NNSA’s Russian Reactor Conversion Program: Historical Overview, Major Accomplishments, Current Status

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Brief Historical Overview

- In the “Atoms for Peace” Programs from the 1950s:
  - The U.S. initially supplied research reactors with <20% enriched uranium fuels.
  - The Soviet Union initially supplied research reactors with 10% enriched uranium fuels.

- In the 1960s power upgrades in many reactors required increased U-235 element loadings to reduce fuel consumption and contain fuel fabrication costs.
  - HEU (93%) became the standard enrichment in U.S. supplied research reactors
  - HEU (80-90%) became the standard enrichment in Soviet supplied research reactors

- Concerns about HEU in multiple countries led to:
  - US DOE to establish the Reduced Enrichment for Research and Test Reactors (RERTR) in 1978 to convert US-supplied reactors to low enriched uranium (less than 20% in U-235)
  - Russia’s Ministry of Atomic Energy also initiated a program around 1978 to convert foreign research reactors from 80-90% enriched uranium to 36% enriched uranium.
  - After 1989, Russia exported only fuels containing 36% enriched uranium to Russian-built research reactors.
Brief Historical Background

- Initial formal contact between RERTR and Russian institutes to discuss potential collaboration on research reactor conversions took place at NIKIET facilities in Moscow in early 1993.
  - An initial collaboration between ANL and NIKIET was established on conversion studies and fuel development (led by VNIINM - Bochvar Institute).

- US-Russia collaboration was significantly expanded when GTRI was created in 2004.
  - Agreement for the return of Russian-origin spent fuel to Russia (RRRFR)
  - LEU fuel development and qualification in Russia to allow conversion of foreign Russian-supplied reactors
    - Uranium dioxide fuels, with densities <3 g/cc, square and hexagonal assemblies
  - Development of advanced high-density fuels (U-Mo dispersion) expanded
  - Qualification of uranium dioxide fuel, 8-tube hexagonal (WWR-K reactor)
  - Collaboration on the conversion of Russian-supplied foreign reactors and return of HEU (fresh and spent) back to Russia
Significant Accomplishments:
Russian-supplied research reactors in third countries

- Conversion to LEU of first set of Russian-supplied reactors in third countries
  - Strong collaboration with Russian Institutes and Government organizations, including the supply of the LEU fuel as well as the return of the HEU spent fuel to Russia
  - Russian institutes developed two types of LEU UO$_2$ dispersion fuel that enabled the conversion of multiple reactors:
    - VR-1, LWR-15 in the Czech Republic
    - IRT-1 and its Critical Assembly in Libya
    - IRT-200 in Bulgaria
    - BRR in Hungary
    - WWR-SM in Uzbekistan
    - DRR in Vietnam (initial partial conversion followed by a full conversion)
  - WWR-K Critical Assembly in Kazakhstan
  - MARIA Reactor in Poland (using US-supplied fuel fabricated in France)
  - Strong collaboration with Russian Institutes for the development of UMo higher density fuel; can support further reactor conversions (primarily, Russian domestic)
Russian Research Reactor Fuel Assembly Geometries

Fuel assemblies in research reactors (cross-sectional view)
# Civilian Russian Research Reactors

<table>
<thead>
<tr>
<th>Reactor</th>
<th>Institute</th>
<th>Location</th>
<th>Power (MW)</th>
<th>Fuel Type</th>
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<tr>
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<td>IVV-2M</td>
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<td>VVR-M5 (UO₂ – Al), Al clad</td>
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<td>NRC Kurchatov Institute</td>
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### Civilian Russian Research Reactors (cont’d)

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<tr>
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<th>Institute</th>
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- Additional HEU fuel research reactors and critical assemblies in Russia – characterization required to identify fuels and conversion feasibility

J. Matos, ANL, in NAS/RAS Research Reactor Committee Briefing, November 29, 2010
V. Ivanov, RAS, in NAS/RAS Research Reactor Committee Briefing, November 29, 2010
Russian Fuel Assembly Geometries (cont’d)

IRT-3M (90%) used in IR-8, IRT, and IRT-T; 36% used in WWR-SM

IRT-2M (90%)

