2002 Fusion Summer Study

Development Pathway Subgroup (E 4)

Final Report

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6. Development Path Scenarios

The development path to realize fusion as a practical energy source must include four essential elements:

1) Fundamental understanding of the underlying science and technology;
2) Plasma physics research in a burning plasma experiment;
3) Configuration optimization such as high performance, steady-state operation;
4) Development of low-activation materials and fusion technologies

Burning plasma physics and configuration optimization: A diversified and integrated portfolio consisting of burning plasma experiment(s), steady-state DD tokamak experiments, ICCs, and theory/simulation is needed to develop the necessary predictive capability in burning plasma physics and high-performance state operation and concept operation. The BPX should be flexible and well diagnosed in order to provide fundamental understanding and physics and technology data for the entire toroidal concept portfolio.

Plasma Support 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 as well as the BPX will provide a wealth data on individual technologies. Among the proposed BPX experiments, ITER will provide valuable data on integration of power-plant relevant plasma support technologies.

Low-activation material and fusion power technologies: All scenarios considered require development of low activation material and fusion power technologies for integration at a subsequent device to BPX. Fusion power technologies are in their infancy and are probably a pace setting element of fusion development. Development of fusion power technologies require:

1) A 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. International Fusion material Irradiation Facility (IFMIF) is an example of such a material test facility and has been included in fusion development plan worldwide.
3) A Component Test Facility (CTF) which is sometimes referred to as a volume neutron source (VNS) for integration and test of power technologies in fusion environment with a high duty factor [13]. Such a device should test and integrate fusion power technologies under proto-typical power and neutron flux and fluence and should address reliability of components in a power-plant environment.

There is a strong consensus in the international fusion scientific community that the tokamak is technically ready for the steps to burning plasma physics and steady-state operation. There is, however, a range of opinions (hence different pathways) about the most cost-effective and technically sound approach. Development paths featuring FIRE, ITER, and IGNITOR all require a strong base program, test stands, and companion experiments and, therefore, fit in 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. The contributions of proposed BPXs, ITER, FIRE, and IGNITOR, on the fusion development strategy are described in sections 6.1 to 6.3, respectively. Table 6.1 summarizes the interplay of integrate and optimize versus optimize and integrate approaches of these scenarios. The role of ICCs in the fusion development path is discussed in Section 6.4.

Table 6.1.
Principal advantages and disadvantages of different development scenarios

Development path based on	**Advantages**	**Disadvantages**
ITER-FEAT-class BPX	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.	Higher cost facility investment.
FIRE-class BPX	Early exploration of integrated burning plasma and steady-state (AT) operation. Reduces initial facility investment costs and allows optimization of experiments for separable missions. Provides further optimization before integration steps, allowing perhaps a more advanced and/or less costly integration step to follow.	A follow-up integration step is necessary, may lead to a longer development path.
IGNITOR-class BPX	Early demonstration of an important fusion milestone, burning plasmas. Low initial facility investment cost.	Require an ITER-FEAT-class or a FIRE-class scenario to follow.

6.1. Fusion development scenario based on ITER-class burning plasma experiment

The logic diagram of fusion development scenario with ITER as the major burning plasma device is shown in Figure 6.1. The elements of this development path are described below.

Burning plasma physics and configuration optimization

It is highly unlikely that an ITER-class experiment would be the only large tokamak experiment in the world. National or regional programs will include performance-extension tokamak devices. Most probably, these devices will explore steady-state advanced tokamak physics. These devices are needed to ensure continuation and growth of national expertise and capabilities. More importantly, physics investigations on these performance-extension devices will allow optimum utilization of ITER-class experiment. Smaller devices would allow thorough investigation of individual physics phenomena and act as a test bed for ideas, which can be tested in an integrated manner in ITER. As such, an international tokamak research program centered around ITER and including these national performance-extension devices have the highest chance of success in thorough examination of burning plasma physics in advanced tokamak modes.

Plasma Support Technologies

Because of its size, its relatively high duty factor, and its neutron flux and fluence, will provide valuable data on integration of power-plant relevant plasma support technologies. A strong base program in plasma support technologies (fueling, magnets, heating, PFC) including experiments on test stands is still necessary to develop advanced technologies necessary for power plants.

Low-Activation Material and Fusion Power Technologies

A unique aspect of an ITER-class burning plasma is the capability for limited testing of fusion power technologies. However, because of the low base-line fluence of 0.3 $MW.yr/m^2$ and relatively low neutron flux, there would be a high risk to proceed to an electricity producing device solely based on ITER testing program. As described above, a strong base program, an intense neutron source facility and a CTF/VNS is necessary before proceeding with the DEMO. ITER capability in testing fusion power technologies as well as the ITER experience on integration and operation of a variety of fusion technologies are valuable to CTF/VNS operation.

