Fusion Development Path Interim Report

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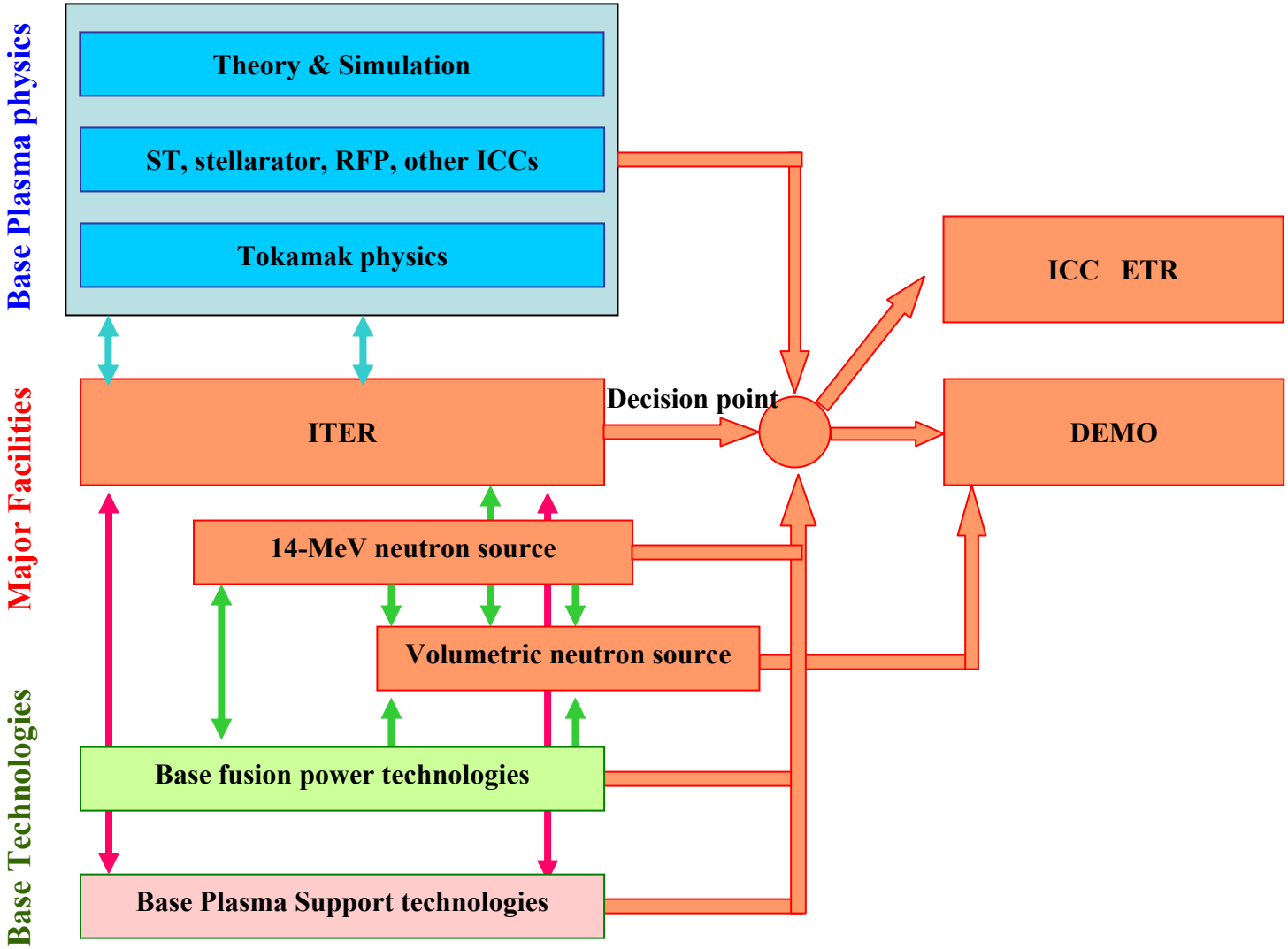
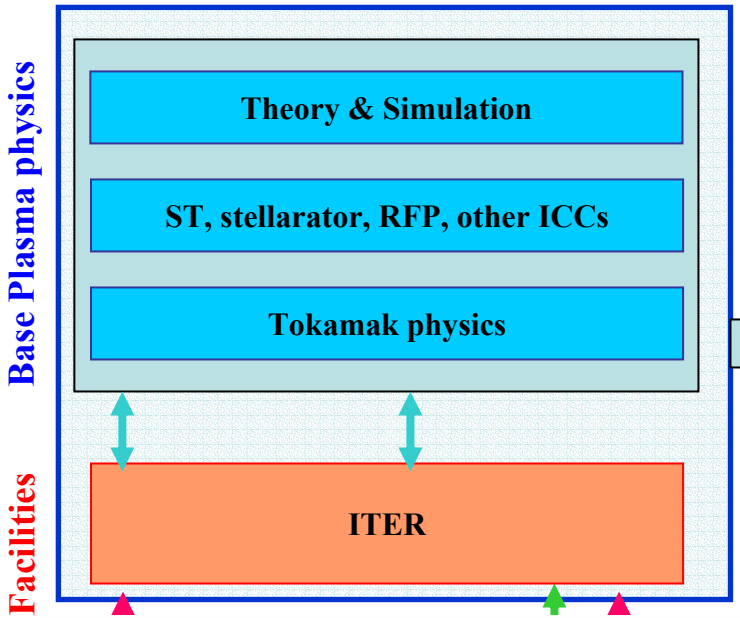
Fusion Development Requires A Portfolio Approach

