Nuclear Reactor Technology Subcommittee Report to NEAC:
Advanced Test/Demo Reactor Options Study

Mike Corradini (UW), Chair
Ashok Bhatnagar (Consultant), Doug Chapin (MPR), Tom Cochran (NRDC emeritus), Regis Matzie (Consultant) , Harold Ray (Consultant), Joy Rempe (Consultant), John Sackett (Consultant)

Nuclear Energy Advisory Committee Meeting
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NRT Subcommittee Scope

- *Congress appropriated funds for "an advanced test/demonstration reactor planning study by the national laboratories, industry, and relevant stakeholders of such a reactor in the U.S. The study will evaluate advanced reactor technology options, capabilities, and requirements within the context of national needs and public policy to support innovation in nuclear energy."*
- The NEAC NRT subcommittee has reviewed and provided comments on the Advanced Test and Demonstration Reactor Options Study since September 2014, as it progressed to its final report in April 2016.
- Since December we have had a number of telecons and a meeting in DC on March 10th, 2016.

AT/DR Study Approach

- Four strategic objectives were defined by DOE spanning the range of key nuclear energy missions and needs as a framework for this study

Demonstration Options

  - Deploy a high temperature process heat application for industrial applications and electricity demonstration using an advanced reactor system to illustrate the potential that nuclear energy has in reducing the carbon footprint in the US industrial sector
  - Demonstrate actinide management to extend natural resource utilization and reduce the burden of nuclear waste for future generations
  - Deploy a small scale demonstration reactor for a less mature reactor technology with the goal of increasing the technology readiness level of the overall system for the longer term

Test Reactor Option

  - Provide an irradiation test reactor to support development and qualification of fuels, materials and other important components (e.g. control rods, instrumentation) of both thermal and fast neutron-based Generation IV advanced reactor systems

Technical Readiness

Assessment of a range of reactor systems at the subsystem level

Recent detailed assessments performed by GenIV International Forum, GNEP, and NGNP programs were used as basis of review

Very Low Maturity

- Gas Cooled Fast Reactor

Low Maturity

- Lead Fast Reactor
- Fluoride-salt High Temp. Reactor
- Molten-salt Fueled Reactor
- Supercritical Water Reactor
- Advanced Sodium-Cooled Reactor
- Very High Temp. Reactor

