An Outline Roadmap for Fusion Energy Science: A Portfolio Approach
– *Discussion Draft* –

Working Group

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Introduction and Overview

Fusion is one of only a few long-term energy supply options. It offers the possibility of an economically and environmentally attractive system for producing central-station electric power, beginning in the middle of the next century. Fusion energy research also provides important near-term scientific and technological benefits to society.

While fusion energy science is supported within the U.S. as a science program, it is necessary to consider this program in the context of its ultimate goal, the ability to proceed to the development of a practical energy source, when so decided by the Nation. As part of this consideration and in the spirit of a science program guided by peer review, this draft Outline Roadmap is prepared for broad discussion.

This Roadmap includes both magnetic fusion energy (MFE) and inertial fusion energy (IFE) approaches within a unified framework, designed to build on the successes in each of these programs. The experimental results of the last decade indicate that fusion can be an energy source, and the challenge now is to optimize the science to make it practical and affordable. This is the central focus of this roadmap.

The roadmap is based on the three-element Fusion Energy Sciences programmatic strategy, composed of:

1) National Stewardship of Plasma Science and Technology.
2) Concept Innovation as the Centerpiece of the Domestic Program.
3) Energy-Producing Plasmas and Fusion Energy Technology, Pursued Internationally

This strategy forms the core of the restructuring of the Fusion Energy Sciences program, which has strong support from Congress, from DOE, and from the fusion energy research community. In this document we propose to implement this strategy through a portfolio approach, which focuses on science, balances risk and promise, and leads ultimately to the most attractive fusion power systems. The portfolio approach described here will provide the needed scientific and technical information in the next five years to decide on whether and how to move fusion into an energy development stage.

Specifically, the strategy discussed here will continue to strengthen general plasma science and technology research. It will broaden the fusion research program to include both a wider range of innovative magnetic confinement concepts and also a stronger program in Inertial Fusion Energy, while sustaining the vitality of the existing major tokamak user facilities. Energy producing plasmas will be studied through international collaboration in MFE, and through DOE Defense Programs facilities in IFE. (DP facilities play a role for IFE parallel to role of the strong international MFE research program for MFE.) Designs will be developed for significant next-step facilities in both MFE and IFE, for decision on construction most likely in the 2003-4 time-scale. These research activities will be supported by programs in Fusion Technology and Materials and in Theory and Advanced Computational Simulation. The latter will benefit from a strong role in the DOE Scientific Simulation Initiative. We believe that this scientific program is consistent with the strategic goals of the DOE, and with wise technical judgment.

The incremental cost for this broadened program, over present investments in DOE Defense Programs, Inertial Confinement Fusion and in DOE Office of Science, Fusion Energy Sciences, is approximately $66M/year. This funding should be provided within DP or SC as deemed appropriate by DOE, consistent with issues of national security and program goals. A closer collaboration of the ICF and OFES programs should be undertaken in this context.

Consistent with the science identity and goals of the Fusion Energy Sciences program, all elements of the existing and future program discussed in this outline roadmap are subject to continuing careful and extensive broad-based peer review, and this roadmap itself is presented as a discussion draft. Thus the program elements and levels of funding discussed here are in this important sense provisional, and subject to change on the basis of ongoing peer reviews of technical progress and promise.

The Next Five Years

The proposed near-term (1999-2003) emphases for each of the three Fusion Energy Sciences programmatic strategic elements are:

1) *National Stewardship of Plasma Science and Technology:*

<u>Increasing support for national science and technology goals using plasmas.</u> Plasmas, the fourth state of matter, are of great scientific interest, because most of the visible universe is composed of plasma. Furthermore, the practical applications of plasmas and associated technologies in industry are of growing importance to the national economy. Basic research in plasma science and associated technologies is therefore a key contribution of the fusion program to the nation. Increased support in this area is needed to optimize this contribution.

The Office of Fusion Energy Sciences, in cooperation with NSF, has taken responsibility for national stewardship of plasma science and technology. The Inertial Confinement Fusion program has been primarily responsible for the development of the science and technology associated with inertial fusion. The scientific work done in the bulk of the MFE and IFE programs drives strongly the advance of plasma science and associated technologies. This includes important contributions from both the broad portfolio of Concept Innovation experiments as well as the large national tokamak and inertial fusion facilities. However funding for general Plasma Science and Technology, outside of direct fusion application, needs to be strengthened to take optimal advantage of the multiple spin-offs from the fusion research programs. In the MFE arena these range from fundamental understanding of plasma processes in the earth's magnetosphere and of the theory of chaos to uses of plasmas for computer-chip processing, in space thrusters and for waste remediation. In IFE these applications range from high energy density science of interest in astrophysics and condensed matter physics, to laser and pulsed power technologies and advanced lithography. The cross-communication between fusion and other areas of plasma science enhances the level of scientific excitement in both areas, and brings talented young researchers into the discipline.