- Fusion development requires development and integration of four scientific challenges:
  1) Burning plasma physics;
  2) High-performance, steady-state operation (including concept optimization);
  3) Plasma support technologies;
  4) Low-activation material & fusion power technologies.
- Development paths featuring FIRE, ITER, and IGNITOR all require a strong base program, test stands, and companion experiments
  - ✓ A Portfolio Approach to Fusion Development
- Fusion development paths based on FIRE, ITER, and IGNITOR differ on the degree of development and integration of the four fusion challenges in the next step device and to the degree that these challenges are deferred.

ITER-Based Development Path



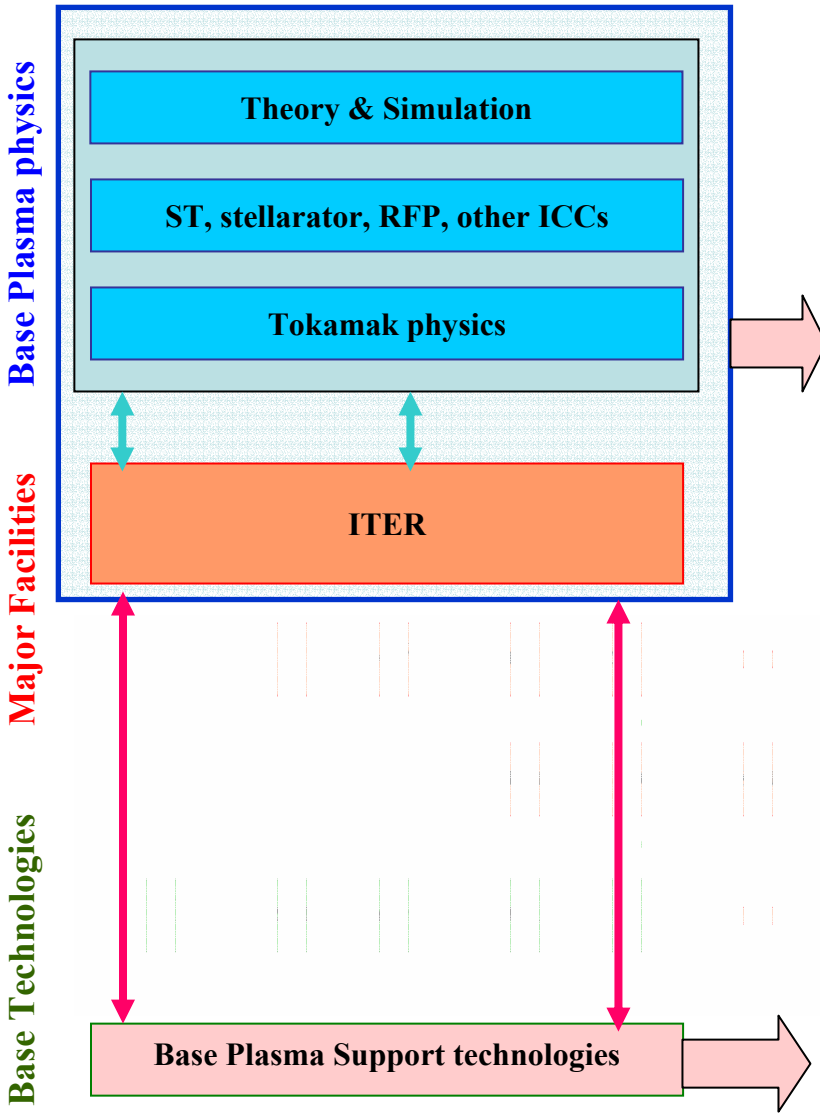
ITER-Based Development Path



Plasma Physics

- An international tokamak research program centered around ITER and including national performance-extension devices have the highest chance of success in exploring burning plasma physics in advanced tokamak modes.
- A diversified and integrated portfolio consisting of advanced tokamak, ICCs, and theory/simulation is needed to achieve the necessary predictive capability.
- BPX should be flexible & well-diagnosed in order to provide fundamental understanding and physics and technology data for the entire toroidal portfolio.

ITER-Based Development Path



Plasma Technologies

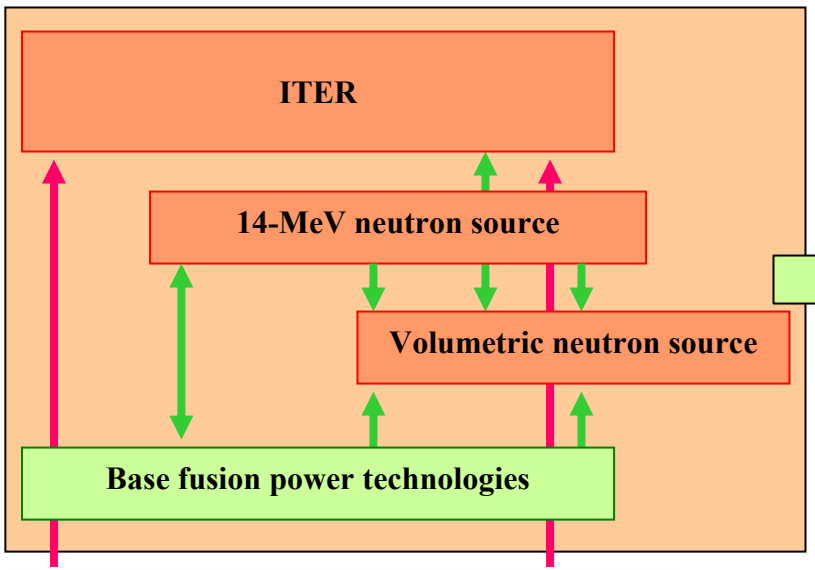
- A strong base program in plasma support technologies (fueling, magnets, heating, PFC) including experiments on test stands is necessary to develop advanced technologies necessary for power plants.
- Experience on present and future high performance and steady state device will provide a wealth data on individual technologies.
- ITER will provide valuable data on integration of power-plant relevant plasma support technologies.