Decision Point

Successful completion of ITER experimental program (demonstration of high-performance AT burning plasma) will allow tokamak concept to move to fusion power demonstration (DEMO). Here DEMO is defined as a device which incorporates all physics and technologies necessary for an attractive commercial power plant. Alternatively, the tokamak concept may be replaced by an emerging but promising alternative concept. A "success-oriented" time table for fusion development in such a scenario is given in Figure 6.2.

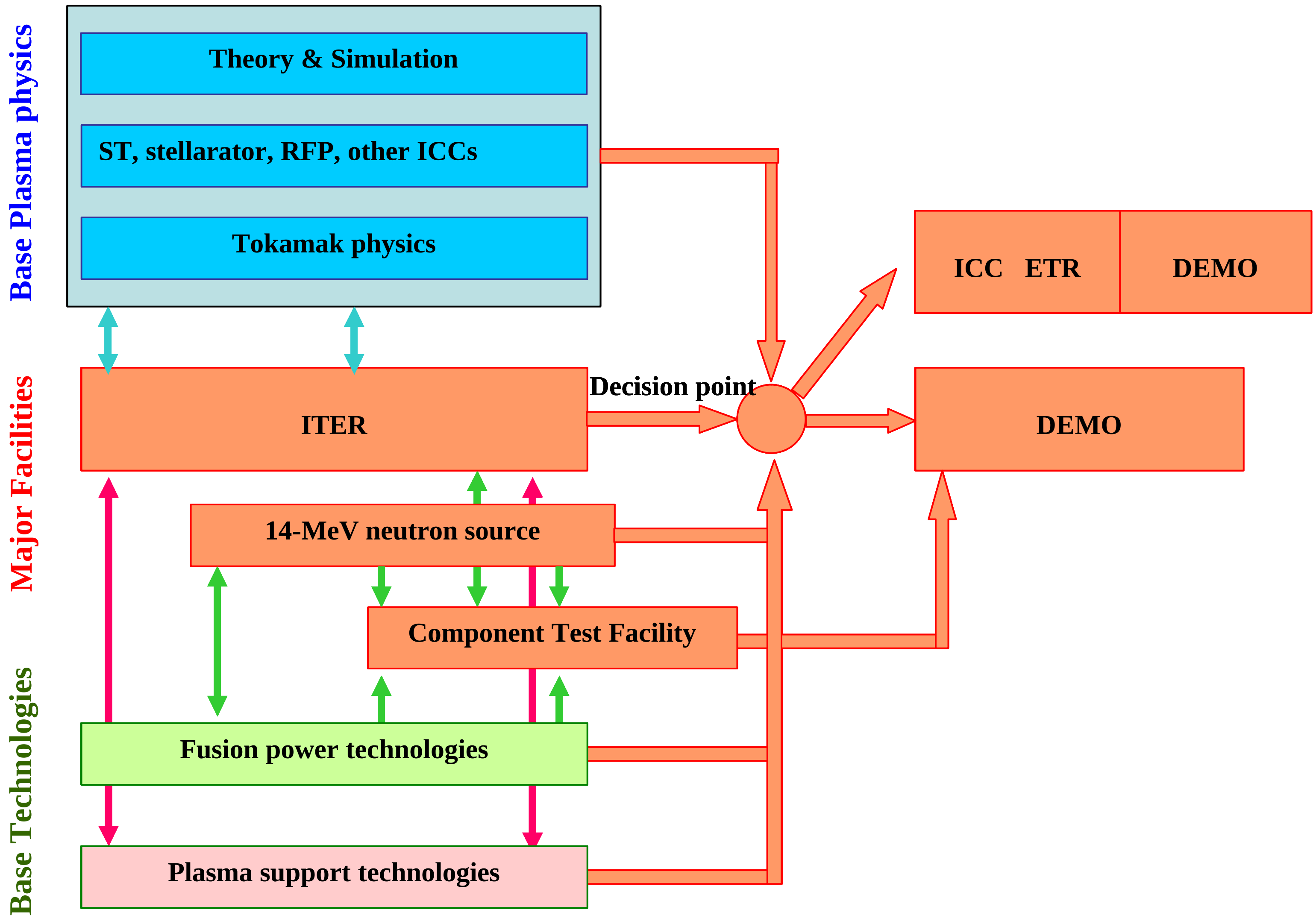

Fig 6.1. Schematic of development path based on ITER-class burning plasma experiment.