2) *Concept Innovation as the Centerpiece of the Domestic Program:*

Strengthening of the “portfolio” of plasma confinement concepts, in both MFE and IFE, as potentially attractive fusion energy sources. A central element of the restructured fusion program is to explore promising ideas for improved fusion concepts, including improvements to the leading tokamak concept. This effort builds on the major advances in the knowledge of fusion physics gained particularly over the last decade, coupled with greatly improved methods for measurement of critically important local plasma parameters. With this new understanding in both MFE and IFE in areas such as plasma turbulence, nonlinear instabilities, particle and radiation transport, MHD stability, wave-particle interactions, and the plasma/material interface, both old and new fusion ideas can be evaluated more thoroughly, and promising ideas can be more readily identified. This naturally leads to the use of a “portfolio” approach. To provide a framework to assess the relative level of development among the different fusion concepts being pursued and to permit the application of appropriate objectives and criteria for success within the fusion portfolio, concepts are expected to advance through a series of distinct stages of experimental development. These stages are identified as “Concept Exploration”, then “Proof of Principle”, followed by “Performance Extension.” Success in these stages then should lead to the technical and scientific basis for making a decision to advance the concept to a stage of “Fusion Energy Development,” and ultimately to a fusion demonstration power plant, as illustrated in Figure 1.

In the Concept Exploration stage, after careful competitive peer review, a promising new idea is typically first tested in a low-cost exploratory experiment, designed to validate the most basic aspects of the concept. If the scientific merit and power-plant attractiveness of such a concept proves favorable through these initial tests, after further detailed review it can graduate to the Proof of Principle stage. This stage includes more complete experimental tests of a range of key scientific and technical principles, although typically still with plasma conditions at a considerable distance from those of a fusion power source. With further peer review of scientific progress and of promise for an attractive power-plant implementation, and taking into account the impact on the full research portfolio, the most successful concepts can then be moved to the Performance Extension stage, with plasmas closer to fusion parameters, in more powerful devices, for more rigorous testing. This stage is likely to include more than one major facility, for example extending fusion gain and pulse length (or time-average power) in separate devices. Validated success at this level would provide the basis to make a decision to proceed with to the construction of full-scale Fusion Energy Development facilities, among which are devices to produce fusion-relevant plasmas using (and testing) technologies for fusion power plants. Such facilities can be designed to produce modest amounts of electric power, on a non-commercial basis. Strong programs of enabling technology development, and of theory and advanced computational simulation are required to support each of these steps.

Figure 1 illustrates how this portfolio approach is applied to both MFE and IFE.

MFE

Within the U.S. MFE program ten peer-reviewed confinement concepts are currently under experimental study at the earliest, and least expensive, Concept Exploration stage. These concepts each support a “vision” for an improved fusion system. Two examples which illustrate the breadth of this research are the Spheromak and the Levitated Dipole. The Spheromak is a compact toroidal system, with no coils threading the plasma torus, thus giving it very favorable geometry as a power system. If plasma confinement can be improved sufficiently in this device, it would lead to an attractive DT power plant. The physics of magnetic reconnection in the spheromak is closely connected with the physics of the solar corona and of coronal mass ejections. The Levitated Dipole, on the other hand, is a larger plasma system, with the main current carried in a superconducting ring, levitated magnetically within the plasma itself. If the confinement and plasma pressure of this device are favorable enough, as suggested by initial theoretical analyses – and by the stability of the closely related Jovian magnetosphere – it may be possible to use it to burn non-DT fuels, which would be an attractive possibility. Additional funds are proposed in the Concept Exploration area to allow new concepts such as these to be explored (including exploratory IFE concepts discussed below) and/or for improved diagnostics and auxiliary systems on existing experiments. Entry even at this lowest funding level has been and will continue to be based on careful peer review.

Exciting new results from the small START spherical torus experiment in England show both good energy confinement, and very high plasma beta (plasma pressure divided by magnetic pressure). The fusion energy development path for the Spherical Torus is potentially highly cost-effective, and the power-plant implementation is attractive. Thus the Spherical Torus, or ST, is about to begin experimental test in the National Spherical Torus Experiment (NSTX) at the next-higher Proof of Principle stage. NSTX will be operated as a national user facility. An experiment at a similar scale, but with complementary research capabilities, MAST, is also under construction in England. Two other magnetic confinement concepts have recently been positively peer-reviewed for advancement to the Proof-of-Principle stage: the Compact Stellarator (CS) and the Reversed-Field Pinch (RFP), both of which are potentially very attractive confinement concepts. The Compact Stellarator promises disruption-free operation and very low recirculating power. It is designed to exploit the thermoelectric current to stabilize the slow tearing instabilities seen in tokamaks, and 3D geometry to prevent the magnetic chaos associated with disruptive instabilities. The Reversed Field Pinch, with a much lower magnetic field than the tokamak, offers the possibility of greatly reduced cost for magnetic field coils, and like the Spheromak, its physics is closely related to that of the solar corona. Magnetized Target Fusion (MTF) – which is intermediate between MFE and IFE – has also been positively peer reviewed and may offer an inexpensive route to significant fusion energy release. Under the proposed plan, these experiments, or others at this level of development, will be implemented in the near future.

