialists)

Handout Materials Provided by the Soviets on Specific Technologies

Heterogeneous Metals Welding

Gas Phase Indicator in Liquid Metal Flow

Oxide Doping Protective Decorative Coatings

Cabled Thermal Convert with Rectangular Working Section

Non-Contact Electromagnetic Transducer of Time of Flight Flowmeter

Solders for Iron and Nickel-Based Stainless and High Temperature Steels

Oxygen Control Sensors in Liquid Metals

Zone Deformation Technology

Emergency Neutron Dosimeter Alarm

Remote Controlled Sensor for Measuring Neutron Flux Density and Radiation Dose Rate

Module of Solar Thermoelectrical Generator with Thermal Tube Products Made of High Refractory Metal Oxides

High Temperature Flexible Thermocouple

Small and Super-Small Thermocouple

Electromagnetic Low Flow Rate Transducer

Sapphire Monocrystal Material

Heat Pipes and Heat Pipe Based Devices

Small Sized Flow Rate Transducer

Electrochemical Cell for In Sodium Detection

Bimetallic Welding Joints of Steel and Molybdenum

New Highly Effective Materials for Radiation Protection Based on Zirconium and Lithium Hydride

Complete Soviet Papers Obtained at the Conference (In English)

Deformation Analysis of Fueled Emitters From Multicell Electric Power Generating Channels of the Topaz Reactor

Heat and Mass Transfer in a Thermionic Fuel Element

Possibilities of High Temperature Uranium Nitride Vented Fuel Element Development

In-Pile Tests of Gas Fission Product Release From Fuel Elements of a Research Nuclear Plant

Deformation Behavior Modelling of the High Temperature Fueled Emitters

Uranium Dioxide Fuel of the Single Cell TFE Process After Reactor Analysis

Modelling of TFE Gas Swelling Based on Diffusion Approach for Their Lifetime Prediction

Investigation of Deposition of Different Iodine Forms on Structural Materials

Problems of the TFE Development

Some Characteristics of Fuel Compositions: UO_2, U(Zr,Nb,Ta)C, and UCS Fuel For TFE

Investigation of Uranium Dioxide of Prestoichiometric Compositions

Electrogenerating Channel for High Voltage Thermionic Reactor

The Main Characteristics of Materials Used In Fuel Assemblies of High Temperature Gas Reactors

Perspective Structural Materials for Nuclear Power Propulsion Systems of Space Complexes

Structural Perspective of Engineering Materials Based on Single Crystal Refractory Metals

Refractory Metals for TFE of NEP

Calculation of Irradiation Characteristics of U_2O

Post Reactor Studies of Helium Migration Process in Beryllium

Slow Neutron Investigation of Potassium Oxygen Melt

The Solubility of Oxygen in Sodium Potassium Coolant in Steel Loop

Interaction of Transition and Alkali Metals: Nature and Mechanism

Appendix D

DISTRIBUTION

1. John J. Easton, Jr., Assistant Secretary for International Affairs and Energy Emergencies, DOE, Washington
2. Earl J. Wahlquist, Defense Energy Projects, DOE, Washington
3. Stephen J. Lanes, Deputy Assistant Secretary, Defense Energy Projects, DOE, Washington
4. Edward J. McCallum, Director, Division of Safeguards and Security, DOE, Washington
5. A. Bryan Siebert, Jr., Director, Office of Classification and Technology Policy, DOE, Washington
6. James A. Reafsnyder, Deputy Assistant Manager, Energy Research and Development, DOE-ORO