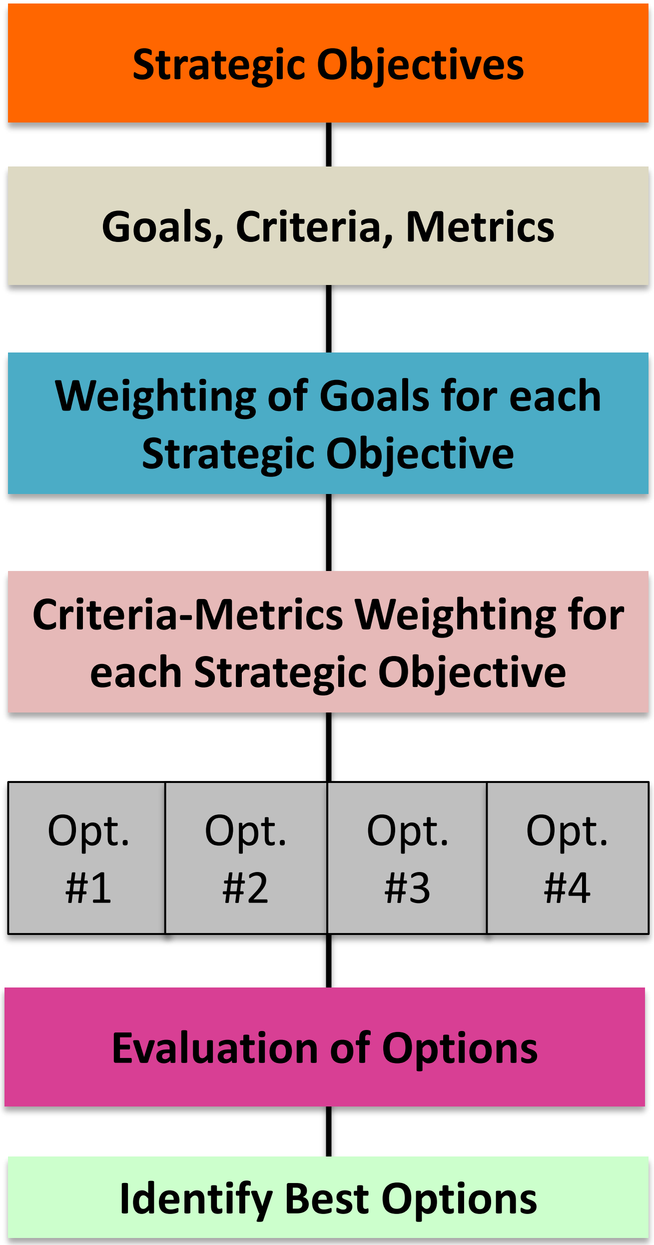
High Maturity

- Modular High Temp Gas-Cooled Reactor
- Standard Sodium Cooled Reactor

AT/DR Approach (cont.)

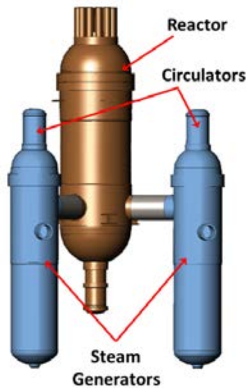
- Demonstration and test reactor point designs were developed by different industrial and lab teams and provided for evaluation against the strategic objectives.
- Expert judgment was used to elicit goals, criteria, metrics from a group of scientists and engineers from the nuclear community spanning industry, national labs and universities.
- Goals, criteria, and metrics were then established, along with weighting factors, in a decision analysis context to evaluate the technology options against the strategic objectives.
- Study aligned best technology option with each strategic objective

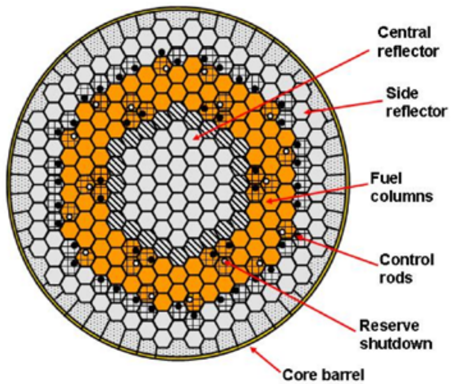
High Level Overview of Approach



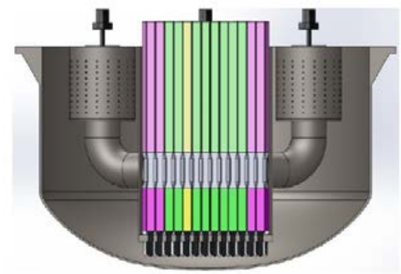
Resultant Top Options

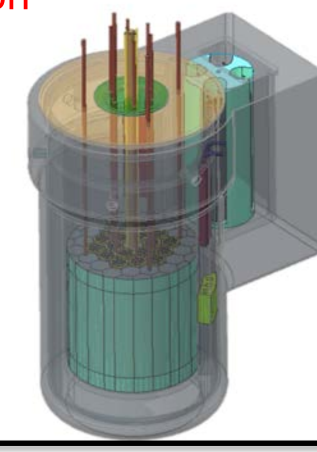
Strategic Objective 1: Process heat demonstration – modular HTGR commercial demonstration



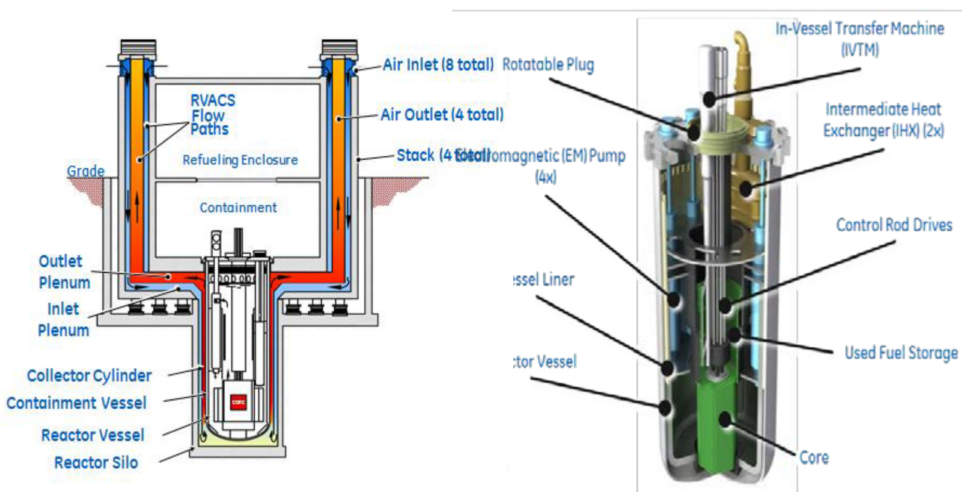


Strategic Objective 3: Demonstrating a Less Mature Technology – FHR or LFR engineering demonstration