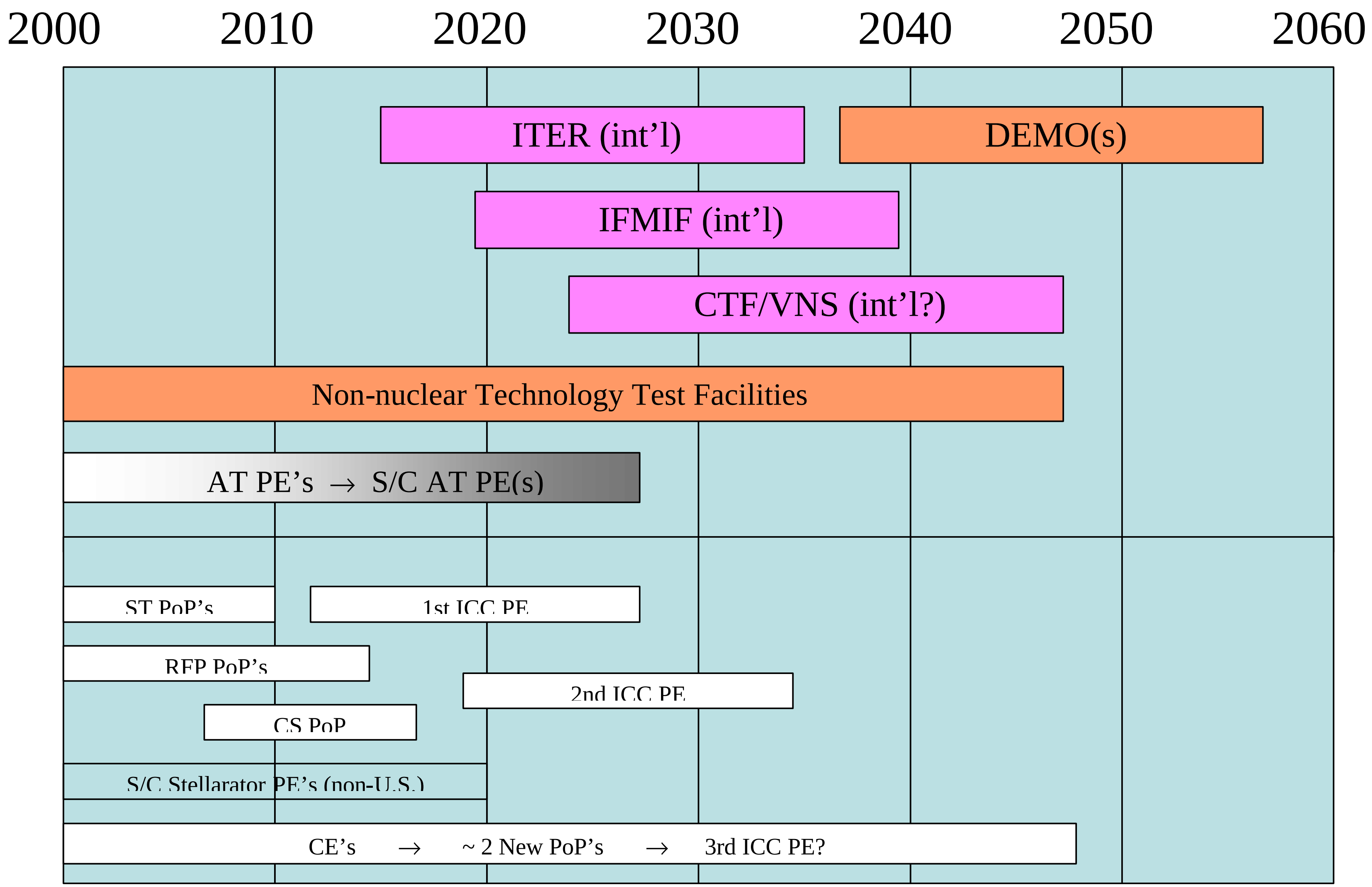

Fig 6.2. A "success-oriented" time table for fusion development scenario with ITER. Boxes indicate facility operation time frame.

An ITER-class BPX allows leapfrog in fusion development path by combination three areas of burning plasma physics, advanced tokamak modes, and plasma support technologies. Assuming successful outcome (demonstration of high-performance AT burning plasma), it would lead to the shortest development time for fusion.

Issues and Responses

Several issues with regard to proceeding with ITER-based development path scenario were identified and discussed during the fusion summer study. These issues and responses are given below:

1) An ITER strategy would have larger initial cost.

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

2) ITER strategy is risky. It must confront all of the major next-step physics/technology issues. In addition, 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.

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

> a) Fusion has had a long and successful history of international collaboration with obvious benefits to all partners.
> b) By joining an international consortium to build a BPX, we can take a more aggressive step, saving both development time and money.
> c) Joining an international consortium to build a BPX would add funding stability to both the construction and operation phases.
> d) Most of the important design decisions for ITER have already been made. In fact, the US had huge input to the process.
> e) 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.
> f) 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.