ITER-Based Development Path

Base Plasma physics

Major Facilities

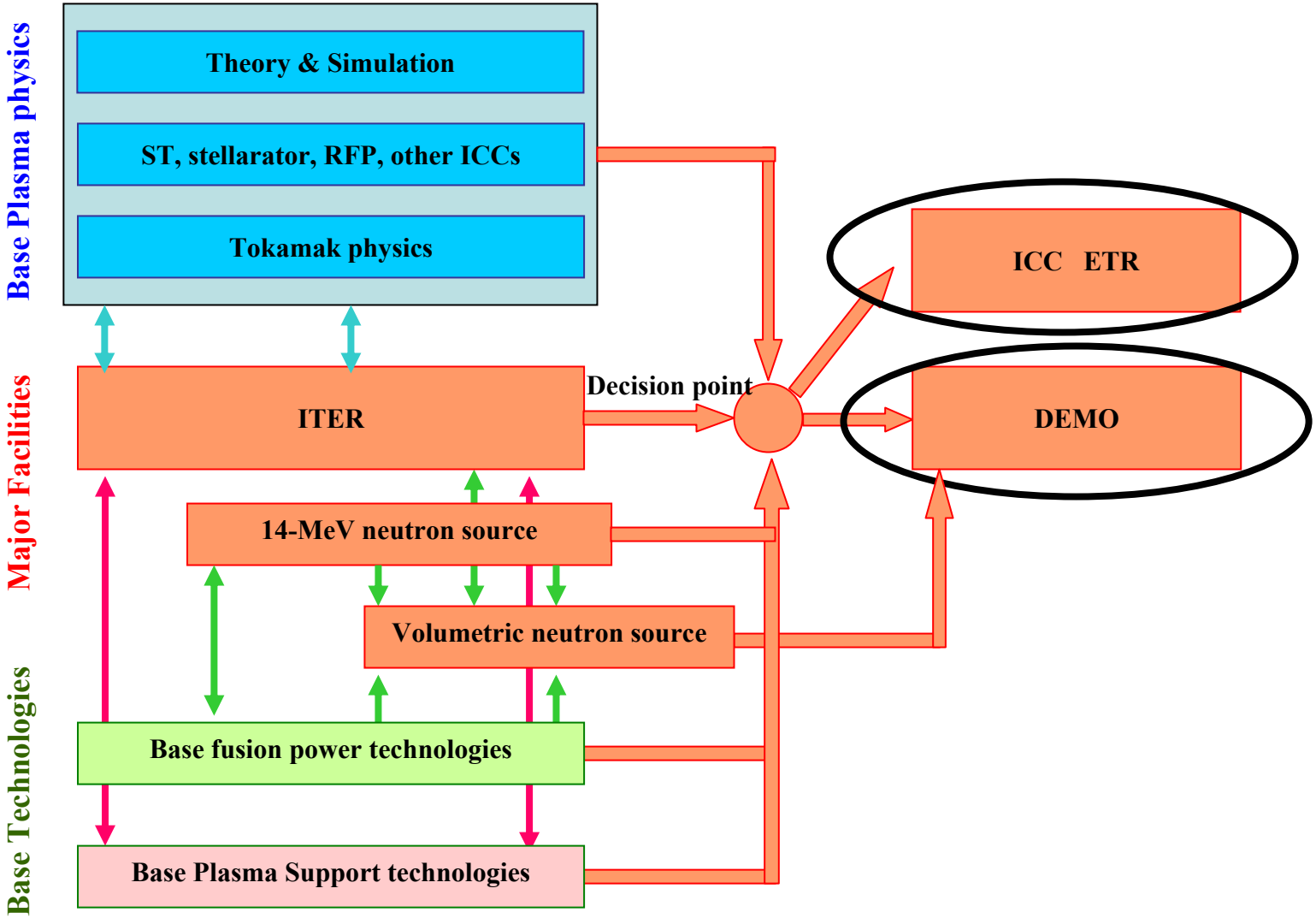
Base Technologies



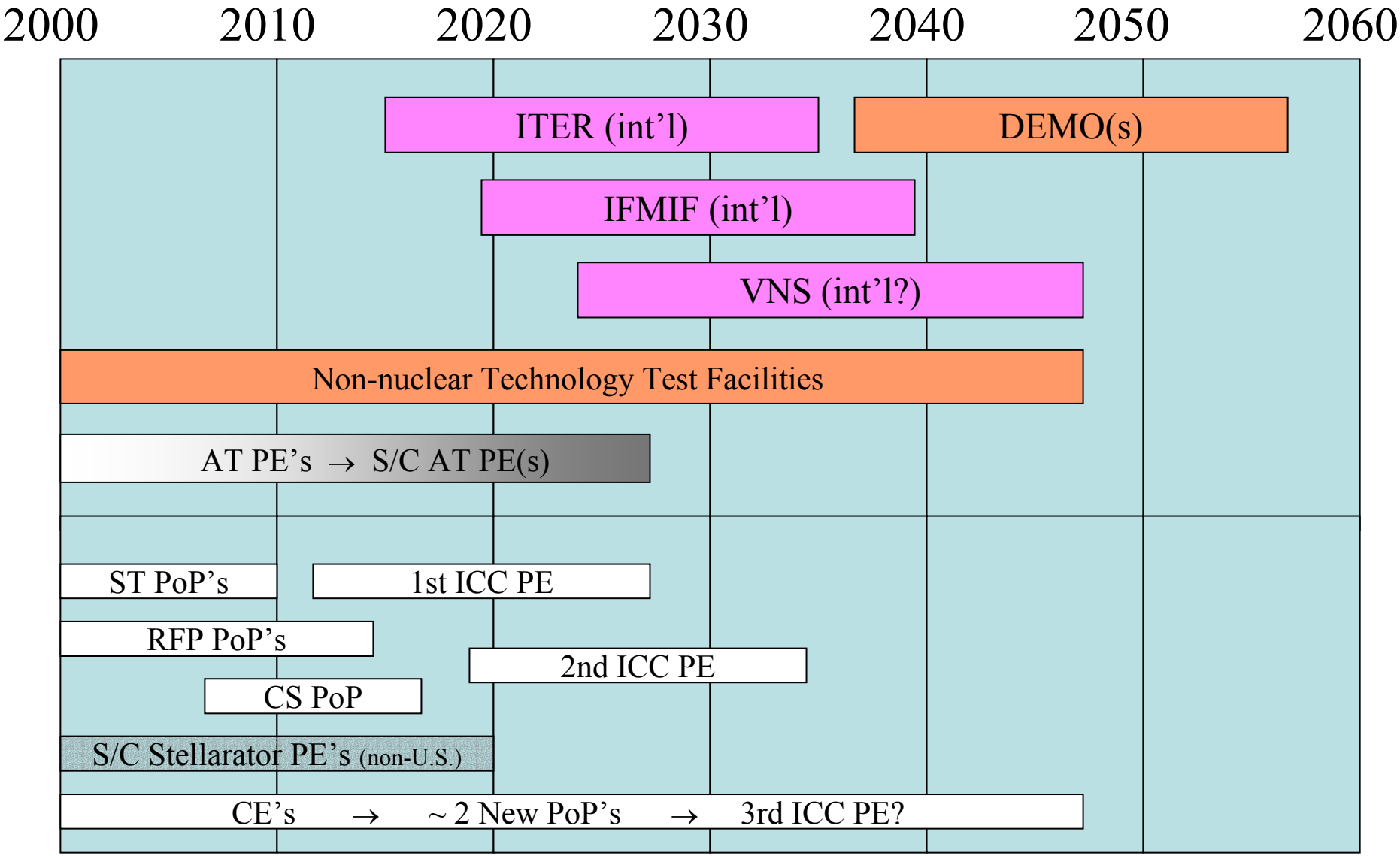
Power Technologies

- Fusion power technologies are in their infancy and are probably the pace setting element of fusion development.
- Development of fusion power technologies require:
  1) Strong base program including testing of components in non-nuclear environment as well as fission reactors.
  2) Material program including an intense neutron source to develop and qualify low-activation material.
  3) A VNS (or a "fusion pilot plant") for integration and test of power technologies in fusion environment.

ITER-Based Development Path



"Success-Oriented" Fusion Development Path



ITER-Based Path: Issues & Response

- An ITER strategy would have larger initial cost:

✓ **Ultimately an ITER-class machine must be successfully built and operated before DEMO, Therefore, cost is not reduced, only postponed.**

- ITER strategy is more risky:
  1) It must confront all of the major next-step physics/technology issues.
  2) Modification and upgrade would be costly and may prohibit test of some ideas.

✓ **A single device has a higher risk compared to a sequence of smaller steps but produces larger opportunities in examining advanced tokamak burning plasmas. Risk should be balanced against benefits.**