WWR-M5 (90%) used in WWR-M

C-36 (36%) used in OR

IVV-2M (90%)

MR (90%) used in MIR-M1

WWR-K and WWR-TS (36%)

J. Matos, ANL, in NAS / RAS Research Reactor Committee Briefing, November 29, 2010
US-Russia Collaboration in LEU Fuel Development

- Goal of the collaboration under the RERTR/GTRI/MMM program is to develop and qualify high-density LEU fuels needed to convert Russian-designed research reactors
  - Cost sharing between NNSA and Rosatom
    - Russian funding concentrated on development of fabrication technology and equipment, including QC
    - U.S. funding concentrated on basic fuel element development and qualification of fuel elements and fuel assemblies (irradiation and PIE)
  - Share program expertise on fuel behavior and fuel testing

- Preliminary generic feasibility assessments were conducted to identify required uranium loadings in fuel elements
  - Need for densities above the existing qualified uranium dioxide LEU fuels (<3 g/cc) were identified for many domestic Russian reactors
Program initiated to develop and qualify high-density fuels based on U-Mo dispersed in Al and solid (monolithic) U-Mo.

Scope included development and qualification of both tube-type (existing design) and pin-type (new design) fuel elements and assemblies:
- Density anticipated in tube-type fuel elements (5.4 gU/cm³)
- Pin-type fuel elements offer the possibility of being a “universal” fuel element useable in many different fuel assemblies.

Basic strategy and scope for U-Mo fuel development and qualification agreed upon in December 2003.
LEU Fuel Development Implementation

- Implementation of the program is through a collaboration between ANL and VNIINM (Bochvar Institute)
  - VNIINM involved other Russian organizations, among them NIKIET (reactor designer), TVEL (fuel supply corporation), NCCP (Novosibirsk fuel fabrication plant)
  - Focus was on the development and qualification of IRT-type U-Mo LEU fuel assemblies
  - Targeted reactor was the WWR-SM reactor in Tashkent, Uzbekistan (Russia had not committed yet to conversion of domestic reactors)
    - WWR-SM is a 10 (11) MW pool type reactor that was using IRT-type HEU (36% enriched) fuel
  - Other reactors that could use the IRT fuel:
    - Russia: IRT-T, IR-8, IRT-MEPhI
    - North Korea: IRT-DPRK
    - Czech Republic: LWR-15
  - Same fuel type (U-Mo in Al, ~5.4 gU/cc) estimated to be useful for conversion of the MIR reactor (and critical assembly), but in MR geometry
  - Both tube and pin-type U-Mo dispersion in Al were included
Monolithic U-Mo LEU fuel development

- Collaboration with VNIINM included the development and irradiation testing of monolithic U-Mo mini-pins (short-length pins)
- These initial monolithic mini-pins were expected to lead to a fuel type that could be used needed for conversion of WWR-M reactor in Saint Petersburg
  - Preliminary studies had determined that U-Mo dispersion fuel would not permit the conversion of the WWR-M reactor
  - The same monolithic fuel type was expected to be of use in the conversion of the IVV-2M reactor in Zarechny, although no studies had been conducted

Development and irradiation testing was performed for:

- Reduced size tubular elements and pins with U-Mo dispersion fuel in Al
- Full size tubular elements
- Full size pin-type dispersion elements
- Reduced size monolithic pins
- Testing of fuel particle coatings and use of Si in matrix was also tested in mini-elements
IRT-type Fuel Assembly with U-Mo Dispersion Pins

Arrangement of Fuel Elements in FA

Cross-section of FA

Pin-type fuel element
LEU Fuel Development - Accomplishments

- Irradiation testing carried out in 3 research reactors: WWR-M, IVV-2M and MIR
  - Irradiation of U-Mo dispersion pins initiated in WWR-M was later moved to MIR because of faster burnup
- US-Russia collaborated in modeling and analysis of fuel meat behavior under irradiation
  - Addition of Si to control swelling was considered unnecessary because of the power densities and heat fluxes at which fuel will operate
- After multiple irradiations and PIE, full size prototype assemblies were irradiated in MIR:
  - 2 full size tube-type assemblies and 2 full size pin-type assemblies
- Leakages were observed before 60% BU was reached
  - Extensive PIE was performed and it was concluded that failures of the tube-type assemblies was caused by manufacturing problems (lack of powder uniformity, etc)
- Final conclusion form fuel development phase (2011) was
  - Fuel performance was acceptable
  - Tube-type assemblies were preferred: more extensive experience and maintenance of cooling geometry
  - Final qualification of the IRT-type U-Mo dispersion fuel was recommended
Other Fuel Development/Qualification Accomplishments