6.2. Fusion development scenario based on FIRE-class burning plasma experiment (Diversified International Portfolio Pathway)

The goal of the Diversified International Portfolio Based pathway is to provide the technical basis for the ARIES vision. The ARIES studies carried out by a national US team over the past decade have studied a range of potential tokamak fusion power plants ranging from those based on today's physics and technology to advanced systems based on expected innovations in physics and technology. The ARIES-RS and AT design studies have identified the key characteristics needed for a magnetic fusion power plant to be economically competitive and have an environmental impact that is benign in terms of safety and waste:

- Advanced tokamak physics – high β ($\beta_N > 4$), steady-state (high bootstrap current fraction)
- Burning plasma physics – high Q, controlled AT modes, ash removal and stable to TAEs, etc
- Advanced technology – HTS magnets, high temperature thermal conversion, etc
- Advanced materials and fusion power technologies – low activation, neutron resistant

Each of these desired characteristics is a significant advance beyond our present capability, and represents a major scientific and technical challenge. Some of these challenges can be addressed in stand-alone facilities while others are coupled and need to be addressed in a more integrated facility. Many of these technical issues are expected to be resolved on differing time scales. A key strategic question is the sequence and scale at which to do the innovation and integration of these key characteristics. The response to this question defines different pathways.

The Diversified International Portfolio Pathway seeks to address the physics and technology issues and develop the required innovations at the earliest time and the smallest scale (lowest cost). The overall international program would be carried out on several complementary facilities distributed among the major parties; each facility would be optimized to address critical fusion science and technology issues in an integrated international program. This type of multi-machine or diversified portfolio program strategy has been described previously by Rebut [14], PCAST [15], Meade [16] and Baker [17].

The logic diagram of fusion development scenario with FIRE as the major burning plasma device is shown in Figure 6.3. The elements of this development path are described below.

Burning plasma physics and configuration optimization

The major next step plasma physics facilities in the International Portfolio Approach are:

1) **Advanced tokamak physics facilities** to address the high-β, high-bootstrap and non-burning plasma physics issues needed to support the ARIES physics design goals. This would require strongly shaped plasmas, with flexible plasma control capability to explore the full range of advanced tokamak capabilities. The goal of these major next step experiments would be to extend the range of advanced tokamak experiments toward power plant plasma parameters, especially ρ^*. A major objective of these experiments would be to achieve and study advanced plasma regimes in non-burning plasmas with $\beta_N = 5$ and bootstrap current fractions = 90% that are sustained for near steady-state

conditions (many plasma current redistribution times). The programs planned for KSTAR, now under construction in South Korea with a construction cost of ˜ $300M, and JT-60SC under design in Japan with an estimated cost of ˜ $500M would be sufficient to address these issues in a non-burning plasma at parameters approaching those needed for ARIES. The larger of these facilities would have advanced tokamak performance capability sufficient to achieve equivalent Q_{DT} ~ 1 – 2 while operating in deuterium. Very limited DT experiments might also be carried out. These facilities would also address the integration of the advanced plasma confinement with high power plasma exhaust technology, and the integration of superconducting coil technology with the tokamak environment.

2) **Burning plasma facility(s)** to address the burning plasma physics issues expected in ARIES-like plasmas. These include to study and determine: conditions needed to achieve burning plasma conditions, control of an alpha heating dominated (P_α/P_{ext} ˜ 2) plasma, the operating window for stable operation with respect to fast alpha driven instabilities, and study and control plasma heat and particle (alpha ash) exhaust. A plasma facility such as FIRE with pulse lengths ~ 2 plasma current redistribution times would be sufficient to address burning plasma issues in the Elmy H-Mode regime (P_α/P_{ext} ˜ 2). Since this regime does not extrapolate to an economic power plant, it is necessary to extend the burning plasma experiments into the advanced tokamak regime with physics parameters approaching ARIES. The most expeditious way to do this is to incorporate the results from the advanced tokamak facilities into the later phases of the burning plasma experiment. The FIRE experiment, being designed in the US with a construction cost of ˜ $1.2B, has adopted strong plasma shaping, geometry and other advanced features identified by ARIES. FIRE has the capability to study ARIES-like advanced modes up to β_N ˜ 3.7, f_{bs} ˜ 70% and P_α/P_{ext} = 1 under quasi-stationary conditions (=1 plasma current redistribution time).

3) **Fusion Plasma Simulator** to contain comprehensive coupled self-consistent models of all important plasma phenomena that would be used to guide experiments and be updated with ongoing experimental results. Most importantly, the Fusion Plasma Simulator would serve as the intellectual integrator of physics phenomena in advanced tokamak configurations, advanced stellarators and tokamak burning plasma experiments. It would integrate the underlying fusion plasma science with the Innovative Confinement Concepts thereby accelerating their development. This envisioned as a major long term effort requiring additional resources of about $0.4B over a $15 year period.

4) **Non-tokamak facilities** to extend physics understanding, and to develop and test the innovations to improve the toroidal magnetic configuration are an essential part of the magnetic fusion program. Diversified facilities at various stages of scientific exploration are needed to carry the fusion program forward. Two large stellarators (LHD, W-7X) and possibly a large compact stellarator will be available to test confinement, and beta limits under steady-state. The plasma simulation initiative, described previously to integrate advanced confinement and burning plasma physics, must also encompass the non-tokamak configurations. This is needed to facilitate the transfer of innovations from these non-tokamak configurations to the tokamak burning plasma experiments, and to then transfer

the scientific knowledge gained from tokamak advanced burning plasma experiments back to non-tokamak configurations.