The tokamak has achieved impressive plasma performance: fusion power of 11 MW in the U.S. Tokamak Fusion Test Reactor (TFTR) device and now 16 MW in the European JET facility, with fusion yield of up to 20 MJ per pulse. Deuterium-tritium energy gain of 0.6 (defined as fusion power yield / power provided to the plasma) was achieved in these experiments. Tokamak research has also driven forward scientific understanding of macroscopic stability and microscopic transport in hot plasmas. Excellent quantitative predictability of many aspects of stability and transport in high-temperature plasmas has now been achieved, on the basis of complex numerical simulations. These tokamak scientific results have also strongly supported concept development in other plasma configurations, such as the ST, CS and RFP. In essence these tokamak results show that toroidal magnetic confinement systems can be used to produce fusion power, and the remaining challenge is to optimize these systems for a practical energy source.

As compared with the conventional, pulsed tokamak, the “Advanced Tokamak” (AT) operating regime offers the further potential for fully steady-state operation, and for higher fusion power density, leading to an attractive reactor concept. This is the focus of a strong international research program, which has already shown dramatic improvements in plasma confinement in AT regimes. The “advanced-tokamak” concept is now beginning to be tested at the Performance Extension stage in two tokamak devices in the U.S.: DIII-D and Alcator C-MOD, which are operated as national user facilities. However key profile-control tools are needed for full tests of AT regimes at the Performance-Extension level on the U.S. experiments, and modest additional funding is required for this purpose.

IFE

Within IFE, high priority is proposed for research on indirect-drive IFE with ion beams (including numerical modeling, target design and chamber technology relevant both to indirect drive and direct drive), at the Proof-of-Principle level, as recommended by two FESAC Reviews. This emphasis is also driven by the completion on Nova of Proof-of-Principle target experiments on indirect drive, as part of the construction decision for the National Ignition Facility (NIF), and by the fact that Performance-Extension experiments on indirect drive form a critical early objective of NIF. Recently developed high-performance target designs for ion-beam indirect drive also support this conclusion.

Recent advances in both laser technology (krypton fluoride and solid state lasers) and in target physics, particularly increased understanding of Rayleigh-Taylor instabilities, have also significantly improved the prospects for laser-driven direct-drive IFE. It is proposed in this plan that laser technologies be advanced as well, subject to appropriate peer review. Furthermore it is anticipated that Proof-of-Principle direct-drive experiments will be pursued by DOE Defense Programs / Inertial Confinement Fusion (DP/ICF) at the Omega and Nike facilities in the near future, and that Performance-Extension direct-drive target studies will be undertaken at NIF after accomplishment of its indirect-drive goals. Innovative concepts in IFE (*e.g.,* fast igniter) are proposed to be pursued at the concept-exploration level.

Recently fast z pinches have produced x-ray pulses with unprecedented power and energy. These x-ray sources are now being developed in configurations which have the goal of driving inertial fusion capsules. A high-yield facility using a z-pinch driver, called X-1, has been proposed to follow the demonstration of ignition on NIF, for national security purposes. Because of the high x-ray power and energy available in current z pinches, there are possible applications of existing technology to IFE chamber studies. Very little research has been done to apply fast z pinches to the production of fusion energy. The rapid progress in performance of these sources warrants support for concept-exploration level peer-reviewed proposals for research into their application to IFE.

Fusion Technology and Materials

The near-term emphasis of this program is on developing better tools for the production and control of high-temperature plasmas. Examples include techniques for heating plasmas to thermonuclear temperatures, methods for accurately injecting IFE targets at high speed, means for injecting particles and extracting "ash" and heat from MFE fusion systems, and the development of powerful and reliable large magnet systems. Near-term benefits to society from these R&D activities include the development of superconducting magnet technology, microwave technologies, plasma processing of computer chips and circuits, coating of materials, waste processing, space propulsion systems, plasma electronics, and improved materials for high-temperature applications.

The longer-term emphasis of the program is on resolving key feasibility issues for the development of fusion energy. These include, both for MFE and IFE, extraction and utilization of heat from fusion reactions, breeding and handling of fuel (tritium) in a self-sufficient system, demonstration of reliable operation, and realization of the safety and environmental potential of fusion energy. Incorporation of improved and new materials into well-engineered systems with strong attention to safety and environmental features is the crucial element. Here the development of reduced-activation materials is particularly important.

