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ATW Technology & Scenarios

Dr. Gregory J. Van Tuyle

ATW Lead Project Leader

Office of the Associate Laboratory Director for Strategic and Supporting Research

Los Alamos National Laboratory

ATW

Outline

- ATW Technology
  - Why Needed
  - Implementation Scenarios
- Technology Development
  - Assess Technology Maturity
  - Identify R&D Needs
  - Potential for Collaboration
- Technical Working Groups

ATW Technology Implementations

- **Implementations of ATW Technology depend on future decisions regarding waste repositories, monitored retrievable storage, advanced nuclear energy systems, and nuclear materials management and disposition**
- **The World ATW Community is converging on ATW design characteristics; most differences are options**
- **While implementation scenarios vary, basic ATW design features remain constant across scenarios**
- **Scenario-specific features can be prioritized and developed as needed**

ATW Subcritical Capability Adds Flexibility

- **Nuclear Systems have always operated "critical"**
- **Subcritical capability adds flexibility**
  - **Can drive systems with low fissile content (Th or M.A.) or high burden of non-fissile materials**
  - **Can operate with fuel blends that could make critical systems unstable (Pu and M.A. wo/ U or Th)**
    (Note: Addition of U to gain stability produces more Pu)
  - **Can compensate for large uncertainties or burnup reactivity swings**
- **Option to operate subcritical is especially useful for addressing fuel cycle issues**
  - **Can jump-start systems with insufficient fissile content**
  - **Can support advanced fuel cycles by transmuting wastes**
  - **Can close-down cycles with depleted fissile content**

ATW Addresses Waste Repository Challenges

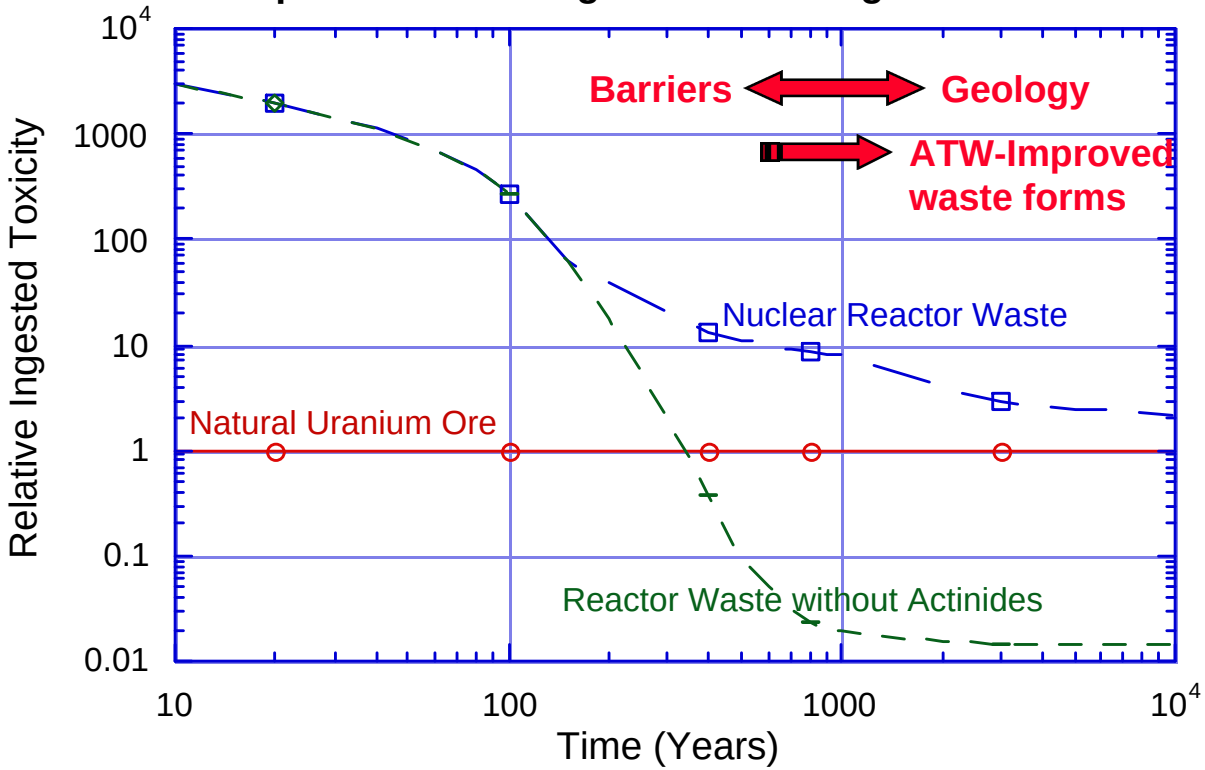
- **Repository essential for current reactors and future nuclear energy systems**
- **Repository technical challenges**
  - **Transmutation reduces long-term hazards and need to rely on favorable geology after containers & barriers degrade**
  - **Removal of Transuranics eliminates criticality issues and allows greater packing densities thereby reducing waste volumes**
- **Repository intrusion issue**
  - **Emplacement of Pu and M.A. invites intrusion by a future generation seeking energy, weapons, other?**
  - **Intrusion will compromise containers and barriers**
  - **It is hard to preclude intrusion, but removal of materials that have obvious value* to future generations reduces risks and possible consequences**