5) **A strong base program** in plasma science and technology is needed to provide the scientific basis for the facilities described above, and to provide the technical infrastructure to exploit the capabilities of the next step facilities. In particular, strong computer simulation initiatives are needed provide the medium for integrating advanced confinement physics, burning plasma physics and plasma boundary physics, and for extending the results from the high intensity neutron source to improved designer materials and components.

Plasma Support 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 as well as FIRE will provide a wealth data on individual technologies. Complete integration with burning plasmas is deferred to the follow-up step.

Low-Activation Material and Fusion Power Technologies

As described above, a strong base program, an intense neutron source facility and a CTF/VNS is necessary before proceeding with the DEMO.

Decision Point

Integration of Program Elements is needed to provide the technical basis for the decision on an Advanced Engineering Test Reactor (ETR). FIRE in combination with non-burning KSTAR and JT-60 SC and a strong burning plasma simulation program (Fusion Plasma Simulator) would provide the integrated physics basis (advanced confinement, high power plasma exhaust and burning plasma) needed for the Decision on proceeding with a tokamak-based Advanced ETR (Fig. 6.3). The integration of technology from the CTF/VNS with the super conducting long-pulse advanced tokamak and the advanced burning plasma tokamak would provide the technology basis for the decision on a tokamak Advanced ETR

The physics basis for a stellarator-based Advanced ETR would be provided by information from steady-state non-burning experiments like LHD and upgrades, W-7X and possibly a performance extension compact stellarator (CS), integrated with the burning plasma results from FIRE using the Fusion Plasma Simulator. The technology basis for a stellarator-based Advanced ETR would result from superconducting and plasma technologies developed on LHD, W-7X, KSTAR and JT-60 SC, and nuclear technologies developed on the CTF/VNS.

The output of this program would provide, in about two decades, the information needed to make a decision on proceeding to the Advanced ETR stage where the plasma physics and technologies needed for an attractive magnetic fusion power plant are integrated in a single power-plant-scale facility. The Advanced ETR would incorporate the advanced physics and technology characteristics that were developed and tested during the prior multi-machine period. During the initial operating phase of the advanced ETR the integration of the physics and technologies would be validated, and the facility would evolve into the DEMO.

The benefits of this type of diversified portfolio or multi-machine strategy have been described previously by Rebut (1991) [14], PCAST (1995)[15], Meade (2000)[16] and Baker (2000) [17]. The Diversified International Portfolio Pathway (Fig. 6.3) seeks to address the physics and technology issues and develop the required innovations at the earliest time and the smallest scale (lowest cost). The overall international program would be carried out on several complementary facilities distributed among the major parties, each facility would be optimized to address critical fusion science and technology issues in an integrated international program. This approach allows the individual steps to be undertaken more rapidly, and allows for a more streamlined management approach. The diversified portfolio approach also reduces the technical risk associated with single point technical failures, and failures of a technical approach. There is also flexibility to incorporate non-tokamak configurations in the overall program.

The capital cost of the major facilities in the next phase of the FIRE Based International Portfolio Development Plan are ~$3B (without CTF/VNS) and $5B with CTF/VNS as shown in Table 6.2.

Table 6.2.
Elements for the Next Phase of FIRE-Based International Portfolio

Base Physics and technology program			
Ongoing Advanced Tokamak program (DIII-D, C-Mod, AUG, JET,…)			
New Initiatives and Facilities		Capital Cost	
KSTAR	$0.3B		
JT-60 SC		$0.5B	
FIRE		$1.2B	
Fusion Plasma Simulator – Comprehensive/integrated simulation of BP/AT including non-tokamak configurations		$0.4B	
Fusion Materials Test Facility(s)			
Intense Neutron Source		$0.8B	
Component Test Facility			$2B
PFC test Facility		$0.05B	
Advanced Magnet Development facility		$0.05B	
Others			
Total		$3B	$5B