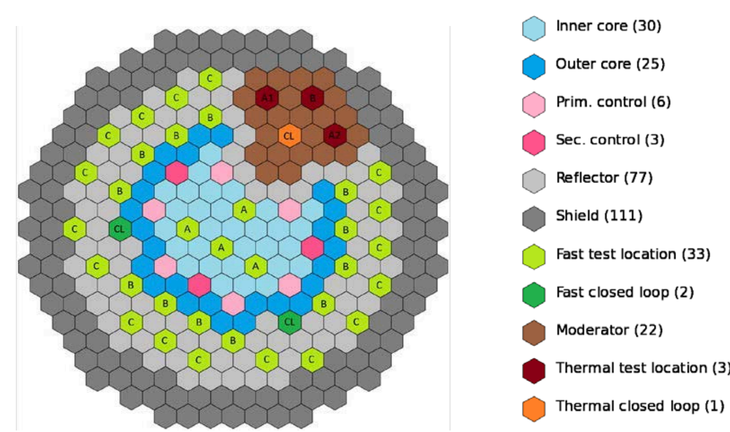




Strategic Objective 2: Resource Utilization and Waste Management – SFR commercial demonstration



Strategic Objective 4: Test Reactor to Provide Fast Neutrons – Sodium–cooled Fast Test Reactor



Reactor Development Steps: US and International Experience for LWRs and Advanced Reactor Systems

Research and Development:
Prove scientific feasibility associated with fuel, coolant and geometrical configuration

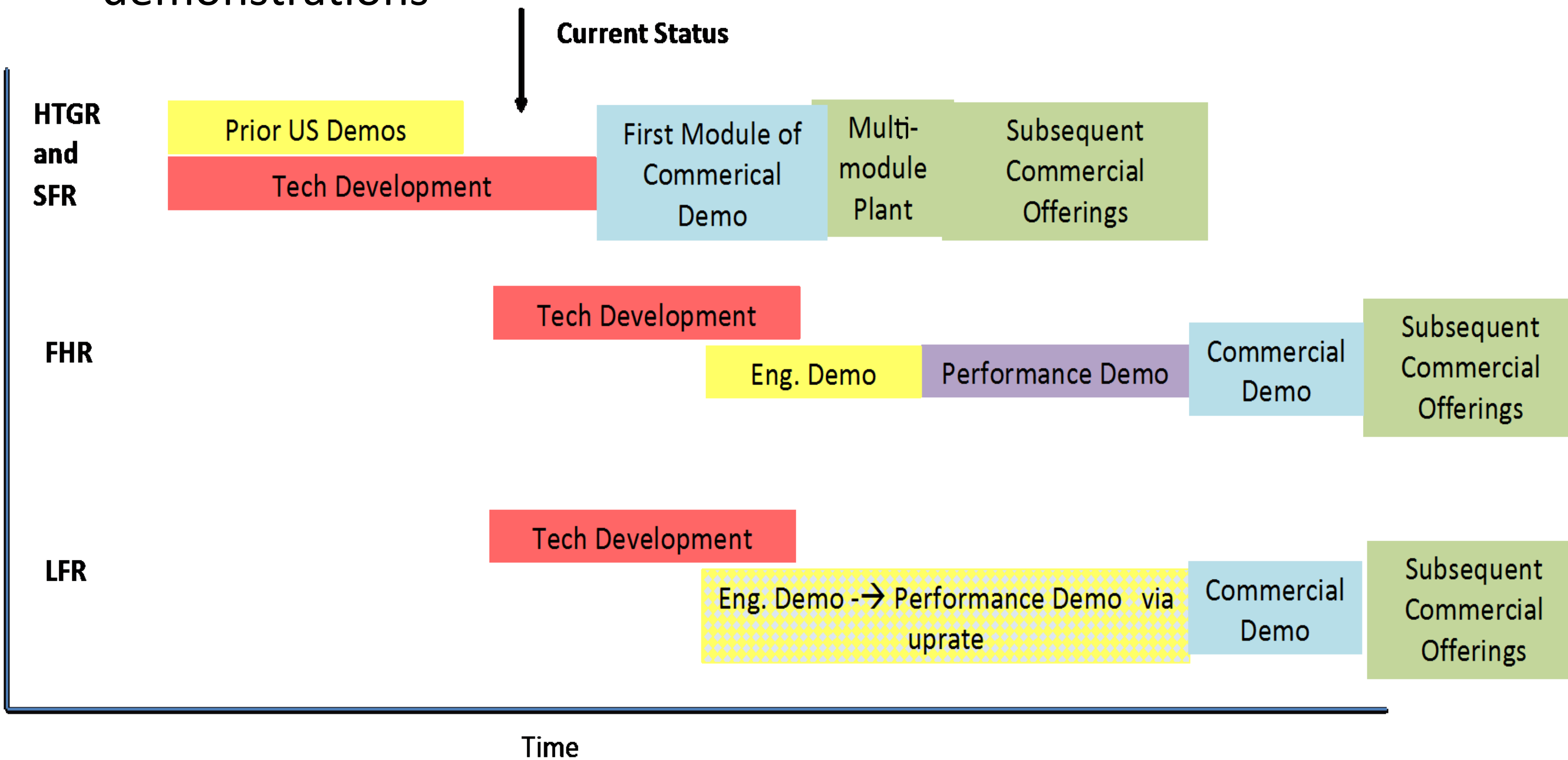
Engineering Demonstration:
Reduced scale proof of concept,
Concepts that have never been built
Viability of integrated system