7-8. D. J. Cook, Director, Safeguards and Security Division, DOE-ORO

9-10. Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831

11. W. J. Barnett, DOE-OSA, NE-53, Washington
12. C. C. Bigelow, DOE-HQ, NE-462, Washington
13. W. P. Carroll, DOE-HQ, NE-52, Washington
14. E. E. Hoffman, DOE-ORO, 4500N, MS 6269
15. R. G. Lange, DOE-HQ, NE-52, Washington
16. E. F. Mastal, DOE-HQ, NE-53, Washington
17. J. A. Turi, DOE-OSA, NE-53, Washington
18. J. W. Warren, DOE-HQ, NE-52, Washington
19. G. L. Bennett, Manager, Advanced Space Power Systems, National Aeronautics and Space Administration, NASA Headquarters, Code RP, Washington, DC 20546
20. Alexander Borshchevsky, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Mail Code 122-108, Pasadena, CA 91109
21. D. Byers, NASA Lewis Research Center, 21000 Brookpark Road, Cleveland, OH 44135
22. Dale S. Dutt, Westinghouse Hanford Company, P.O. Box 1970, Mail Stop W/C/91, Richland, WA 99352
23. T. Grobstein, NASA Lewis Research Center, 21000 Brookpark Road, Cleveland, OH 44135
24. J. A. Hassberger, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94550
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26. R. Bruce Matthews, Associate Group Leader, MST1, MS505, Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, NM 87545
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28. Michael J. Schuller, Department of the Air Force, Space Applications Branch, Air Force Weapons Laboratory/AWYS, Kirtland Air Force Base, NM 87117-6008
29. J. Sovie, NASA Lewis Research Center, 21000 Brookpark Road, Cleveland, OH 44135

30. R. H. Titran, NASA Lewis Research Center, 21000 Brookpark Road, Cleveland, OH 44135
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60. J. O. Stiegler
61. V. J. Tennery
62. A. W. Trivelpiece
63. F. W. Wiffen
64. G. L. Yoder
65. A. Zucker
66–67. Laboratory Records Department
68. Laboratory Records Department–RC
69. Laboratory Protection Division
70. ORNL Patent Section
71. ORNL Public Relations Office
72. M&C Records Office

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ERA ☐	RIP ☐	DOE ☐	SPF ☐	2.
EPA ☐	ATF ☐	SNI ☐	LIM ☐	3.
WDA ☐	CRF ☐	HGF ☐	CTE ☐	4.
CRA ☐	WDF ☐	☐	ACD ☐	5.
				6.

AUGMENTATION:

DESCRIPTORS	FLAGS
Nuclear Power	
ENGINEERING IN SPACE	

FORM TI-70 (7-87)

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Topaz Reactor. G. M. Gryaznov of the Science Production Corporation provided the talk on the Topaz program. Gryaznov's talk was highlighted by the fact that the Soviets provided a full-size mock-up of the Topaz reactor in the lobby of the conference hall. Many members of the U.S. delegation photographed this mock-up in detail. Major technical features of the Topaz reactor were (1) it is designed to deliver 7 kW(e) by generating ~152 kW(t) at the beginning of life and 160 kW(t) at the end of life for a net efficiency of ~4.6%; (2) reactor outlet temperature to the radiators is ~408°C; (3) Topaz design activities were initiated in 1976 and proceeded through four major design changes (10 electrically heated mock-ups were tested during this period to confirm a 1000-h lifetime); and (4) at this point the program has succeeded in the successful deployment in space of two thermionic reactors, Comos 1818 and 1867. These reactors successfully demonstrated the reactor system for operational times of 200 and 300 days, respectively, and demonstrated the effectiveness of the alkali metal pump, radiator, and radiation shield as well as confirmed the performance model for the integrated system.

Nuclear Propulsion. This talk (delivered by V. P. Smetannikov from the Research and Design Institute of Power Engineering) discussed the status of gas-cooled reactor systems for both high electrical power generation and thermal propulsion applications. The electrical power systems would utilize a Brayton cycle for power conversion. On the basis of this talk, it would appear that the reactor utilizes a UC fuel, ZrC structure, and He or He/Xe mixed coolant. The propulsion system appears to also use UC fuel but with hydrogen as the coolant. For both applications fuels assemblies have been fabricated and tested in the appropriate coolant as test assemblies in an existing reactor.

Radioisotopic Power. This talk (given by V. A. Checchurov of the All-Union Research Institute of Technical Physics and Automation) implied that there is an increased demand for radioisotopic power systems. To date the Soviets have used Sr-90 fuel for small power levels. They are considering using Pu-238 fueled system coupled to Stirling engines for power levels to 1 kW(e).

In the third plenary session, excellent talks were given by Earl Wahlquist of DOE-HQ on the status of the U.S. space nuclear program and Dick Verga (SDI program) and Jim Turi (DOE-HQ) on the U.S. radioisotopic space power program. These talks are not described in this report.