    (*-value greater than cost of recovery)
  - **ATW would eliminate most plutonium and minor actinides from repository; could also target other materials**

Removal of Actinides Reduces Waste Isolation Requirements

- **Unprocessed spent fuel contains materials that require isolation from environment for > 10, 000 years -> *Geologic* Repository**
- **If Plutonium and Minor Actinides are removed, requirements change:**
  - **Toxicity falls below natural uranium ore within a few centuries**
  - **Current Man-made containers can provide up to 1, 000 years of isolation**
  - **ATW-improved waste forms can provide isolation for much longer**

Impact of Removing & Transmuting Actinides



TRU=Transuranics

TRU includes Pu, Np, Am, Cm, etc.

Removal of plutonium and M.A. also reduces likelihood and impact of intrusions, which could compromise containers & barriers

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Monitored Retrievable Storage (MRS)

- MRS Provides interim secure storage of spent fuel
- MRS allows more time for:
  - More thorough characterization of repository
  - More technology development, such as ATW
  - More time to reconsider plutonium recycle
- Potential for great synergy between MRS, ATW, and advanced nuclear energy options
  - Allows postponement of decisions regarding materials of value for advanced nuclear systems
  - Allows advanced nuclear systems, including ATW, to reduce inventory of hazardous materials for disposal
- Repository ultimately required, but by the time it opens:
  - It will be thoroughly characterized over extended time period
  - ATW and/or advanced reactors may have significantly reduced the long-term hazards associated with the wastes