With the transition from strong U.S. involvement in ITER to support for a broader portfolio of tokamak and non-tokamak initiatives, this program will also take on a broader focus, examining attractive new approaches. With the roll-off of ITER activities only a specific strengthening of the IFE component of the program is proposed here.

Theory and Advanced Computational Simulation

A key role is played in this program, at all levels of development, by theory and advanced computational simulation. In MFE, recent years have seen dramatic advances in quantitative predictive capability for macroscopic plasma stability, for thermal transport in plasmas, for wave propagation and heating, and for plasma-wall interactions. These areas of theoretical research have strong and close ties, and provide reciprocal benefits to, space and astrophysical plasma physics research, fluid turbulence and chaos research, and to the development of plasma systems for materials processing and space propulsion, to name a few.

Significant advances have also been made in the simulation of high-current ion accelerators, and in IFE target design, including 2D and increasingly 3D calculations of nonlinear hydrodynamic instability of pellets. The theoretical work on intense ion beams has close ties to other high-current beam R&D such as the Spallation Neutron Source, the Accelerator for the Production of Tritium, and x-ray backlighting systems for Defense Programs facilities. Theoretical radiation-hydrodynamic studies are closely coupled with analyses of astrophysical phenomena such as supernova explosions.

The new DOE Scientific Simulation Initiative (SSI), which seeks to accelerate progress in realistic modeling capabilities, will provide access to more powerful computers, and equally importantly will provide computer science support for the development of more advanced computational algorithms. The current SC/OFES funding for theory and advanced computational simulation is $21M/year. A significant increment associated with the SSI is anticipated to provide the enhanced capabilities required to support the proposed experimental program in both MFE and IFE.

3) Energy-Producing Plasmas and Fusion Energy Technology, Pursued Internationally

Pursuing within MFE a strong program of research collaboration on energy-producing plasmas using the powerful scientific facilities abroad, while participating actively in an international effort to define lower-cost next-step facilities. This international research program in MFE is presently supported at over $1 billion annually, and represents enormous potential leverage for the US domestic program. The program described here includes a more active role for the U.S. Fusion Energy Sciences program in scientific participation on the billion-dollar class magnetic fusion facilities operating or under construction abroad (the major tokamaks JET in England, JT-60U in Japan and KSTAR in Korea, the stellarators LHD in Japan and W7-X in Germany), in order to take greater advantage of their advanced scientific capabilities. These facilities will permit advanced ideas developed in the U.S. to be tested at larger scale.

In addition, international processes within multi-lateral and/or bilateral frameworks, should be used to define and assess next international MFE steps at the advanced Performance-Extension or Fusion Energy Development levels. These international activities will maintain a strong collaborative presence for the U.S. fusion program abroad, consistent with DOE goals articulated by Secretary Richardson, despite termination of U.S. involvement in ITER design. To carry out the new and expanded activities described here, we propose to use some of the funds made available by the termination of ITER activities. Hence no additional funds are requested in this area.

The tokamak concept is presently at the stage of readiness to pursue burning plasma physics, and a significant contingent of scientists both in the U.S. and abroad support moving forward expeditiously either with the reduced-cost/reduced technical objectives version of ITER under design by Europe, Japan and Russia, or with a more compact copper-coil burning plasma experiment. The timing of the international decision processes involved in moving forward with a burning plasma experiment of either sort is uncertain, and could come before the 2003–4 timescale estimated here. It is imperative therefore to be prepared for such an early opportunity, by pursuing the definition and assessment activities described above.

Studying within IFE the physics of indirect-drive fusion using NIF, starting in 2002, with ignition and significant fusion gain expected in about 2007, and then studying direct-drive ignition physics starting in ~2008. This DP-supported research, using a billion-dollar class facility, will first provide critical information on ignition and significant gain with indirect drive and then will also investigate direct-drive physics, possibly providing even higher fusion gain. A collaborative program on non-classified topics will be undertaken with Lasér Megajoule (LMJ) in France, which will also be an advanced Performance-Extension class facility in the billion-dollar class.

The Assessment in 2003–4

The roadmap outlined above will lead to the necessary knowledge base, and next-step device designs, for a key assessment in 2003–4 of whether and how to move into a more aggressive fusion energy development program. Success with one or more of the present front-running MFE or IFE concepts will provide the technical justification for such a step. If these concepts, on the other hand, do not show adequate progress and promise, then other concepts in the portfolio, which look potentially more attractive at that time, would move into the lead roles in a rebalanced portfolio.

In the 2003-4 time frame key decisions could concern:

At the Proof of Principle level:
- Next-step facility or facilities for MFE and/or IFE concept development, possibly taking advantage of existing infrastructure at one or more of the existing U.S. facilities.