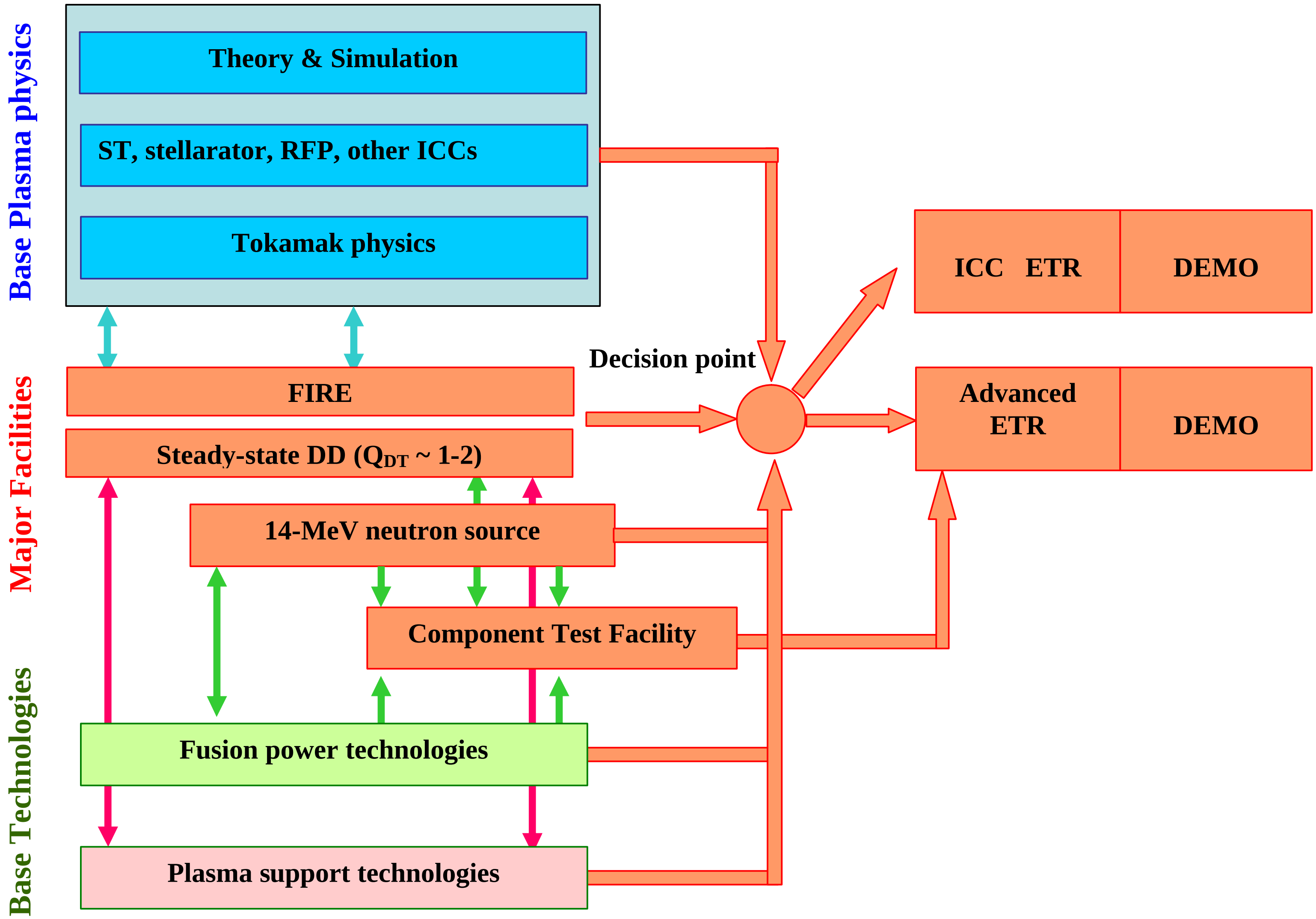

Fig. 6.3. Schematic of development path based on FIRE-class burning plasma experiment.

Issues and Responses

Several issues with regard to proceeding with FIRE-based development path scenario were identified and discussed during the Fusion Summer Study. These issues and responses are given below:

1) 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 thereby requiring only one power-plant scale device to be built, which may shorten the path to an attractive fusion power plant.

2) 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.

> The number of shots is comparable to the number of full-power shots on present devices. A sufficient study of integrated burning plasma physics in advanced modes could be carried out through an integrated program plan that utilized the results from FIRE, the non-burning advanced tokamaks coupled with a strong fusion plasma simulation program.

3) FIRE-based scenario is not a lower cost option as the cost of follow-up integration step should be included.

> This scenario has a lower cost first stage which allows further optimization before the integration step, allowing either a more advanced and/or less costly integration step to follow. Most importantly, this plan requires the construction of only one power-plant-scale device.

4) It is an international portfolio approach requiring international participation. However, the international community is planning to proceed with ITER.

> Many of the elements of this international portfolio are already in place or under consideration. Since the construction of ITER is not certain, the design study and optimization of the FIRE device should continue in case ITER is not constructed. In addition, FIRE device itself is a strong candidate as a national base program device in support of ITER-based scenario.

6.3. Fusion development scenario based on IGNITOR-class burning plasma experiment

The major advantage of IGNITOR is demonstration of fusion burn, a major milestone for fusion energy development, at earliest date and at the lowest 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.

6.4. Role of ICC’s in the Fusion Energy Development Plan

A sound magnetic fusion energy development plan includes the advancement of a portfolio of magnetic confinement configurations as one of its key elements. This is necessary for generating a validated and reliable predictive capability for magnetic confinement that spans multiple concepts and for ensuring that decisions on future steps will be the best from a range of choices. The portfolio includes a spectrum of toroidal configurations, including the tokamak as well as non-tokamak variants, which are distinguished by variables such as the plasma shape, the magnetic field twist, the degree to which their magnetic fields are generated by plasma currents or by coils, and how they are maintained in steady-state. The portfolio also includes concepts quite different from the tokamak which strive to make the path to fusion energy much faster and/or cheaper. All can contribute to decisions on fusion development beyond the burning plasma experiment and to the overarching goal of developing a predictive capability for designing fusion energy systems.