Performance Demonstration:
Establish that scaled up system works
Gain operating experience to validate integral system behavior
Proof of performance

Commercial Demonstration:
Full scale to be replicated for subsequent commercial offerings if systems works as designed

Deployment

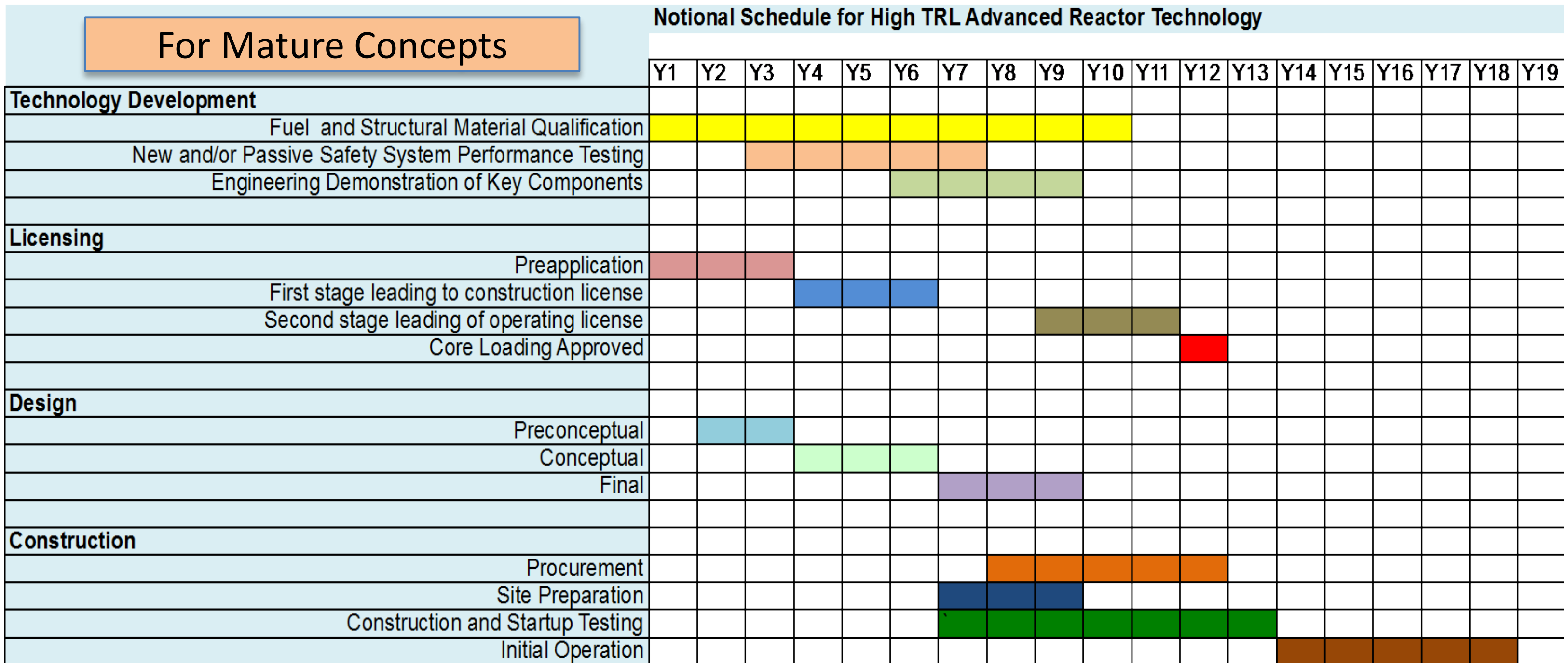
- Depends on maturity of the concept
- SFR (by GE) and MHTGR (by AREVA) are closest to commercial deployment. Basic technologies have been demonstrated. Less mature technologies require additional R&D and early stage demonstrations