At the Performance Extension level:
- A next-step DT Spherical Torus (DTST) to establish the scaling of ST physics towards power-producing plasma conditions.
- Integrated Research Experiment(s) (IRE) for IFE, capable of addressing issues associated with average-power drivers (ion beams and/or lasers), target fabrication, and chamber technology, for direct and/or indirect drive.

At the Fusion Energy Development level:
- A reduced-cost superconducting DT tokamak Engineering Test Reactor (ETR), (*e.g.*, a reduced-cost ITER. The decision to participate in ITER construction could arise in 2001.)

– or a combination of two powerful *Performance Extension* class devices:
    - A copper-coil burning plasma Advanced-Tokamak facility (DTAT) +
    - A superconducting-coil steady-state DD Advanced-Tokamak facility (SSAT).
- A Point Neutron Source (PNS) for materials development for both MFE and IFE.

The decision to take the steps at the Performance Extension and Fusion Energy Development levels in ~2003-4 will be based on strict peer-reviewed standards of scientific merit, cost-effectiveness, and attractiveness of the ultimate fusion power plant. If the decision is taken to move fusion development to the higher levels at that time, a budget increase in the range of ~$100M/year would be required. A Secretary of Energy Advisory Board Subcommittee may be asked to provide advice on this key decision, in part because the decision to move forward to the fusion energy development level will depend on factors outside of fusion research, including the degree of success of other energy technologies (*e.g.,* carbon sequestration), further knowledge about global climate change, and the perceived need for new energy sources. In all cases, international collaboration will be pursued vigorously in order to make maximum use of U.S. investments. As a result, the timing of key U.S. decisions may need to be adjusted to account for international processes, such as the ITER construction decision, or a proposal to proceed with a compact burning plasma experiment. Other decisions, for example to advance the Compact Stellarator to the Performance Extension level, might occur in the ~2010 time frame. Lower-level portfolio decisions will occur more frequently.

Energy Production from Fusion

Success with this portfolio-based plan, including both the facilities described just above and the supporting programs in technology and theory and advanced computational simulation, will provide the knowledge base to proceed in ~2015 with the design of fusion devices, in MFE, IFE or possibly both, capable of producing electric power on a precommercial basis. Such facilities could be on line by 2025. The first demonstration power plants would be available then in mid-century.

SC/DP Collaboration

Closer collaboration on fusion energy is desirable between the DP/ICF and SC/OFES efforts. Some aspects of IFE research should be managed within DP/ICF for example because of direct relevance to national security applications, use of sensitive technologies or application of classified codes, but other aspects of Fusion Energy Research are more appropriately managed within SC/OFES. The appropriate division needs to be resolved within DOE. A closer coordination of the IFE-related DP activities with SC/OFES activities, however, is clearly warranted, and should be overseen by the Fusion Energy Sciences Advisory Committee.

Funding Increment

The funding increment during the period up to 2003–4 for the program described here totals $66M/year over the FY99 Congressional budget, exclusive of funding for the DOE Scientific Simulation Initiative, as shown in Table 1. The incremental funding is about evenly split between MFE and IFE related elements. This level is conservative relative to recent PCAST recommendations, while the proposed program is broader. The specific breakdown outlined here is only indicative, and will be the subject of a series of ongoing reviews. However budgets in this range will certainly be required to support the broadened research program outlined here.

Conclusion

The central deliverable from this proposal is that in the next five years key scientific information and design concepts will be developed such that an informed assessment can be made as to whether and how the United States should move forward more aggressively with fusion energy development starting in the 2003 – 4 time frame. This clearly defined goal, coupled with the broader scientific portfolio rigorously advocated here, will help to revitalize the U.S. fusion energy sciences program. The timing of the 2003 – 4 decision is commensurate with the time scale for key information on global climate change to be accumulated and for progress in other energy technologies to be assessed.