ATW and Advanced Reactors

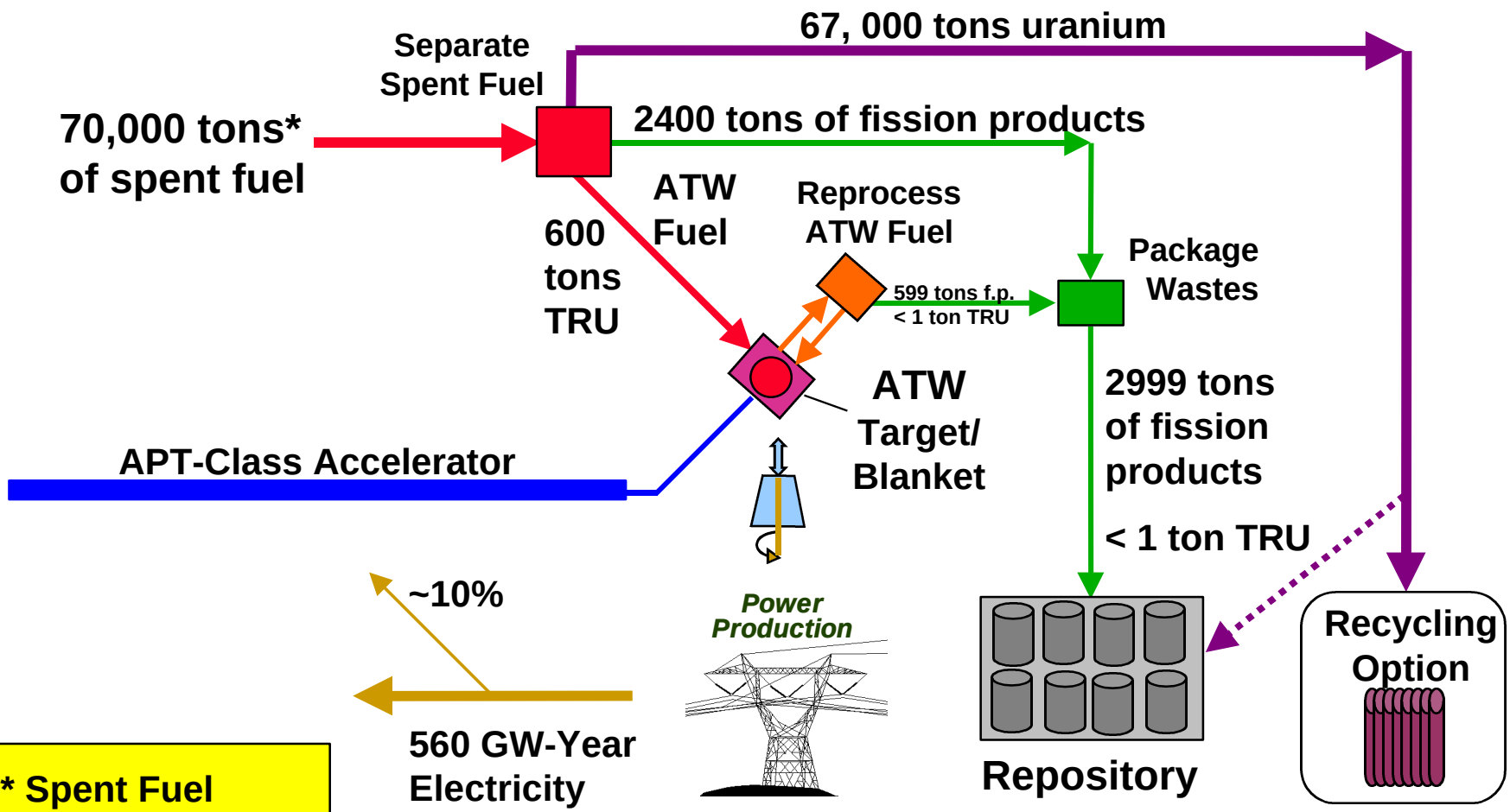
- **PCAST and others stress need for future energy sources**
- **Essential characteristics of next-generation reactors**
  - **Nearly fool-proof safety (inherent safety, passive systems)**
  - **Economics to compete with fossil fuels (when taxed?)**
  - **Minimal waste stream with assured waste disposal**
- **ATW can support next generation of reactors by transmuting the residual waste stream**
- ***Technologies needed for ATW could also improve advanced reactors, e.g., liquid lead-bismuth coolant***

Accommodating Scenarios in Road Mapping

- **ATW technology requires a decade or more to demonstrate**
- **Priorities may change**
  - **Repositories and/or Monitored Retrievable Storage (MRS)**
  - **Advanced nuclear reactor systems under development**
    - » **Fuel could be same, MOX, Pu-based, or Th-based**
    - » **Waste solution could be burial or recycle, w/ or wo/ ATW**
  - **Nuclear nonproliferation efforts could be intensified**

- **Need to develop basic ATW system and technology with design options and implementation schemes to cover possibilities** ***(not as hard as it sounds)***

ATW Implementation to Support Repository without Advanced Reactors or Thorium Cycle



* Spent Fuel Generated in U.S. through 2015

ATW

What is ATW Core Technology?

- High power accelerator delivering 5 to 40 MW beam power
- Spallation targets- Liquid Pb-Bi is first choice
- Subcritical blankets
  - Basic configuration based on reactor experience and physics
  - Fast spectrum is most flexible and requires least development
  - Solid fuels require less development and provide better safety
  - Coolant choices- Pb-Bi preferred
  - Fuel form : Metal fuel
- Pyrometallurgical processing has advantages re: bulk separations and nonproliferation

- <u>Options</u>
  - Blend of actinides in fuel: Pu, M.A., Th
  - Pyro processing could vary somewhat with blend of actinides

Addressing ATW Implementation Scenarios

- ATW objectives would vary somewhat depending on implementation scenario
- Determine that a core ATW system with fuel-related options could support credible scenarios
- Determine the design options required to deal with implementation scenarios
- Develop ATW Road Map to develop the core ATW technology and the highest priority design options