Cost and Schedule

Mature Concepts

- Cost and Schedule are technology independent
- Cost to operation of first module for mature concepts is ~$4 B based on vendor input
  - Still has significant uncertainty at this stage
- Schedule is ~15 years (design, licensing, construction) First module operation: ~2030



Less Mature Concepts

- Costs for engineering demonstration of a less mature concept is ~$2-4 B and is highly uncertain and takes ~ 20 years to get through operation of initial demonstration
- Requires a follow-on performance demonstration in 2040 timeframe and commercial offerings in 2050 timeframe. Costs for these activities are multi-billion

Summary Comments from NRT

- General NRT Conclusion: The Options Study is a good piece of work that meets the legislative intent from FY-2015 Congressional action

- Consensus NRT comments on AT/DR Options Study:
  - Need for an Overall Nuclear Energy Strategy
  - Demonstration Reactor Concepts
  - Advanced Reactor Development: Process Improvements
  - Advanced Reactor Licensing Framework
  - Licensing Clarification
  - Domestic Test Reactor

Need for an Overall Nuclear Energy Strategy

- NRT has concerns on how Options Study will be used in the absence of an overall strategy for nuclear
- The Options Study was limited to non-LWRS by choice of the DoE
- Sustaining the existing LWR fleet, facilitating GenIII+ LWRs (ALWRs), and developing, licensing and demonstrating the capabilities of Small Modular Reactors (SMRs), needs to be considered in this overall strategy; e.g., such a strategy should clearly support and complete necessary funding for the current license support program for SMRs.
- ALWRs, including SMRs, offer more timely options for addressing the goal of large-scale de-carbonization than do advanced non-LWRs.
- While the Options Study is not an overall strategy for advanced reactors, it can be quite useful to that end.
- NRT strongly recommends that NEAC review the broader strategy that DOE-NE has currently in development (needs to include LWRs).

Demonstration Reactor Concepts

- Evaluations focused on point designs from four technologies: a gas-cooled high temperature reactor, a sodium cooled fast reactor, a lead cooled reactor, and a molten salt reactor.
- These reactors were evaluated because designers could provide design information, varying from preliminary to pre-conceptual design. There were numerous other advanced concepts being proposed for many of these advanced reactor technologies.
- The conclusions from this study relate to the ability of a reactor technology to meet a specific strategic objective and can be applied to proposed variations in a reactor technology type.
- The conclusions from this study can be generalized to the technologies for which each point design represents.

Advanced Reactor Development: Process Improvement

- The Options Study should identify lessons from past nuclear reactor technology development programs (e.g., NGNP). NRT subcommittee recommends that DOE-NE consider a different process for advanced reactor technology development:
  - Historically DOE-NE has been the ‘decider’ as to what technology option would be ‘best’ to pursue.
  - Rather than ‘decider’ NRT suggests it would be better for DOE-NE to take on the role of a ‘facilitator’ and support efforts that are initiated and led by an appropriate industry team.
  - The DOE-NE GAIN program is a limited first step. DOE-NE needs an integrated approach as part of its overall advanced reactor technology development plan.

Advanced Reactor Licensing Framework

- Study noted many advocates for developing a new set of NRC regulations that are non-LWR based before advanced reactor technologies can be effectively licensed.
- In contrast, the study advocates continuing the current DOE-NRC approach in which the existing NRC framework is retained, but requirements are adapted to accommodate advanced technologies while preserving the underlying safety bases.
- Study notes this is the most effective use of NRC and applicant resources, with existing NRC processes and feedback mechanisms for performing focused reviews of technology-specific topics.
- NRT agrees. We also note that giving early staged feedback to the applicant from the regulator is useful and is being done now for current licensing actions and can be used for advanced reactors, thereby providing more certainty to the process.