2.2 Conference – Nuclear Power Engineering in Space - May 16, 1990 – Tour of Scientific Industrial Association "Lutch", Podolsk, USSR

On the morning of May 16, 1990, a group about of 35 people from the French and U.S. delegations were bused to the site of the Scientific Industrial Association located in Podolsk. The short name for this site is "Lutch" which I am told translates to "beam" in English. Podolsk is a town of 100,000 to 200,000 people located about 40 km south of Moscow. The actual site, Lutch, appeared to be a large materials processing and fabrication facility. Although the Soviets declined to give any exact information on the size of the facility or the number of employees, the site appeared to be at least as big EG&G Mound Applied Technologies, Inc., and possibly as big as the Oak Ridge Y-12 Plant.

Our principal hosts for this tour were the Director and Deputy Directors of Lutch (Ivan Ivanovich and Yury Vyacheslavovich, respectively). The site tour was initiated in the Director's office where he gave an overview of Lutch. The Director indicated that Lutch is oriented toward technology development and limited production of successful technologies. In all cases, these technologies are oriented toward nuclear applications. In reviewing my notes on this visit, I found information was provided indicating the following materials have been or are currently being worked on at Lutch: (1) high-temperature structural ceramics and metals systems including W, Mo, and Nb alloys; (2) high-temperature reactor fuels including UO_2, USC, UC, and UC+Zr; (3) electrical insulators for thermionic applications including Al_2O_3, Si_2O_3, and Y_2O_3; (4) zirconium hydride moderator for reactor applications; and (5) beryllium for reactor reflector applications.

The first stop on our tour was to a moderate-sized laboratory set up to display a variety of hardware. A large number of Lutch staff members were there to support subsequent discussions. During this portion of the tour we were shown large single crystals of Al_2O_3 grown in both rectangular and tubular shapes. I would guess that one of the Al_2O_3 single-crystal tubes to have been about 10 in. long by 1 in. diam with a 0.3-in. wall. We were also shown a large number of single-crystal molybdenum and tungsten alloy tubes that are for thermionic emitter use. The reference emitter material at this time appears to be the molybdenum alloy. Both the molybdenum and tungsten tubes are solution alloy hardened to improve the creep strength over that of unalloyed single-crystal material and polycrystalline material. Our hosts also indicated that the single-crystal material had improved compatibility with the UO_2 fuel. There was also some discussion of the ZrH moderate material. It appears Lutch fabricates large shapes having a Zr to H ratio of about 1.85.

Following the more formal presentations at this first stop, we were given the opportunity to talk with the various staff members. I found people working on refractory alloys and was also able to locate people who had worked on the Soviet equivalent of PWC-11 (Nb-1Zr-0.1C). Although the translator help at this point was rather poor, I am of the impression that the Soviets have a significant mechanical property and compatibility data base for this alloy. They have characterized the aging phenomena in the alloy and have characterized the compatibility of a mixed Nb-1Zr/PWC-11 loop in flowing lithium; my contact was Igor Karetnikov.

The next stop on the tour was a mechanical properties testing laboratory. The purpose of this stop was to show us data on the creep properties of the molybdenum and tungsten alloy single crystals. Little or no information was given about the creep test systems in terms of vacuum capability or the method by which strain was measured in the test specimen.

We were also shown an electron-beam (EB) welding laboratory where single-crystal molybdenum and tungsten alloy emitters are welded to the rest of the thermionic fuel element assembly. Our Soviet welding experts claimed that they could weld the single crystal and maintain a single crystal structure in the weld metal. Although they showed us some photomicrographs, the photos seemed inadequate to prove the point. The Soviets were extremely confident about their ability to maintain good ductility in the tungsten and molybdenum weld metal. They indicated this required stringent control of the chemistry of the base metal and a high-purity vacuum environment. In this case, their EB welder was ion pumped. The same welders indicated that they had made niobium to Fe-Ni-Cr alloy joints that had performed well for 30,000 h at 600°C. Their solution to this problem was considered proprietary, and they would provide no information regarding this joint.