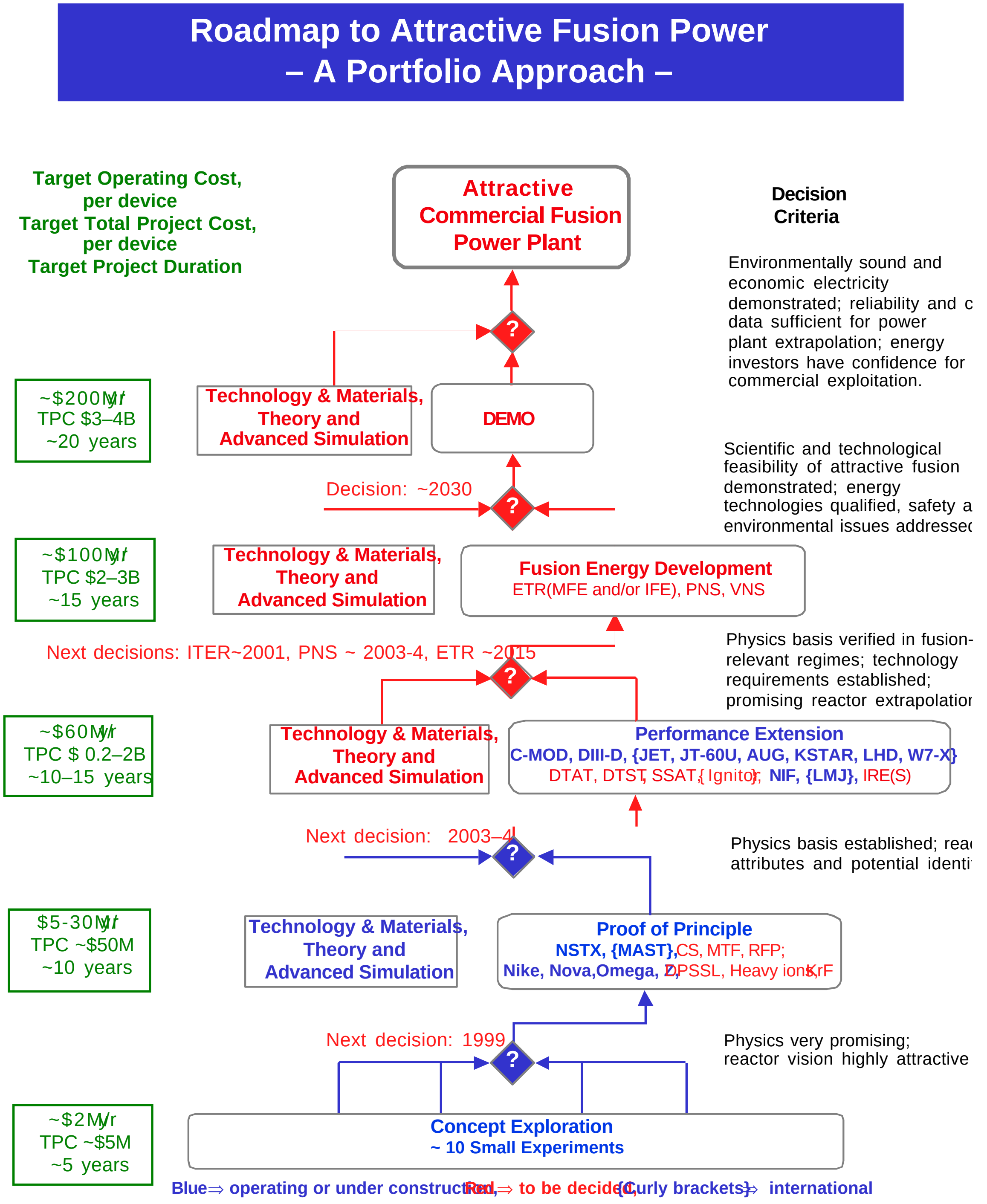

Figure 1: Roadmap to attractive fusion power, illustrating stages of fusion energy development, and the role of the portfolio concept.

Example Budget

	FY99 Cong. SC/OFES	FY99 Cong. DP/ICF	Proposed Increment
Gen. Plasma Science and Technology	$6M	(in ICF)	+$3M
Concept Exploration (MFE and IFE)			
MFE and IFE	$22M	(in ICF)	+ $10M
Proof of Principle			
Spherical Torus	$27M		
CS, MTF, RPF	$3M		+ $24M
ICF: Indirect Drive		$173M	
ICF: Direct Drive		$41M	
Ion Beam Development	$9M		+ $5M
KrF Laser Development		$8M	+ $6M
DPSS Laser Development		$2M	+ $9M
Performance Extension			
Tokamaks, Domestic	$79M		+ $5M
MFE, International	$16M		
IFE, NIF		$284M*	
Fusion Technology			
MFE + IFE	$29M		+ $4M
Materials	$7M		
Theory and Advanced Simulation	$22M	(in ICF)	+ SSI
Other	$6M	(in ICF)	
Total	$223M	$508M	+ $66M + SSI

* peak annual funding in FY99

Table 1: Current funding levels, and increments consistent with the program plan discussed here. Increments should be viewed as indicative, subject to ongoing review, bur the overall level is required to support the broadened program discussed here.

The increments proposed in this document can be supported either through SC/OFES or DP/ICF as appropriate, taking into consideration issues of national security and program goals.

Glossary

Advanced Tokamak – An tokamak operating mode which promises higher fusion power density, and so a more compact system, as well as intrinsic steady-state operation due to high self-generated "bootstrap" plasma current. Requires current profile control and some current drive capability. (See tokamak.)