Factoring Scenarios/Options into the ATW Road Map Effort

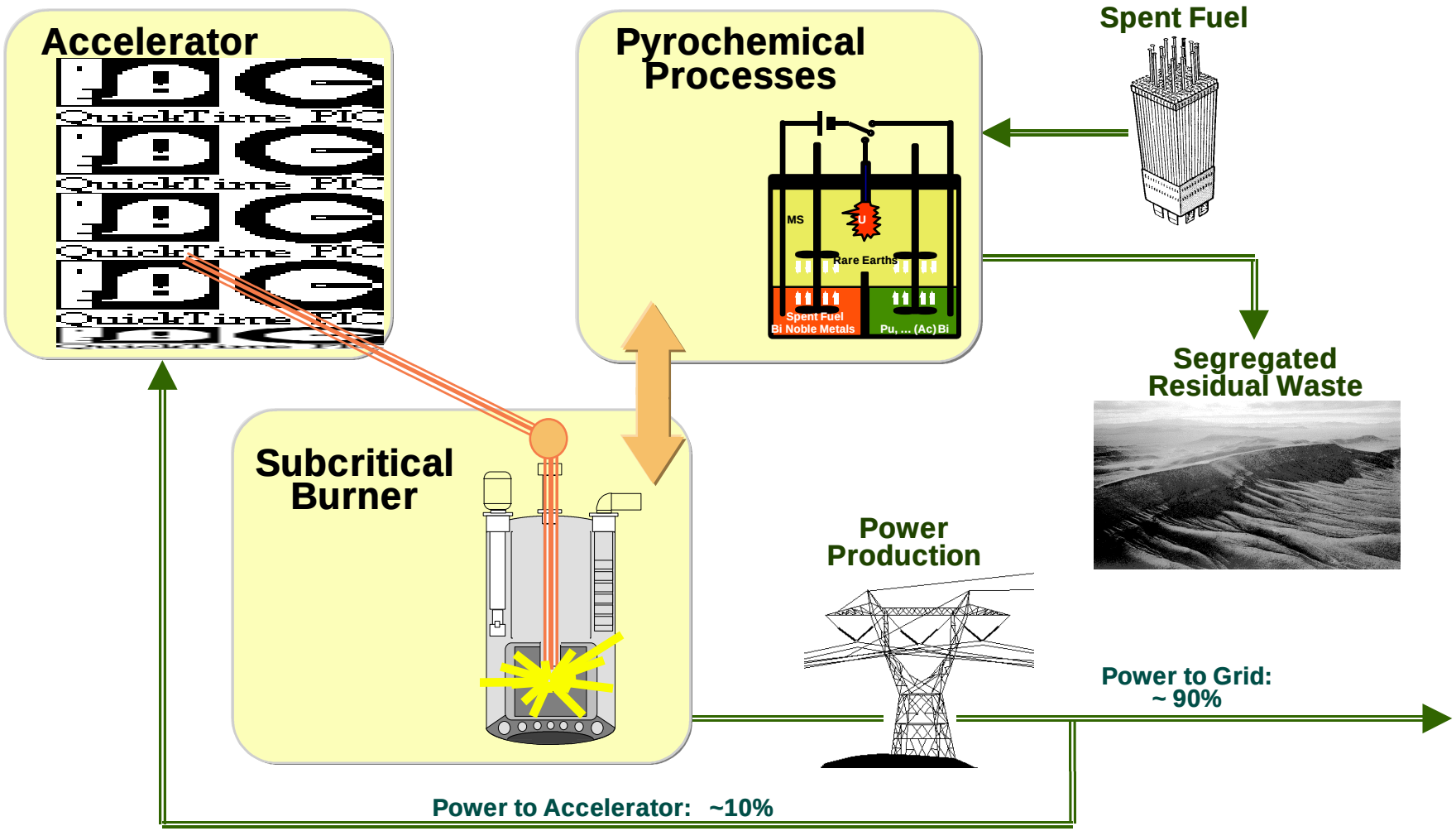
- Must first consider implementation scenarios
- Must define Core ATW technology and design options
- Must assess maturity of key aspects of ATW core technology and address gaps
- Must weigh priorities regarding design options, and then address any gaps in those technologies

- Recommend that one technical working group focus in this area: ATW Systems and Scenarios

ATW Technology is More Mature than @ STATS Review

- ATW systems and scenarios
- High power accelerators
- Nuclear design and safety
- Fuels, Coolants, and Materials
- Separations technology & Waste forms

ATW's Technology Blocks



ATW Systems and Scenarios

- Several possible implementation scenarios envisioned
- Need systematic scoping analyses of plausible implementation scenarios
  - Materials mixes and through-put
  - ATW operating modes
  - Waste streams
- Is there any impact from scenarios on core ATW design
- What design options are needed? What fuels? What separations?
- What are the programmatic priorities?