The last stop on the tour was to a laboratory where we received a briefing on fuel for a gas-cooled reactor. The Soviets are looking at a gas-cooled reactor for high electrical power needs and propulsion. It remains unclear to me if this design is bimodal or two separate reactor systems. The structural material for the systems appears to be ZrC. They also indicated that fuel assemblies have been tested in a reactor. The hydrogen cooled propulsion system has operated at 3100 K for a total of 4000 s in four runs of about 500 s each. The Brayton cycle fuel system has been operated at 2000 K for 5000 h. It is unclear if this was an uninterrupted run or not.

The wrap-up meeting of the tour of Lutch was led by the Director and Deputy Director of the facility. They made it very clear that they were interested in selling some components to the United States.

2.3 Conference – Nuclear Power Engineering in Space - May 17 & 18, 1990 – Technical Sessions

Rather than discuss the numerous technical papers presented, the remainder of this section will highlight the response to the paper I presented and private technical discussions with Soviet engineers on LiH fabrication and coatings for oxidation protection of niobium alloys.

Technical Paper. On May 17, 1990, I co-chaired the session on High Temperature Fuels and Structural Materials and also presented a paper on fuel, cladding, and structural alloy development for space power reactors. This paper was prepared by Bruce Matthews of Los Alamos National Laboratory, with contributions from Dale Dutt of Westinghouse Hanford Company, Gene Hoffman of DOE-ORO, and me. Because Bruce was not able to make the trip, I presented the paper. The Soviets asked many questions on how we monitored and/or controlled weepage of lithium through the niobium alloy structure of the SP-100 system. They appeared to be familiar with the need to control the oxygen content of the alloy, postweld heat treatments, and control of oxygen level in the test environment. Successful applications of these measures appears to have created some problems for them in the past.

Lithium Hydride. Some interesting capabilities in the fabrication of complex shapes of Li, Zr, and U hydrides were on display at the conference. These materials were shown for radiation shielding applications. A lead engineer for fabricating these materials is K. J. Tkack from the Research and Development Institute of Power Engineering. Dr. Tkack and I discussed the Soviet LiH fabrication technology at some length. The Soviets appear to fabricate their LiH components by a casting process. The resulting material is about 2 to 3% rich in lithium and has a final density of 0.72 to 0.73 g/cm^3. They felt comfortable in casting shapes up to 800 mm long by 1100 mm in diameter. The shapes could be complex configurations, including numerous penetrations. According to Dr. Tkack, the Institute would be very interested in making some LiH components for us; it was unclear if they were interested in selling the casting technology to us.

Oxidation Protection Coatings for Niobium-Based Alloys. During the course of the meeting I met Dr. A. G. Arakelov who has done a great deal of work on refractory alloy/alkali metal compatibility. In our discussion, Dr. Arakelov described a coating the Soviets developed to provide oxidation protection for niobium-based alloys. In particular, the coating has been used for the operation of niobium alloy/alkali metal loop systems in test environments having a high oxygen partial pressure, protection of niobium alloys from atomic oxygen exposure when used in low earth orbit, and coating the niobium-alloy structural skin used in the Soviet space shuttle. The coating is a multilayer plasma-sprayed coating which relies ultimately on a silicon-rich outer layer for the oxygen protection. Dr. Arakelov indicated that the coating can tolerate about a 3% deformation of the substrate without failing. Further, a coated niobium alloy was exposed to a oxygen partial pressure of 10E-2 atm for 6000 h at 1100°C. Oxygen uptake of the base materials was less 100 ppm. Coated niobium alloys have also been exposed to several thousand thermal cycles from −198 to 1600°C, with no delamination or degradation of the coating. Dr. Arakelov indicates that the Institute would be particularly interested in coating some specimens for us to evaluate the process and to sell us rights to the coatings technology. This technology, if it is indeed as effective as described, would be extremely valuable for the SP-100 Nuclear Assembly Test (NAT), as it would allow us to significantly reduce the vacuum vessel and pumping requirements.

2.4 Commissariat A L'Energie Atomique – May 30, 1990 – Paris, France

On May 30, 1990, I met with Frank Carre of the Commissariat A L'Energie Atomique to discuss the status of the French space nuclear power program. The French program has been under way for about 7 to 8 years. During that time the emphasis had been on paper studies oriented primarily toward selecting an optimum reactor approach and to initiate some long lead technology activities. As a result of these studies, the French have selected a gas-cooled reactor using a Brayton cycle power conversion approach. The high-temperature structural alloy selected was Mo-Re alloy having a rhenium content between 7 to 40 wt %.