Alcator C-MOD – A small, high-field Performance-Extension advanced tokamak at MIT which operates at high plasma and power density. It will ultimately be capable of advanced-tokamak pulses long compared with its current profile relaxation time.

ASCI – Accelerated Strategic Computing Initiative, part of DP weapons stockpile stewardship program.

ASDEX-Upgrade (AUG) – A Performance-Extension class tokamak experiment in Germany, with similar plasma parameters to DIII-D, but less configurational flexibility.

Beta – Ratio of plasma pressure to magnetic field pressure. Since higher plasma pressure implies higher fusion power density, and higher magnetic field implies higher cost, increasing beta is generally favorable.

CDX-U – Current Drive Experiment – Upgrade, a small Spherical Torus experiment at PPPL.

C-MOD – See Alcator C-MOD.

Concept Exploration Experiment – A small, inexpensive experiment used to test out the most basic principles of a fusion concept.

CS – Compact Stellarator, a stellarator design which attempts to make a robust, stable stellarator configuration in a more compact size.

DIII-D – A medium size, medium field Performance-Extension tokamak at General Atomics in San Diego, with very flexible plasma shaping and preliminary profile control tools.

DP – Office of Defense Programs. Responsible for nuclear weapons stockpile stewardship including Inertial Confinement Fusion, ICF, within DOE.

Dpa/year – Displacements per atom per year. Typically 10 DPA in a metal corresponds to about 1 MW year / m^2 of neutron fluence.

DPSSL – Diode pumped solid state laser, a potentially efficient rep-rated glass laser system.

DTAT – A resistive coil advanced tokamak experiment to be designed for advanced tokamak studies in deuterium-tritium.

DTST – A resistive coil spherical torus experiment to be designed for advanced performance studies in deuterium-tritium.

ETR – Engineering Test Reactor, the step before a Demonstration Fusion Power Plant in either MFE or IFE, capable of producing modest quantities of non-commercial electrical power.

FACA – Federal Advisory Committee Act, which defines procedures for committees that advise the Federal Government.

FEAC/FESAC – Fusion Energy Advisory Committee, which was replaced by the Fusion Energy Science Advisory Committee. FACA committees to advise DOE on fusion policy matters.

Heavy Ion Beams – Beams of heavy ions such as cesium or lead, accelerated to the GeV range and used for compressing and heating IFE targets. The acceleration systems under consideration in the U.S. and Europe. are induction and RF linacs, respectively.

Hohlraum – A volume in which the walls and radiation are in thermal equilibrium. Used to provide symmetrized x-ray capsule drive in indirect-drive inertial fusion.

ICF – Inertial Confinement Fusion, used to denote the study of fusing plasmas which are confined by their own inertia only. The DOE DP ICF program is primarily driven by nuclear weapons stockpile stewardship needs.

IFE – Inertial Fusion Energy, the application of ICF for commercial energy production.

Ignitor – An Italian design for a very small DTAT.

IRE – Integrated Research Experiment, an IFE Performance-Extension facility to integrate driver, target and chamber studies at the tens of kilojoules per pulse level, with continuous rep-rated operation.

ITER – International Thermonuclear Experimental Reactor, a device under engineering design by Europe, Japan and Russia to demonstrate the physics and technology of long-pulse and ultimately steady-state fusion power production, at the level of hundreds of megawatts, in a superconducting, deuterium-tritium device.

JET – Joint European Torus, a powerful billion-dollar class Performance-Extension tokamak facility operated by the European Union, which has produced up to 16 MW of fusion power in deuterium-tritium, and is currently addressing advanced tokamak issues.

JT-60U – A powerful billion-dollar class Performance-Extension tokamak at a similar scale to JET, but only capable of operating in deuterium. It currently has more complete diagnostics and more extensive experience studying advanced tokamak physics. Both devices have potentially powerful systems for profile control which have not been fully exploited..

KrF – A gas laser concept which has particularly high bandwidth, facilitating techniques for beam smoothing, which have proved successful in suppressing laser imprint, which can seed Rayleigh-Taylor instability, and reducing laser-plasma instabilities.

KSTAR – A superconducting tokamak device under construction in Korea to study long-pulse / steady-state advanced tokamak physics. It is more modest in scale than JET or JT-60U, being similar in concept to a steady-state DIII-D.

LHD – Large Helical Device, a $1B class stellarator device which has just come on line in Japan, and has already produced very favorable results.

Light Ion Beams – An IFE driver approach using light ions (e.g., lithium) at 10's of MeV accelerated across a small number of diode gaps. This approach has proven more difficult than initially expected, but a good new idea in light-ion source technology could reinvigorate it.

LLNL – Lawrence Livermore National Laboratory.

LMJ – Lasér Megajoule, a facility similar to NIF under construction for similar purposes in France.