In the U.S. program, all non-tokamak configurations are often called Innovative Confinement Concepts (ICCs). The pulsed tokamak is sufficiently developed to be the basis for a burning plasma experiment (BPX) which will be used to develop the physics and technology of burning plasmas for magnetic fusion. The broader portfolio is being developed with a view to developing the best fusion energy sources and for advancing the fundamental understanding of plasma physics that comprises the scientific basis for fusion energy. The requirement for coherent integration across elements in the fusion program drives each element to develop a level of understanding and predictive capability such that knowledge transfer across magnetic configurations becomes possible. In this sense, developing a predictive capability for ultimately designing the best fusion power plant is the integrating principle across program elements.

In the U.S., a framework for studying ICCs has been established in recent years, with options advancing through stages of development. Ideas are initially explored at the Concept Exploration (CE) level, progress to more integrated configuration studies at the Proof-of-Principle (PoP) level, and approach fusion parameters at the Performance Extension (PE) stage. The U.S. has proof-of-principle programs in spherical tori, compact stellarators, and reversed-field pinches. Spheromaks and field-reversed configurations are at the concept exploration stage. In the worldwide program, the tokamak and the stellarator are currently at the Performance Extension stage.

The development of ICC’s in the framework of a fusion energy development plan leading to DEMO is shown in Fig. 6.4. It is expected that the portfolio will mature, with concepts advancing from PoP to PE, and from CE to PoP, based on merit, in parallel with the construction and operation of a burning plasma experiment. The role of this advancing portfolio in the overall development path is explained next.

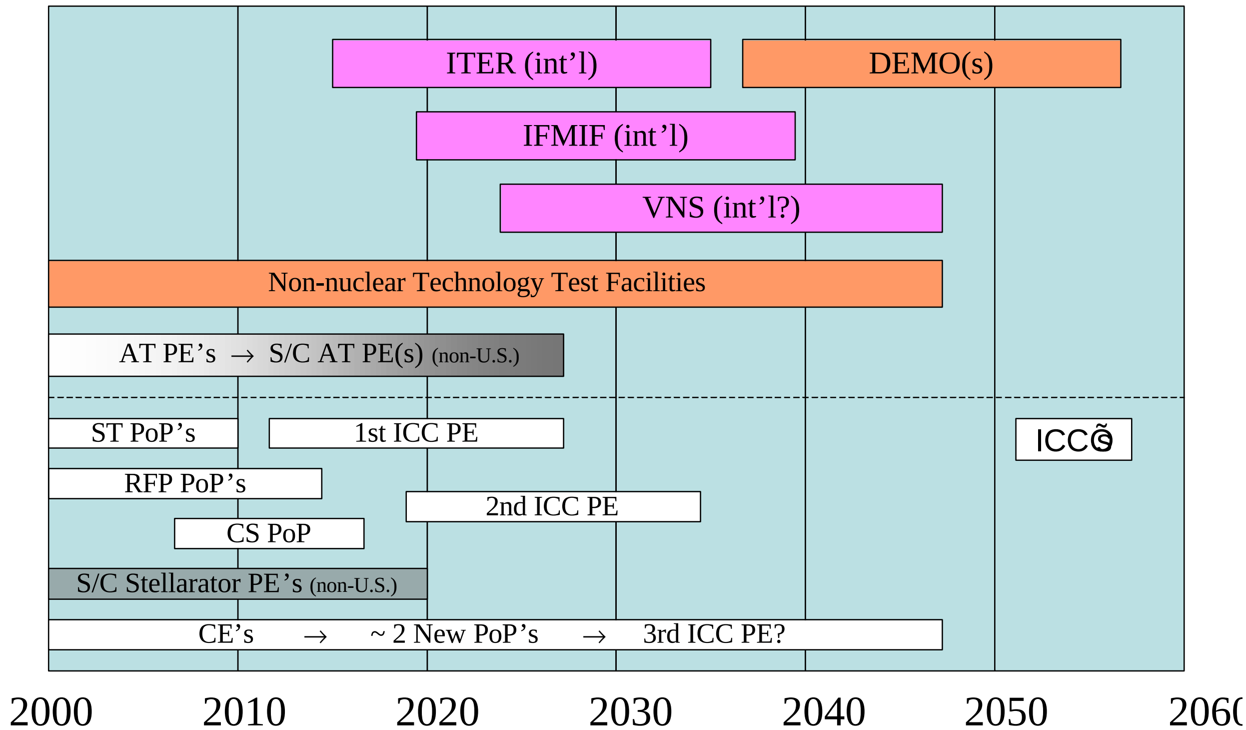

Fig. 6.4. Development Plan Leading to an MFE DEMO.