Apparently French government support for space nuclear power has declined, and the program was canceled early this year. Frank Carre is currently coordinating the orderly close-out of the program. Close-out activities will be completed in June and the space nuclear power program staff will be assigned to other tasks starting in July.

SUMMARY

This trip provided an excellent opportunity to assess the status of the Soviet space nuclear power program and, in my case, the status of the materials technology that supports their program. Relative to the space power program in general, at this moment it would appear the Soviets are ahead of us by virtue of the numerous Romashka and the Topaz systems they have flown. However, their future space power objectives appear no more aggressive than ours, relative to objectives and planned launch dates.

In the area of materials and fuels, it appeared that a large number of people are working on a wide variety of problems. I have the impression that the Soviets have a larger base technology program than the United States; however, the applied work associated with the building hardware and generating engineering data for future systems may be about the same.

I believe the Soviets have at least four technologies that could be of significant interest to us.

1. The coating for protection of niobium-based alloys from oxidation appears to be a well-developed system that could have significant benefit to the SP-100 Project by (a) helping to reduce the cost of the NAT vacuum and pumping system and reducing the risk of contaminated Nb-1Zr alloys structure and (b) reducing the potential degradation of the Nb-1Zr structural alloy in actual flight applications due to exposure to atomic oxygen.

2. I believe the Soviets have acquired a great deal of information on the performance of an alloy that is practically identical to PWC-11. The purchase of this information in the form of a comprehensive technical report could save the United States a significant portion of the cost necessary to confirm the feasibility and develop the preliminary engineering data base for the PWC-11 alloy.

3. The Soviet work with Li, Zr, and U hydrides is very impressive. They appear to be ahead of us in their ability to make complex configurations to near net shapes.

4. Yury Vyacheslavovich, Deputy Director of Lutch, suggested the use of molybdenum- or tungsten-alloy single-crystal tubes for fuel cladding for advanced alkali metal cooled fuel pin reactors. Although this would be a long and costly development program, the concept appears feasible and offers the potential for a significant increase in fuel operating temperature.

With regard to the French space power program, it is disappointing to see this program coming to an end. The French were doing some good work in the area of Mo-Re alloys. Their work was oriented toward obtaining some answers to questions that were identified in the early phase of the SP-100 Project when Mo-13Re was being considered as a candidate structural and fuel-clad material.

Appendix A

ITINERARY

1990	
5/11	Travel to Paris, France
5/12-5/13	Paris, France
5/14	Travel to Obninsk, USSR
5/15-5/27	Obninsk, USSR
5/28	Travel to Paris, France
5/29	Saclay, France
5/30-6/1	Paris, France
6/3	Travel to Oak Ridge, Tennessee

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Appendix B

SIGNIFICANT CONTACTS

Conference Organizer

N. N. Ponomarev-Stepnoi, First Deputy Director, I. V. Kurchatov Institute of Atomic Energy

Conference Hosts

M. F. Troyanov, Director, Institute of Physics and Power Engineering

A. V. Vorobjev, Deputy Head of Division of International Relations, Institute of Physics and Power Engineering

Site Visit to Podolsk - Scientific Industrial Association "Lutch"

F. I. Ivanovich, Director

N. Y. Vyacheslavovich, Deputy Director

L. N. Pernyakov, Head of Department on Technology of Fuel Element Materials

Individual Technical Contacts

K. G. Tkack, Institute of Inorganiz Materials (LiH Radiation Shields)

A. G. Arakelov, Science-Production Cooperation-Energiga (Coatings for Refractory Materials)

Commissariat A L'Energie Atomique

Frank Oliver Carre, Manager, Eux-Atom Program

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Appendix C

LITERATURE ACQUIRED

Conference Information

Final Program, Anniversary Specialist Conference on Nuclear Engineering in Space

Transactions, Anniversary Specialist Conference on Nuclear Engineering in Space (Abstracts of Papers of Soviet Specialists)