High Power Accelerators

- Need beam power in the 5 MW to 40 MW range; at roughly 1000 Mev (1 GeV)

- ATW linac would be within APT linac design envelope
  - Toughest challenge for high current linac is low energy
  - APT demonstrated the injector; RFQ demonstration to be completed by Spring 1999

- High power cyclotrons are under development
  - Power limits are lower than those for linacs
  - For some scenarios, power requirements are lower
  - Could focus multiple cyclotrons on a target

- There are no potential show-stoppers

Nuclear Design and Safety

- Spallation target design has matured under APT
  - Liquid lead-bismuth should make excellent target
  - If there are issues, they will be materials related
- Subcritical blanket design will be based on reactors
  - Pb-Bi cooled array of metal fuel pins
  - If issues, probably related to fuels
- Safety by design implies factoring safety into design process
  - Pb-Bi coolant should provide excellent heat removal, including under natural circulation conditions
  - Reactivity feedback characteristics could be undesirable
    - » Potential for accidental reactivity and power increases
    - » Need to set subcritical limits and heat removal margins to accommodate worst case events
- There are no potential show-stoppers

Fuels, Coolants, and Materials

- **Fuels**
  - **Metallic fuel behavior can be complex, depending on mix**
  - **ATW fuel differs from IFR fuels, need additional irradiations**
- **Coolants**
  - **While theoretically an excellent coolant (and spallation target), Pb-Bi can be corrosive**
  - **The Russians worked through the challenges, using special steels and operating controls. The claims of success must be demonstrated.**
- **Materials**
  - **APT has demonstrated materials performance sufficient to support APT mission**
  - **ATW must, in addition, qualify materials that are compatible with liquid Pb-Bi**

- **There are no potential show-stoppers**

Separations technology & Waste forms

- Pyro- processing appears to provide the appropriate level of separations for ATW
  - Bulk separations sufficient, and minimize waste stream and proliferation concerns
  - Process is tolerant to radiation and heating
  - Process for LWR spent fuel into Pu and M.A. fuel established
  - May need to review processing for alternate fuels & cycles
- ATW waste stream can be optimally packaged for disposal
  - No separation and transmutation scheme scores 100%
  - Residuals waste can be formed into stable forms optimized for performance in repository
  - Likely approach for strontium and cesium
- There are no potential show-stoppers

ATW Technology- R&D Needs

- ATW systems and scenarios
- High power accelerators
- Nuclear design and safety
- Fuels, Coolants, and Materials
- Separations technology & Waste forms

Nuclear Design and Safety- R&D Needs

- **Nuclear design**
  - **Improve nuclear data regarding plutonium and minor actinide cross sections, especially at higher energies**
  - **Most nuclear design work is analytical; update codes and data libraries**
  - **May need to do subcritical or critical tests to confirm data and analyses prior to a full scale ATW demonstration**

- **Safety**
  - **Heat removal may be a design strength**
  - **Reactivity feedbacks depend on data and analyses, and therefore contain uncertainties**
  - **Initially: Must compensate with uncertainties with margins**