Russian-Supplied reactors in Third Countries

- Conversion of reactors in Kazakhstan
  - WWR-K and its critical assembly at INP, Almaty
    - $\text{UO}_2$ dispersion fuel. 8-tube hexagonal assembly
    - ~2-year Irradiation testing started in March 2011 – qualification in 2013
    - Critical Assembly converted in 2012; Reactor planned for 2016
    - Fuel could be used for WWR-TS reactor in Russia
  - IGR and IVG-1 reactor at IAE, Kurchatov City
    - Fuel qualification under way. Unique fuel design.
    - Samples fabricated in Russia

- Conversion of the MARIA reactor in Poland
  - Irradiation testing of LEU fuel supplied by Areva-CERCA was completed in 2012
  - Conversion to LEU fuel took place in August 2012
  - In collaboration with Russia, Institute is qualifying higher density $\text{UO}_2$ ($\sim3.6 \text{ g/cc}$) with samples supplied by TVEL
Reactor Conversion: Russian Domestic Reactors

- Rosatom and NNSA reached an agreement to conduct feasibility studies for the conversion of 6 research reactors (identified by Rosatom in 2008)
  - OR, IR-8, ARGUS at National Research Center-Kurchatov Institute, Moscow
  - IRT-MEPHI reactor at the National Research University MEPHI, Moscow
  - MIR.M1 reactor at the Research Institute of Atomic Reactors, Dimitrovgrad
  - IRT-T reactor at Tomsk Polytechnic Institute, Tomsk
- Implementing Arrangement to initiate the feasibility studies for the six research reactors signed by Rosatom Director Kiriyenko and DOE Deputy Secretary Poneman on December 2010
  - Scopes of work had been previously agreed and institutes started the studies shortly thereafter
- A working group was established to monitor progress on these studies
- Russia did not decide up front whether to convert all 6 domestic reactors
  - A decision to convert the research reactors will be partially based on the outcome of the feasibility studies on a case by case basis
U.S. – Russia Cooperation 2010-2014: Growing Political Consensus

2012 Seoul Nuclear Security Summit Communique
“We encourage States to take measures to minimize the use of HEU, including through the conversion of reactors from highly enriched to low enriched uranium (LEU) fuel, where technically and economically feasible, taking into account the need for assured supplies of medical isotopes, and encourage States in a position to do so, by the end of 2013, to announce voluntary specific actions intended to minimize the use of HEU. We also encourage States to promote the use of LEU fuels and targets in commercial applications such as isotope production, and in this regard, welcome relevant international cooperation on high-density LEU fuel to support the conversion of research and test reactors.”

June 2012 Poneman – Kiriyenko Joint Statement on Reactor Conversion
“The Russian side informed the U.S. side that according to existing plans the conversion of one or two research reactors is expected to be carried out, as feasible, in 2014…..the U.S. side will continue to make efforts to convert its remaining research reactors as promptly as possible.”

September 2012 Chu – Kiriyenko Joint Statement at the IAEA GC
Highlights June 2012 Joint Statement “in which Russia indicated its intent to convert up to two research reactors from HEU to LEU by 2014 and the United States committed to continue working to convert its HEU reactors to LEU fuel.”