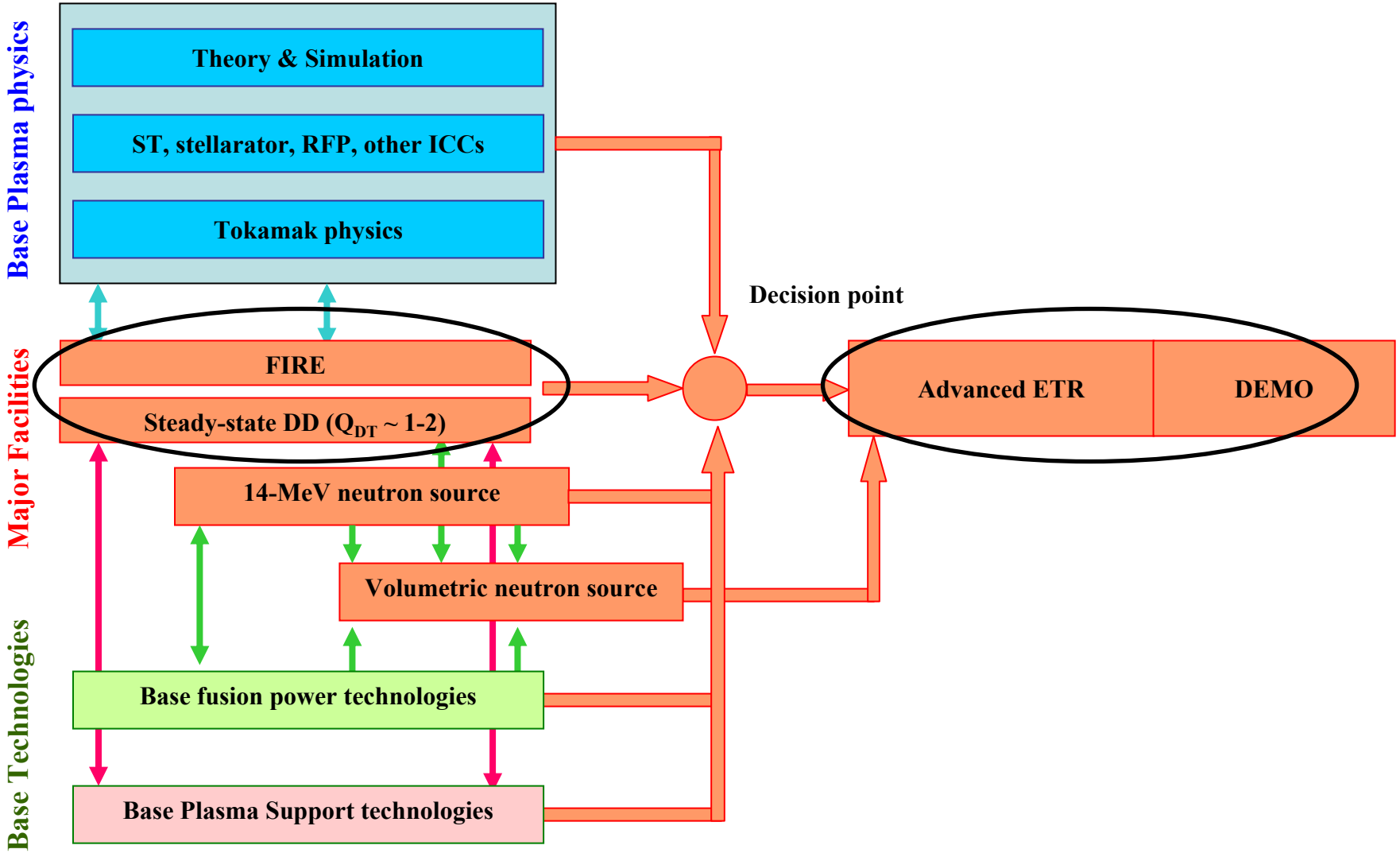
✓ **Risk can be minimized by aggressive, focussed R&D and maintaining strong base program, including tokamaks, ICCs and theory/simulation.**