6.4.1. Role of ICC's in DEMO Development

The knowledge base for DEMO configurations decisions will require a mature portfolio. This requirement can be satisfied by continuing to follow the current ICC development strategy. The three configurations that are now at the proof-of-principle stage are more closely related to the tokamak and in the next 5-15 years are natural candidates for promotion to performance extension, joining tokamak and the stellarator at the PE stage. (Fig. 1 assumes, for planning purposes, that two of the three are promoted.) Concepts presently at the CE stage could advance to the PE stage on a somewhat longer time scale. Clearly a substantial performance extension knowledge base spanning a large range of toroidal configuration variables can be made available by the time DEMO decisions need to be made, in about 2025.

This plan has an excellent chance of developing magnetic configurations by ~2025 that are preferable in terms of power plant economics to the tokamak configuration being adopted now as the basis for the BPX. It would be desirable for the DEMO design to adopt such an improved configuration, but a question is whether it would require an intervening burning plasma step to confirm the new configuration, delaying fusion development. While the possibility of such a delay cannot be ruled out entirely at this time, it can plausibly be avoided. Consider for purposes of illustration the stellarator, which already has two PE-class experiments (LHD in Japan and W7-X in Germany) and could add a third in the late 2010's if the CS is successful at the PoP stage. There will be a substantial experimental data base on stellarator physics and long-pulse integration at near-power-plant plasma parameters by 2025. Meanwhile, the BPX will develop a knowledge base on toroidal physics in the regime of alpha-dominated, large-size plasmas in a tokamak. Together, this base of knowledge will underlie validated predictive models for advanced toroidal systems performance. Given the programmatic commitment to dramatic advances in fundamental understanding and predictive theory and modeling of both tokamak and stellarator physics in this time period it is probable that sufficient fidelity in our predictive capabilities will allow for the performance data of a tokamak BPX to be extrapolated to the stellarator with sufficient confidence for a DEMO step. On the technology side, the knowledge developed in BPX should be readily transferable to stellarators.

The illustration above depends on the close similarity of the stellarator to the tokamak. More importantly, to firmly establish a basis for any DEMO, it will be crucial to demonstrate more general predictive capability in toroidal magnetic confinement physics, spanning the full range of configuration variables. The robustness of predictive science will be demonstrated only when major configuration knobs are adjusted and the outcome correctly predicted. The elements of the toroidal magnetic portfolio must therefore mature together and in synch with the tokamak BPX.

While it must be acknowledged that the path to fusion beyond the BPX could prove to be more complicated and longer, success in developing the ICC's does not inevitably mean a delay in developing fusion energy. Indeed, the strategy of developing a portfolio of configurations and predictive capability in parallel with a tokamak BPX increases the range of options available for choosing the best path beyond the BPX to a to a practical fusion DEMO and may well shorten the development time.

6.4.2. Role of ICC's in Component Test Facility Development

The discussions at Snowmass-2002 have highlighted the importance of a volume neutron source, or component test facility, as an element of the fusion development plan leading to DEMO. Its role in this plan is to support the development of fusion power plant components such as blankets by providing a facility for testing them at moderate to high neutron flux and fluence and under power plant conditions. With sufficient progress in their physics development, an advanced tokamak or a spherical torus operating at substantial duty factor (~30%) but possibly low fusion gain (Q=1-2) could meet the requirements for component testing. The challenge is to demonstrate adequate physics performance and develop a non-inductive operating scenario on the needed timescale, i.e. almost two decades before DEMO operation. The ST is of particular interest for this application because of its compact size. If its primary PoP physics goals (high beta, good confinement, and non-inductive current drive development) can be expeditiously achieved, the ST could become the first of the current PoP concepts to move to a PE-class device, which could complete the ST physics development needed for a component test facility. An updated study of component test facility options would take into account advances in understanding and performance of the concept portfolio.

6.4.3. Implications for Achieving Predictive Capability in Toroidal Confinement

A key element of our strategy for fusion energy research is a permanent commitment to deepening our understanding of the physics of magnetically confined plasmas and developing a reliable, validated predictive capability for their behavior. Such a capability is needed for designing facilities and the experiments conducted on them to have a high probability of success.

The ICC portfolio has a central role in this strategy because they provide strong tests of theoretical ideas and they produce experimental data needed to validate models applicable across the portfolio. A flexible, well-diagnosed tokamak burning plasma experiment is a key requirement of this strategy, so that it can contribute to fundamental physics understanding needed to predict performance not only in tokamaks but in other closely-related configurations as well.

In summary, advancement of a portfolio of magnetic configurations is a central feature of our plan for fusion energy development. The portfolio will provide the knowledge base for selecting a DEMO configuration, will support the design of a component test facility, and will rapidly advance the predictive capability for fusion plasma behavior. The portfolio must be developed in a coherently integrated program, not as separate concepts, to test physics understanding and provide efficient knowledge transfer across the portfolio. The integrated development of a BPX, a portfolio of configurations, and theory and modeling will provide the predictive capability needed to develop fusion energy.

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