Licensing Clarification

Options Study Executive Summary, page ix, states:

"As a part of the point design effort focused on Strategic Objectives #1 and #2, both reactor vendors (AREVA and GEH) proposed licensing the first module using the two-step Part 50 process to confirm the prior data in an integrated manner. Operational experience from this first module then supports design certification and licensing of the follow-on modules using the one-step Part 52 licensing process."

NRT completely agrees with this practical approach; however, the logic and basis is difficult to follow. Clarification is needed of the anticipated and acceptable use of Part 50 and Part 52 as has been outlined by AREVA and GE for new first-of-a-kind reactor plants. NRT recommends a revised wording that is given below.

<u>Suggested Revised Wording</u>

"As a part of the point design effort focused on Strategic Objectives #1 and #2, both reactor vendors (AREVA and GEH) proposed licensing the first module using the Part 50 process which allows detailed design to be completed during construction and the operating license process. Operational experience from this first module can then be used by the reactor vendor to obtain a design certification which will avoid reactor design review for follow-on modules using the Part 52 licensing process."

Domestic Test Reactor

- Objective 4 of the study concludes that a test reactor with thermal and fast neutron spectra is only needed in support of GenIV non-LWR reactor designs being considered.
- NRT is not convinced. Study has not made a clear case that a test reactor is needed only to accommodate future non-LWR testing needs.
- NRT considers that the study should have placed more emphasis on the domestic need for a cost effective test reactor that can accommodate fuel and materials of LWRs as well as advanced reactor fuels and materials; e.g., note of the CEA-JHR.
- NRT supports the concept of a new domestic test reactor that is primarily motivated by industry needs and future plans and can handle not only non-LWR fuels and materials objectives, but can also accommodate needed testing of advanced LWR fuels and materials.
- NRT also emphasizes that the infrastructure surrounding a test reactor needs to maintained and standardized or else it will not meet user needs.

Questions and Comments?