ITER-Based Path: Issues & Response

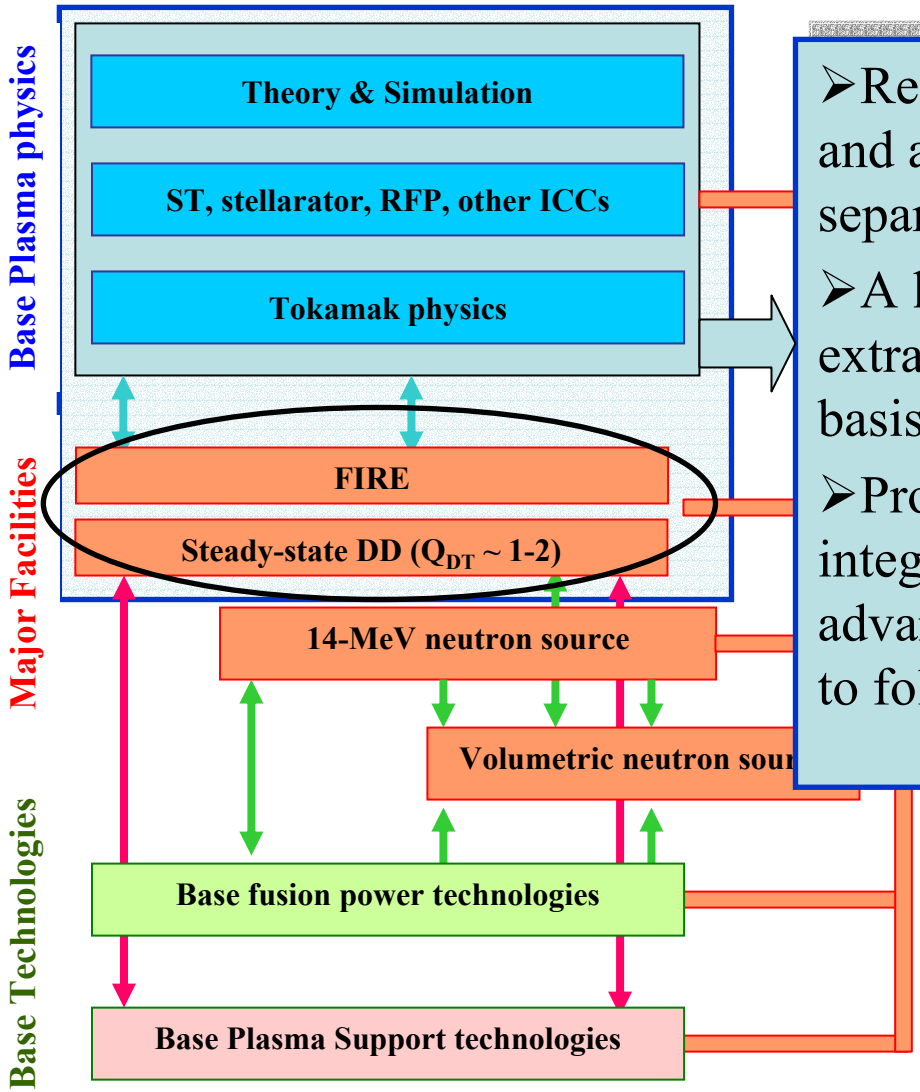
- There are a large number of uncertainties with an international device:
  1) Agreements on siting, cost-sharing, project management, *etc.* are required.
  2) Key decisions need to be made by negotiation leading to consensus.

- ✓ **Fusion has had a long and successful history of international collaboration with obvious benefits to all partners.**
- ✓ **By joining an international consortium to build a BPX, we can take a more aggressive step, saving both development time and money.**
- ✓ **Joining an international consortium to build a BPX would add funding stability to both the construction and operation phases.**
- ✓ **Most of the important design decisions for ITER have already been made. In fact, the US had huge input to the process.**
- ✓ **Physics has no respect for national sovereignty. The operating program will be structured by the need to extract the physics rather than by parochial national interests.**
- ✓ **This is not to minimize the problem, only to point out that the international approach can be made to work. Early participation in negotiations is key.**