Handout Materials Provided by the Soviets on Specific Technologies

Heterogeneous Metals Welding

Gas Phase Indicator in Liquid Metal Flow

Oxide Doping Protective Decorative Coatings

Cabled Thermal Convert with Rectangular Working Section

Non-Contact Electromagnetic Transducer of Time of Flight Flowmeter

Solders for Iron and Nickel-Based Stainless and High Temperature Steels

Oxygen Control Sensors in Liquid Metals

Zone Deformation Technology

Emergency Neutron Dosimeter Alarm

Remote Controlled Sensor for Measuring Neutron Flux Density and Radiation Dose Rate

Module of Solar Thermoelectrical Generator with Thermal Tube Products Made of High Refractory Metal Oxides

High Temperature Flexible Thermocouple

Small and Super-Small Thermocouple

Electromagnetic Low Flow Rate Transducer

Sapphire Monocrystal Material

Heat Pipes and Heat Pipe Based Devices

Small Sized Flow Rate Transducer

Electrochemical Cell for In Sodium Detection

Bimetallic Welding Joints of Steel and Molybdenum

New Highly Effective Materials for Radiation Protection Based on Zirconium and Lithium Hydride

Complete Soviet Papers Obtained at the Conference (In English)

Deformation Analysis of Fueled Emitters From Multicell Electric Power Generating Channels of the Topaz Reactor

Heat and Mass Transfer in a Thermionic Fuel Element

Possibilities of High Temperature Uranium Nitride Vented Fuel Element Development

In-Pile Tests of Gas Fission Product Release From Fuel Elements of a Research Nuclear Plant

Deformation Behavior Modelling of the High Temperature Fueled Emitters

Uranium Dioxide Fuel of the Single Cell TFE Process After Reactor Analysis

Modelling of TFE Gas Swelling Based on Diffusion Approach for Their Lifetime Prediction

Investigation of Deposition of Different Iodine Forms on Structural Materials

Problems of the TFE Development

Some Characteristics of Fuel Compositions: UO_2, U(Zr,Nb,Ta)C, and UCS Fuel For TFE

Investigation of Uranium Dioxide of Prestoichiometric Compositions

Electrogenerating Channel for High Voltage Thermionic Reactor

The Main Characteristics of Materials Used In Fuel Assemblies of High Temperature Gas Reactors

Perspective Structural Materials for Nuclear Power Propulsion Systems of Space Complexes

Structural Perspective of Engineering Materials Based on Single Crystal Refractory Metals

Refractory Metals for TFE of NEP

Calculation of Irradiation Characteristics of U_2O

Post Reactor Studies of Helium Migration Process in Beryllium

Slow Neutron Investigation of Potassium Oxygen Melt

The Solubility of Oxygen in Sodium Potassium Coolant in Steel Loop

Interaction of Transition and Alkali Metals: Nature and Mechanism

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Appendix D

DISTRIBUTION

1. John J. Easton, Jr., Assistant Secretary for International Affairs and Energy Emergencies, DOE, Washington
2. Earl J. Wahlquist, Defense Energy Projects, DOE, Washington
3. Stephen J. Lanes, Deputy Assistant Secretary, Defense Energy Projects, DOE, Washington
4. Edward J. McCallum, Director, Division of Safeguards and Security, DOE, Washington
5. A. Bryan Siebert, Jr., Director, Office of Classification and Technology Policy, DOE, Washington
6. James A. Reafsnyder, Deputy Assistant Manager, Energy Research and Development, DOE-ORO

7-8. D. J. Cook, Director, Safeguards and Security Division, DOE-ORO

9-10. Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831

11. W. J. Barnett, DOE-OSA, NE-53, Washington
12. C. C. Bigelow, DOE-HQ, NE-462, Washington
13. W. P. Carroll, DOE-HQ, NE-52, Washington
14. E. E. Hoffman, DOE-ORO, 4500N, MS 6269
15. R. G. Lange, DOE-HQ, NE-52, Washington
16. E. F. Mastal, DOE-HQ, NE-53, Washington
17. J. A. Turi, DOE-OSA, NE-53, Washington
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32. B. R. Appleton
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63. F. W. Wiffen
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65. A. Zucker
66–67. Laboratory Records Department
68. Laboratory Records Department–RC
69. Laboratory Protection Division
70. ORNL Patent Section
71. ORNL Public Relations Office
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