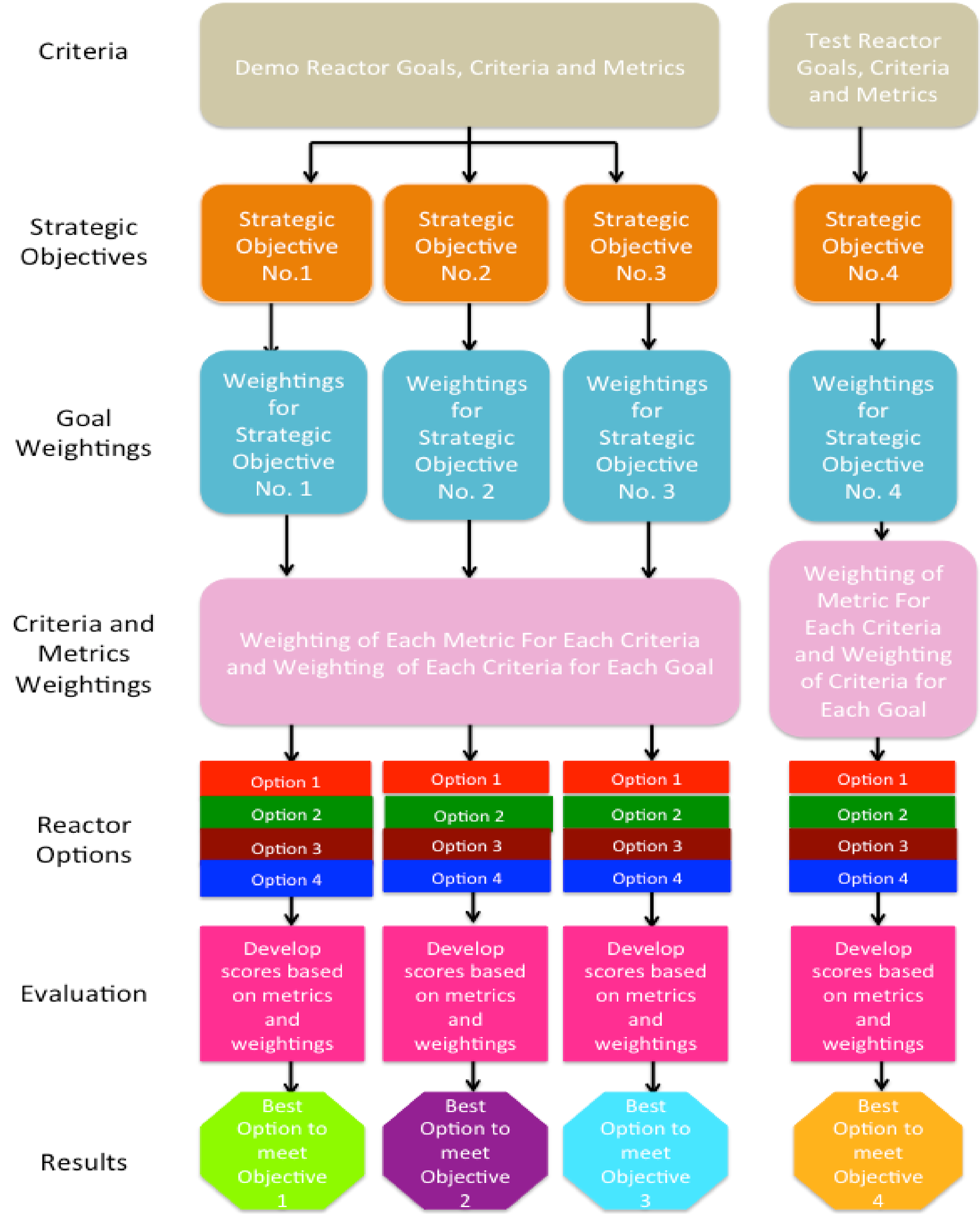
Evaluation Process

Evaluation of conceptual designs for the test reactor is a separate activity from the evaluation of conceptual designs for the demonstration reactor.

There are different goals, criteria and metrics for test reactor concept evaluation than for demonstration reactor concept evaluations.

Our committee concluded this was appropriate and the overall formulation of the goals, criteria and metrics were reasonable.

In order to test the process, we suggested to use the ATR and the EBR-II as real-world examples of a test reactor and demonstration reactor designs to illustrate how the evaluation process would work.



Demonstration Reactor Goals, Criteria, and Metrics

Demonstration Reactor Goals, Criteria and Metrics		
Goal	**Criteria**	**Metrics**
1. Demonstration Reactor significantly advances the technology toward a potential FOAK plant	1.1 Capability to demonstrate safety behavior of commercial system	1.1.1 Does the demonstration system have safety characteristics and systems/components expected in the commercial plant?
	1.2 Detailed instrumentation and data for code validation tests	1.2 1 Does the design have adequate instrumentation and will it gather appropriate data for code validation tests?
	1.3 Scalable technology choices	1.3.1 Does the design implement technology selections that are prototypic or scalable to commercial unit?
	1.4 Scalable maintenance techniques and schedules	1.4.1 Does the design have maintenance approaches that are prototypic or scalable to commercial unit?
	1.5 Scalable fabrication options	1.5.1 Does the design use prototypic of scalable technologies in the fabrication of important systems and components?
2. Demonstration Reactor operations help resolve technical barriers (e.g. predictability) to advanced reactor economics and reliability	2.1 Construction Costs and Schedule	2.1.1 Project Cost
		2.1.2 Schedule
	2.2 Operational Costs and Schedule	2.2.1 Annual Operating Costs
	2.3 Reliability of Operations	2.3.1 Availability Factor
3. Demonstration Reactor has a robust Safety Design Basis for	3.1 Licensed by NRC	3.1.1 Ability to address key licensing issues for follow-on commercial units
4. Demonstration Reactor Supports demonstration of technology and system integration (enhancing immediate, intermediate and long term value of the project)	4.1 Facilitate component demonstration	4.1.1 Does the system facilitate component demonstration of that expected in follow-on commercial units?
	4.2 Demonstrate alternate core configurations and fuel types	4.2.1 Number of alternative core configurations
		4.2.2 Number of alternative fuel types
	4.3 Demonstrate integration with various energy conversion systems or industrial applications (hybrid energy systems)	4.3.1 Number of energy conversion systems or industrial applications
	4.4 R&D required before demonstration reactor construction/operation	4.4.1 R&D Time
		4.4.2 R&D Cost
	4.5 Provide ability to conduct irradiations of materials and fuels under prototypical conditions	4.5.1 Flux Conditions (Fast and Thermal)
		4.5.2 Irradiation Volume and Length
5. Demonstration Fuel Cycle of Advanced Reactor	5.1 Prototypic fuel fabrication	5.1.1 Is the fuel fabrication approach prototypic or scalable to commercial unit?
	5.2 Prototypic fuel performance	5.1.2 Is anticipated fuel performance prototypic or scalable to commercial unit?
	5.3 Spent fuel handling	5.1.3 Is the spent fuel handling prototypic or scalable to commercial unit?