J. Chamberlin, Russia – United States Research Reactor Conversion Cooperation, RERTR-2012
Reactor Conversion: Accomplishments

**ARGUS** Reactor, NRC-KI
- 20 KW Homogeneous Solution Reactor
- Feasibility Study was successfully completed: conversion to LEU fuel was feasible (conversion allowed the reactor to maintain its intended use without significant impact, although power level was reduced)
- Economic impact study was performed to assess modifications necessary to perform the conversion, as well as equipment and processes needed to prepare the new solution.
- Decision to convert was taken by NRC-Kurchatov Institute in ~May 2012
- The scope and schedule of conversion activities was developed and work started in summer 2012
- Conversion was accomplished by downblending the solution to less than 20%
- Conversion milestone was reached in July 2014:
  - Measurements of the LEU solution were performed; reactor was taken critical and key neutronics parameters were measured
  - Regulatory authorization for these activities
- Activities have continued to complete the characterization of the reactor with the LEU solution and to operate at power (completion expected in December 2015)
  - License renewal activities in process at the same time
Reactor Conversion: Accomplishments (cont’d)

**OR Reactor, NRC-KI**
- 300 KW Reactor, rod-type HEU (35% enriched) fuel
- Feasibility Study was successfully completed for IRT-4M fuel (square assembly): conversion was feasible (conversion allowed the reactor to maintain its intended use without significant impact)
- Economic impact study was performed to assess modifications necessary to perform the conversion
  - NRC-KI decided against using this fuel in the conversion, because of the need to replace the reactor grid, among other reasons – change in geometry was not acceptable
- Studies to convert with rod-type LEU fuel were pursued. UO$_2$ dispersion with moderate densities would make the conversion feasible
  - Extensive experience with UO$_2$ dispersion fuels with higher densities
  - Fuel not commercially available, but experience for similar geometries makes fabrication likely
  - Qualification program developed (very low BU) that involved moderate irradiation testing followed by insertion of lead test assemblies in OR
  - Gradual conversion planned for simplification of licensing procedures
- Entire plan for fuel qualification, safety analysis, and conversion activities developed and agreed between ANL and NRC-KI in Fall 2014
- No decision to convert has been reached
- Scope currently on hold
Reactor Conversion: Accomplishments (cont’d)

- **IR-8 Reactor, NRC-KI**
  - 8 MW Reactor, IRT-type fuel
  - Feasibility Study was successfully completed for IRT-3M (U-Mo) fuel: conversion was feasible, provided fuel could be fully qualified
  - Economic impact study was performed to assess modifications necessary to perform the conversion
    - Some, but not very significant, modifications would be needed
  - Safety analysis has been performed for the licensing of the LEU fuel and almost completed by summer 2014
    - Planned for a gradual conversion, as HEU fuel was gradually replaced during refueling
    - Very extensive analysis was performed, including analysis of mixed cores
  - Plan for completion of safety analysis, licensing and conversion activities developed
  - No decision to convert has been reached
  - Scope currently on hold
Reactor Conversion: Accomplishments (cont’d)

- **IRT-MEPhI** Reactor, MEPhI
  - 2.5 MW Reactor, IRT-type fuel
  - Feasibility Study was successfully completed for IRT-3M (U-Mo) fuel: conversion was feasible, provided fuel could be fully qualified
  - Economic impact study was performed to assess modifications necessary to perform the conversion
    - Some, but not very significant, modifications would be needed
  - Safety analysis has been completed (2014) and codes used in the analysis are in process of certification with regulatory agency. Work to be completed in 2015
    - Planned for a full conversion of the entire core, given that BUY is small and consumption os about 1 assembly/year
    - Very extensive analysis was performed
  - Plan for completion of licensing and conversion activities developed
  - No decision to convert has been reached
    - University, Rosatom, and possibly Ministry of Education have to be involved in the decision
  - Scope beyond current activity will be on hold
Reactor Conversion: Accomplishments (cont’d)

- **IRT-T** Reactor, Tomsk Polytechnic University
  - 6 MW Reactor, IRT-type fuel
  - Feasibility Study was successfully completed for IRT-3M (U-Mo) fuel: conversion was feasible, provided fuel could be fully qualified
  - Economic impact study was performed to assess modifications necessary to perform the conversion
    - Minimal modifications would be needed
  - Safety analysis has been initiated (2014). Initial installment underway and will be completed in 2015-2016.
    - Initial analysis will contribute to determine whether conversion will be performed at once or gradually
  - Plan for completion of licensing and conversion activities developed
  - No decision to convert has been reached
    - University, Rosatom, and possibly Ministry of Education have to be involved in the decision
  - Scope beyond current activity will be on hold
Reactor Conversion: Accomplishments (cont’d)