Fuels, Coolants, and Materials- R&D Needs

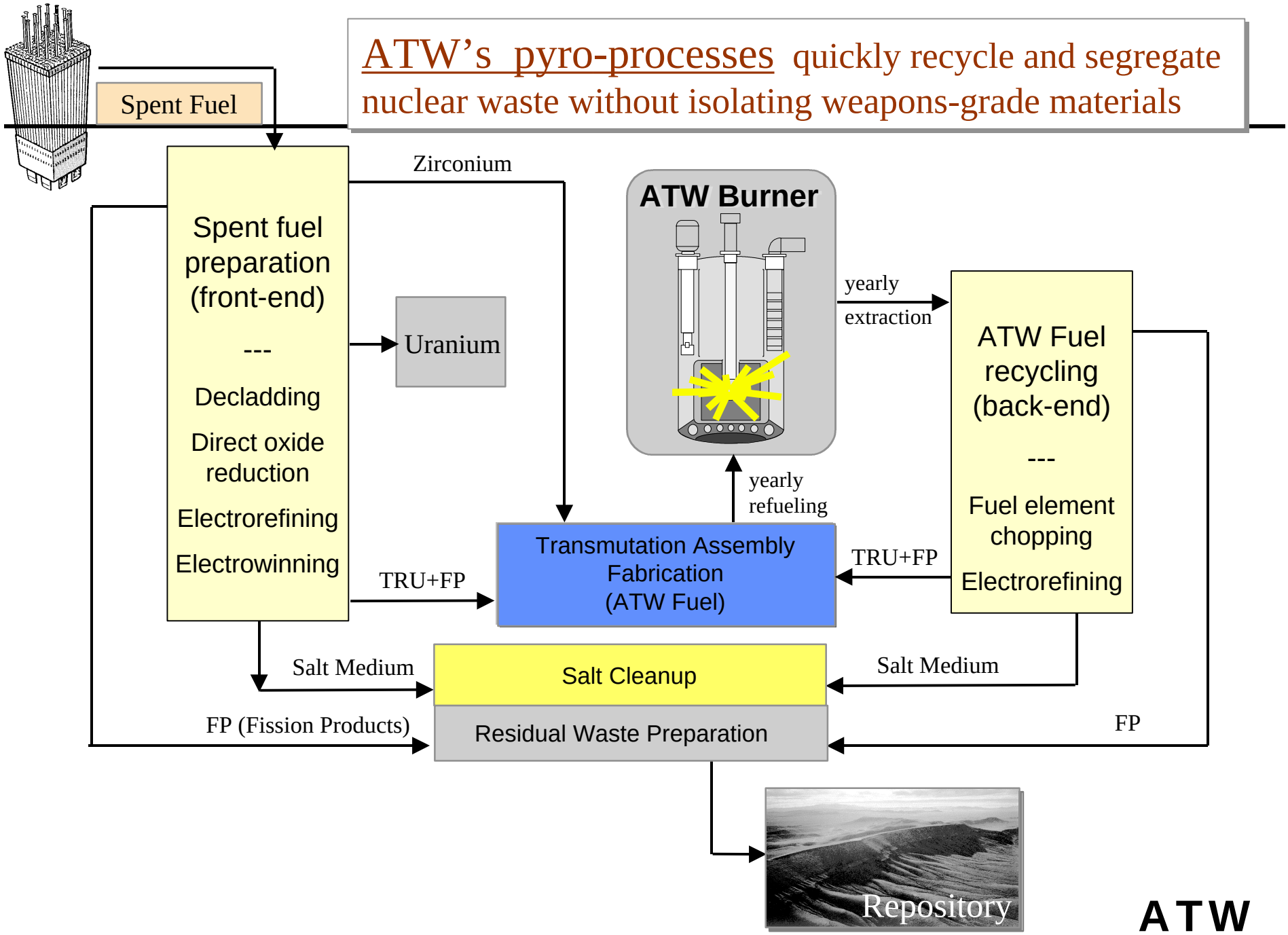
- **Fuels**
  - **Depending on the blend of actinides and zirconium, the metal fuel fabrication & performance can vary significantly**
  - **Some fuels testing may be required, possibly using Russian reactors**
- **Coolants**
  - **Russians have reportedly resolved biggest challenges**
  - **Must irradiate Pb-Bi target and loop in proton beam at LANSCE to determine performance under p-irradiation**
- **Materials**
  - **Must confirm performance of Russian steels**
  - **Alternate steels with higher temperature limits could improve ATW system thermodynamic efficiency**

  - ***Note: this may be biggest R&D area***

Separations technology & Waste forms- R&D Needs

- **Extend processing data base**
  - **Develop process scaling information by designing, fabricating, and testing various size electrochemical cells, reduction systems, and reductive extraction systems**
  - **Establish complete process data base for Cm (with Am), Np (from U), Iodine and Tc (dispose or recover & transmute?)**
- **Develop preliminary chemical engineering design of process system and plant**
  - **Need more detailed material balances for process chemistry**
  - **Work iterative process between separations waste streams and waste form development for repository**
- **Determine impact of scenarios on separations & fuels**

ATW's pyro-processes quickly recycle and segregate nuclear waste without isolating weapons-grade materials