MAST – Mega-amp spherical torus, a proof-of-principle spherical torus experiment about to come on line in England. It features a somewhat more spacious vacuum vessel than NSTX, but has much less heating power and lacks a close fitting conducting shell for mode stabilization.

MFE – Magnetic Fusion Energy, the production of commercial fusion power from a hot plasma confined by a magnetic field.

MTF – Magnetized Target Fusion, a concept in which a small magnetically confined plasma is inserted in a metal shell, which is then rapidly compressed to bring the plasma to high temperature and density for fusion.

NIF – National Ignition Facility, a Performance-Extension glass laser and ICF target system located at LLNL . It is designed to achieve of order 10 MJ of fusion energy production for of order 2 MJ of laser energy delivered to the target.

Nike – A KrF laser system located at NRL which has specialized in developing beam smoothing techniques and studying the development of Rayleigh-Taylor instabilities on flat targets, driven either by laser or by target non-uniformity.

Nova – A glass laser facility at LLNL used to demonstrate compression of fusion capsules using indirect drive.

NRC – National Research Council.

NRL – Naval Research Laboratory.

NSTX – National Spherical Torus eXperiment, a proof-of-principle spherical torus experiment which will come on line in 1999 at PPPL. It features very high heating power, a close-fitting conducting shell and pulses long compared with the current profile relaxation time..

OFES – The Office of Fusion Energy Sciences within Science in DOE, responsible for R&D on fusion energy.

Omega – A glass laser facility at the University of Rochester used for direct-drive laser fusion research.

PCAST – The President's Council of Advisors on Science and Technology.

Pegasus – An extreme low aspect ratio Spherical Torus concept exploration experiment at the University of Wisconsin.

PNS – A Point Neutron Source for testing small samples of materials in neutron fluences comparable to the first wall of a fusion reactor.

Poloidal – The direction the short way around a torus, or doughnut.

PPPL – Princeton Plasma Physics Laboratory.

Performance Extension Experiment – A fusion experiment capable of producing plasmas which approach the parameters of a true fusion system, and so can test scientific and technological issues in highly relevant plasma regimes.

Proof of Principle – A fusion experiment which permits the study of a range of the key principles behind a fusion concept, but does not produce plasmas which approach fusion system parameters.

RFP – Reversed Field Pinch, a toroidal fusion confinement system with a low toroidal magnetic field, which makes it potentially highly cost-effective as a fusion power source, but also results in less stability and more transport than a similar-sized tokamak.

SNL – Sandia National Laboratory.

SC – Office of Science, responsible for scientific research in DOE, including the Office of Fusion Energy Science.

SSAT – Steady-state advanced tokamak, a design for a superconducting tokamak facility capable of steady-state operation in Performance-Extension conditions, to allow tests of long-pulse control of advanced tokamak modes of operation. Typical designs would allow no, or very limited, deuterium-tritium operation.

SSI – Scientific Simulation Initiative, a new initiative within DOE and elsewhere in the government to make high-performance, massively parallel computing available for scientific research, such as fusion plasma science.

START – Small Tight Aspect Ratio Torus experiment. A concept-exploration level Spherical Torus experiment in England which has produced very favorable results.

Stellarator – A toroidal plasma system which generates some or all of its poloidal magnetic confining field from non-axisymmetric coils outside of the plasma, rather than relying exclusively on current within the plasma to generate this field.

ST – Spherical Torus, the low-aspect ratio limit of the tokamak, in which the center-hole in the doughnut is shrunk to its minimum size. This configuration can have demountable copper magnets surrounding the plasma, and so allows a much simplified power-plant maintenance scheme. Preliminary experimental results from Concept Exploration experiments confirm theoretical expectations of very high plasma pressure relative to magnetic pressure.

TFTR – Tokamak Fusion Test Reactor, the first experimental fusion device to exceed 10MW of fusion power production. Shut down in 1996, after 15 years of productive scientific discovery.

Tokamak – A toroidal confinement system with a strong toroidally directed magnetic field. The poloidally directed magnetic field which surrounds the plasma is generated by a strong current in the plasma itself. In pulsed operation, this current is driven by transformer action from a central solenoid, intrinsically limiting the pulse length.

Toroidal – Shaped like a doughnut. Also, as a direction, the long way around the doughnut.

VNS – Volume Neutron Source, a relatively compact systems such as an ST, which produces fusion neutrons for blanket and component testing.

W7-X – Wendelstein–7-X, a highly optimized stellarator design with good particle confinement, high plasma pressure limits, and very little plasma current, presently under construction in Germany. Its drawback is that it projects to a very large fusion system with low power density.

Z – A powerful z-pinch device at SNL, which has demonstrated efficient x-ray production by passing very high currents through arrays of thin wires. Within these wire arrays, impressive hohlraum temperatures have been produced.