- **MIR** Reactor (and **MIR PM** – or **CA**), **RIAR**
  - 100 MW Reactor, MR-type fuel
  - Feasibility Study was successfully completed for MR geometry fuel using
    - U-Mo dispersion fuel
    - \( \text{UO}_2 \) high density dispersion fuel
  - Conversion is feasible with either fuel, provided they can be fully qualified
    - U-Mo fuel may provide longer fuel assembly life (higher U loading)
    - \( \text{UO}_2 \) fuel has been extensively used, although at lower densities
  - Economic impact study was performed to assess costs necessary to perform the conversion
    - Minimal modifications would be needed
  - Safety analysis has been initiated (2013). First part of safety analysis initially intended to select fuel type. RIAR decided to continue with both fuels for the remaining safety analysis
  - No decision to convert has been reached
  - Full scope for safety analysis and conversion activities was developed and agreed between ANL and RIAR (Fall 2014)
  - Scope currently be on hold
Reactor Conversion: Accomplishments (cont’d)

- **IRT-3M (U-Mo) Fuel Qualification**
  - The critical path activity for conversion of the three IRT-type reactors studied (IR-8, IRT-MEPhi, IRT-T)
  - Follow up recommendation from fuel development efforts:
    - Fabrication and irradiation testing of 2 full assemblies to a BU of 60% and under conditions that envelop those of the three research reactors
  - A detailed scope and contract were negotiated and signed in September 2013 for the fabrication and irradiation of the two lead test assemblies:
    - TVEL has fabricated the assemblies at their plant in Novosibirsk (NCCP)
      - The fabrication process – atomization of the powder – has been improved to prevent a recurrence of the previous fabrication problems during the extrusion process
    - The assemblies will be irradiated in the MIR reactor and examined at RIAR
    - VNIINM will advise on the post irradiation examination requirements
    - TVEL will lead the compilation of documents to obtain the license to fabricate the fuel after the successful irradiation and examination of the test assemblies

Acceptance of the test assemblies took place in Novosibirsk on April 9th. Documentation – fabrication data and X-rays - for the tubes in the 2 assemblies were examined, as were the assemblies. The assemblies meet all requirements and RIAR has formally accepted them for irradiation in MIR. The oversight committee confirmed the acceptance and ANL has endorsed it.
Current Status and Future Work

- Previous slides summarize the status for the conversion work for the 6 original reactors designated by Rosatom including the fuel qualification activities.

- Impact of current political situation:
  - New work (activities not already underway) cannot be currently initiated:
    - Initial constraint established by Rosatom (Russian Government) in October 2014
    - Followed by similar constraint by US Government in December 2014

- Path forward had previously (2013) been identified as:
  - Establish a working group under US-Russia MNEPR agreement
  - Discuss expansion of scope under the working group
    - Determine eligible reactors – possible scoping studies
    - Determine technical constraints and fuel development or qualification needs
    - A few specific reactors had already been broadly discussed: GIDRA, WWR-TS
  - Agree on a cost sharing framework
  - Develop joint convert-remove projects
Conclusions

• Great success has been obtained in the conversion of HEU-fueled Russian-supplied research reactors in third countries
  • All reactors have been addressed and most already converted
  • Only reactors in Kazakhstan, where intensive efforts are taking place, remain to be converted
• Russia and the United States made unprecedented progress:
  • (1) in their agreement to study conversion of an initial group of 6 domestic reactors
  • (2) in their joint efforts in 2012, highlighted by commencement of work on the conversion of Argus – the first Russian research reactor to convert to LEU fuel, in 2014.

• Excellent technical cooperation between Russian and U.S. experts has been established

• The technical challenges going forward will be significant, but can be resolved with strong technical collaboration

• Should the current political difficulties be overcome, the framework to continue the joint work on reactor conversion had been established and will need to be put in place.