FIRE-Based Development Path

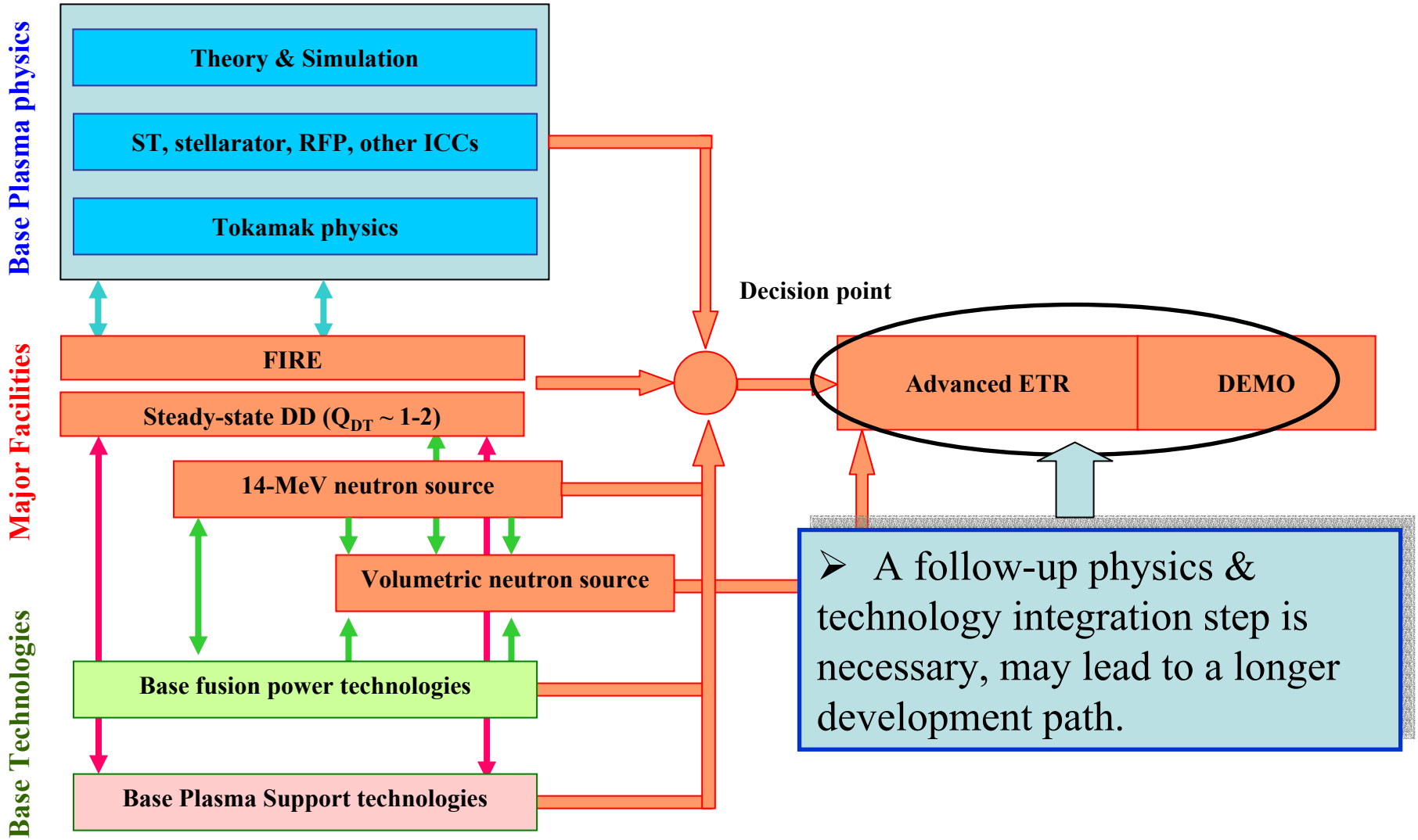


FIRE-Based Development Path



- Reduces initial facility investment costs and allows optimization of experiments for separable missions.
- A lower risk option as it requires "smaller" extrapolation in physics and technology basis.
- Provides further optimization before integration step, allowing perhaps a more advanced and/or less costly integration step to follow.

FIRE-Based Development Path



- A follow-up physics & technology integration step is necessary, may lead to a longer development path.

FIRE-Based Path: Issues & Response

- ➢ It requires accompanying high-performance DD device(s). It is an international portfolio approach.
- ✓ **An alternative to ITER approach.**
- ✓ **A strong candidate as a national device.**

- ➢ Thorough examination of integrated burning plasma physics in advanced modes is limited by low number of full-power DT shots. Requires a follow-up physics & technology integration step.
- ✓ **Number of shots are comparable to present devices.**

- ➢ A follow-up integration step is necessary, may lead to a longer development path.
- ✓ **It may be possible to combine advanced ETR and Demo functions in one device.**

Role of IGNITOR in Fusion Development

- IGNITOR allows early demonstration of an important fusion milestone, burning plasmas.
- IGNITOR has a low initial facility investment cost.
- Because of its short pulse length, IGNITOR cannot thoroughly investigate burn control and/or advanced tokamak modes.

- **As an element of a national base program, IGNITOR would support ITER-based or FIRE-based development scenarios.**

Principal Advantages of Different Development Scenarios

ITER:

- Early exploration and optimization of integrated burning plasma, steady state (AT) operation, and plasma support technologies.
- Minimizes number of steps (and time) to tokamak-based fusion power.

FIRE:

- Reduces initial facility investment costs and allows optimization of experiments for separable missions.
- Provides further optimization before integration steps.

IGNITOR:

- Early demonstration of an important fusion milestone, burning plasmas.
- Low initial facility investment cost.

Fusion Power technologies are the pace setting element of fusion development. Their development requires:

1) Strong base program including testing of components in non-nuclear environment as well as fission reactors.
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Plans for This Week

- Subgroup report, interim results, etc. available on the Web:

  http://aries.ucsd.edu/E4/

- Discussion meeting to finalize the report and summary slides
  - Wed. & Thu. 1:30-4:30 at Roof Top Tent.

- Written comments on the report and summary slides are welcome.