Test Reactor Goals, Criteria, and Metrics

Test Reactor Goals, Criteria and Metrics		
Goal	**Criteria**	**Metrics**
1. Test Reactor provides irradiation services for a variety of reactor and fuel technology options	1.1 Irradiation Conditions	1.1.1 Flux Conditions (Fast and Thermal)
		1.1.2 Irradiation Volume and Length
		1.1.3 Maximum sustainable time at power, to provide a time-at-power for a single irradiation (i.e. cycle length)
		1.1.4 Provisions for testing prototypic and bounding conditions (Temperature, Coolant, Chemistry)
	1.2 Support diverse irradiation testing configurations concurrently (accommodate various sizes and tailor irradiation parameters to wide group of simultaneous users)	1.2 1 Number of Test Zones
		1.2.2 Number and type of irradiation test loops with cooling systems independent of the primary reactor coolant
		1.2.3 Ability to insert/retrieve of irradiation specimen while staying at power
2. Test Reactor will be built and operated reliably and in a sustainable cost-effective manner. (Need to be able to justify initial and long-term expense)	2.1 Project Costs and Schedule (including contingency that reflects technical maturity of the concept)	2.1.1 Project Cost
		2.1.2 Schedule
	2.2 Operational Costs and Schedule (including contingency that reflects technical maturity of the concept)	2.2.1 Annual Operating Costs
	2.3 Reliability of Operations	2.3.1 Availability Factor
3. Capability to accommodate secondary missions (e.g., electricity, isotope production, etc.) without compromising primary mission of testing fuels and materials for advanced reactor technologies	3.1 Identification of Secondary Missions	3.1.1 Number of Secondary Missions

Example of Metric - #1

Metric 1.1.1. Flux conditions (fast and thermal)

Note: Test reactors usually have a range of flux conditions within their testing environment to allow flexibility to meet a wide range of needs. In addition, the physical volume over which that flux exists also can vary (and is captured in Metric 1.1.2) For simplicity here, the fast and thermal flux conditions do not necessarily have to occur in the same location within the test reactor. Nor will a specific volume be required. The fast and thermal flux levels will be evaluated individually and the scores averaged to obtain a final numerical value.

Metric	>5 x 10^{15} n/cm^2-s fast (>0.1 MeV) >5x10^{14} n/cm^2-s thermal	5x10^{14} to 5 x 10^{15} n/cm^2-s fast (>0.1 Mev) 1 to 5x10^{14} n/cm^2-s thermal	<5 x10^{14} fast (>0.1 MeV) <1x10^{14} thermal
Score	3	2	1

- Defined, quantifiable performance feature
- Grouped from best (3) to least (1) performance

Example of Metric - #2

Rationale: Advanced reactors have both inherent and passive design features that should enable a demonstrable benefit for public acceptance. However, the size of the demonstration reactor or other constraints may limit the ability of the system to demonstrate the safety behavior of the ultimate commercial system because of lack of prototypicality and/or scalability.

Metric 1.1.1. Does the demonstration system have safety characteristics and systems/components expected in the commercial plant?

Metric	Demo replicates the safety characteristics and has prototypic systems/components	Safety behavior of Demo can be confidently scaled to the commercial system	Safety behavior of Demo has important non-prototypic aspects
Score	3	2	1

- Rationale also provided for each metric
- Qualitative performance feature
- Grouped from best (3) to least (1) performance

Weighting Factor Exercise

- Weight factors reflect different strategic objectives of the decision-maker
  - Also called value functions in other evaluation studies

- To assess the evaluation approach, four potential strategic objectives were considered
  - Do the metrics distinguish between these objectives?
  - Are the priority/emphasize weightings clear?

- All four objectives evaluated independently by Lab teams at Argonne, Idaho, and Oak Ridge
  - Metric priorities do change between the different objectives
  - Weighting functions were consistent between the three teams
  - Metrics were refined, based on specific issues identified