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Potential for Collaboration

- International Collaboration
  - Russian institutes- Pb-Bi technology, Fuel irradiations, Reactivity measurements
  - European and Asian ATW Programs - Core ATW technologies and fuel/separations options
- National Laboratory Collaboration
  - ANL- Pyro-processing, metal fuels, waste forms
  - LLNL- Waste packaging, Repository interface, Nuclear data
  - SNL- Safety, Transportation
  - BNL- Systems, Nuclear design
- Industry Collaboration
  - Westinghouse (incl. SRS) - Nuclear design, materials, ops
  - AES - Systems, Accelerators
  - GA - Thorium cycle, gas turbines?
- University Collaboration - MIT, UCB, Michigan, Illinois

Proposed Technical Working Groups
with some ideas re: membership & chairs

- **ATW systems and scenarios**
  - Candidates for Chair: D. Hill (ANL), G. Van Tuyle (LANL)
  - Candidate Members: W. Davidson (LANL), M. Kazimi (MIT), T Myers (AES), J. Ireland (LANL), D. Beller (LANL)
- **High power accelerators**
  - Candidate Chairs: G. Lawrence (LANL), L. W. Funk (W-SRS)
  - Candidate Members: B. Richter (SLAC), W. Joho (PSI), T. Ward (DOE/DP Consultant), S. Schriber (LANL), Mandrillon (CERN)
- **Nuclear design and safety**
  - Candidate Chairs: W. Barthold (Consultant), J. Scott (Consultant), F. Venneri (LANL)
  - Candidate Members: M Carelli (W), J. Khalil (ANL), M. Driscoll (MIT), M. Cappiello (LANL), E. Greenspan (UCB), J. Kelly (SNL), D. Poston (LANL)
- **Fuels, Coolants, and Materials**
  - Candidate Chairs: N. Todreas (MIT), D. Crawford (ANL-W)
  - Candidate Members: M. Louthan (W-SRS), N. Li (LANL), K. Woloshun(LANL), J. Stubbins (Illinois), W. Sommer (LANL)
- **Separations technology & Waste forms**
  - Candidate Chairs: P. Cunningham (LANL), J. Laidler (ANL)
  - Candidate Members: M. Thompson (W-SRS), M. Williamson (LANL), W. Halsey (LLNL), J. Ackerman (ANL), E. Gay (ANL), R. Morely (LANL), J. Ahn (UCB)

ATW development plan provides technology support for large-scale integration and deployment

Phase 1: Feasibility

To confirm the feasibility and viability of all the technical elements of the ATW concept.

Development activities in Phase 1 will include:

- Operation of large LBE test loops;
- Import and validation of Russian LBE technology;
- Design, fabrication and testing of the LANL/IPPE LBE spallation target;
- Experiments to gather relevant pyrochemical data bases;
- Operation of a small-scale pyroprocessing system.
- Fuel and materials development work;
- Design of a Subcritical Test Facility (STF) and an ATW Processing Facility (APF) (the focus of Phase 2), and of a ATW Demonstration (DEMO) Plant (the focus of Phase 3)
- Point design to serve as the basis for ATW performance assessments, cost evaluations and the identification of future R&D work needed in Phases 2 and 3.
- Nuclear data as required
- Accelerator design

- Scenario Related Options:
  - Alternate fuels
  - Alternate Spearations

Phase 2: Prototype

Final design, licensing, construction and operation of a Subcritical Test Facility (STF) and an ATW Process Facility (APF).

- Fuel tests,
- Tests of components and systems,
- Integrated operation and transmutation experiments
- Preliminary design of DEMO Plant

STF is likely to be the first liquid lead nuclear system constructed outside of Russia. <u>Strong international collaboration potential</u>

Phase 3: Demo

The goal is to start operation of the ATW DEMO Plant.

The DEMO Plant (~100 to 1000 MW of fission power) will include pyrochemical processing of spent fuel, and immobilization of residuals after transmutation.

Continuing STF operation

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Summary

- **The World ATW Community is converging on ATW design characteristics; most differences are options. While implementation scenarios vary, basic ATW design features remain constant across scenarios.**

- **Much of the technology needed for ATW success is available, but R&D is needed in a few key areas, including fuels and materials**

- **The ATW Road Map should focus on ATW core technology and key implementation scenarios**

- **Collaboration is essential in resolving open technology issues effectively and efficiently**