Reflections on Fusion's History and Implications for Fusion's Future*

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Abstract

History shows that all the major opportunities to advance fusion research were the result of a major external event – often of a global nature. The same is true for the downturns the program has experienced. Scientific achievements have never been sufficient, in and of themselves, to create a major and sustained upturn in support for the quest for fusion energy. The program's scientific and technical progress has led to incremental gains in support over time, and may have helped place a floor beneath the program's budget during times of funding cutbacks. The program's balance and degree of readiness at the time of an episodic opportunity is critical in determining the extent of an upturn or downturn.

The key lesson to draw from this history is that the fusion research community should, as a matter of policy, organize its program to respond effectively to a major unexpected external event. This means the community must aim to achieve a solomonic balance between its often competing desires: to gain further basic understanding of fusion-grade plasmas; to demonstrate optimal magnetic or inertial confinement configurations; to demonstrate performance capability at burning plasma conditions; and to develop and demonstrate the technologies and designs needed for an attractive and practical fusion energy system.

Gaining support for using the twin guideposts of "balance" and "staying at the ready" in making decisions will be key for the future. The ICF program showed in 1997 that it was sufficiently "balanced" and "ready" to take advantage of a major opportunity. The fusion energy sciences community likewise should take great pride in the fact that, over the past five years, it has changed, sometimes with considerable pain, into a forward looking and balanced enterprise. Keeping it that way is everyone's task.

I. Introduction

We have been engaged in the quest for practical fusion energy for commercial purposes since shortly after the Second World War. Over these past 50 years, great progress has been made in this long journey, a journey described by many as one of the most difficult facing science and mankind. Today, we stand on the threshold of achieving the plasma conditions needed for a practical fusion power system. Fusion researchers have achieved the equivalent of "scientific breakeven" using the tokamak magnetic confinement concept and we can, with high certainty, design an experiment to achieve "ignition and sustained burn" with this approach. Inertial confinement fusion (ICF) researchers have achieved great success as well. Two major facilities, the National Ignition Facility (NIF) in the U.S. and the Laser Megajoule facility (LMJ) in France, are now being constructed with the aim to achieve target gain greater than one, and to study ignition and burn using the laser driven approach to ICF. These facilities will begin operation in the 2006-2008 timeframe.

Yet despite these successes, there is still a long way to go before we achieve a practical fusion power system. Progress was slower than anticipated in the early years, but both understanding and practical results have been extraordinary in the recent past. Nonetheless, I will suggest that over these past 50 years, fusion researchers have for the most not been in control of their own destiny. In essence, history shows that the fusion program is greatly impacted by major episodic events of an external nature, events that are entirely outside the control of the program itself.

Certainly over the past 30 years, all the major opportunities for fusion research to grow sharply in the U.S. were the result of our government's response to an external event – often one of a global nature. The same is true for the downturns the program has experienced. In other words, the scientific achievements made in fusion research have never been sufficient, in and of themselves, to create a major upturn in support for the quest for fusion energy. The scientific and technical progress has at best led to incremental gains over time, and may have helped place a floor beneath the program's budget during times of program funding cutbacks. The program's "degree of readiness" at the time of an episodic opportunity has similarly been critical in determining the extent of the upturn.

This is an important observation offered to us by history and it can be a difficult one to accept. After all, it is not easy to admit that one does not have control over the primary causes of ones major ups or downs. In my view, this lesson of history has profound consequences for both the research community and the government regarding our policy on fusion energy development and how the program should be managed.

What lessons can be drawn from the historical record? I believe the key lesson is that the fusion program should, as a matter of policy, be organized to respond effectively to a major unexpected external event. That response needs to be a credible response, one that is convincing with respect to moving the field sharply forward towards the goal of fusion power, if and when that opportunity arises. Likewise, the organization of the program should be such as to permit a stout defense against arguments that fusion's achievements have been ineffective, unproductive or insufficiently general if the program is under attack.

This means that the program needs to attain and maintain a solomonic balance between its often competing desires: to gain further basic understanding of fusion-grade plasmas; to demonstrate optimal magnetic or inertial confinement configurations; to demonstrate performance capability at burning plasma conditions; and to develop and demonstrate the technologies and designs needed for an attractive and practical fusion energy system. Often, these tugging desires are expressed as the tension between a science-oriented program and an energy-oriented program. Tendencies to overly focus the program on any one of these sub-objectives will leave the program vulnerable to downturns and less than optimally prepared for upturns.

Guided by the January, 1996 report, "A Restructured Fusion Energy Sciences Program", the program has made major changes. The report was produced by the Fusion

Energy Advisory Committee (FEAC) of the DOE, and benefited from extensive involvement of the fusion community. In turn, the FEAC report benefited from the July, 1995 report, "The U.S. Program of Fusion Energy Research and Development" written by a panel of the President's Committee of Advisors on Science and Technology.

The fusion energy sciences program today is smaller than in 1994 but it has significantly greater balance among its "competing desires". The program continues to generate first-rate scientific and technological results. The restructuring and balance, when combined with continuing scientific success, is in my view the reason why, for the first time in five years, Congress has approved an increase of almost 14% for the Fusion Energy Sciences program. Congress is also supporting strongly the defense-oriented Inertial Confinement Fusion program, but for different reasons, but overall, funding for fusion research is very significant.

Now, as we continue the quest for fusion energy, and with history as our guide, the foremost elements of a fusion program strategy should be "balance" and "staying at the ready". Applied sensibly, these two guiding principles will yield a program that is prepared and able to move forward rapidly towards a practical energy system when the opportunity arises.

With this introduction and summary, let me now turn to a "walk through the garden" of fusion's history, beginning around 1970. These reflections are clearly personal, as 1970 is about the time I first become engaged in fusion energy research. Over the past thirty years, there were many unexpected events and my purpose is not to cover them all. Rather, I will focus on the major events, always external ones, that led directly or indirectly to a significant change in the course of fusion energy development. I'll discuss the causes of those changes in a "walk" that will proceed decade by decade. The lessons to be drawn from this reflection on fusion's history will be sprinkled throughout the story and reprised at the end.

II. Fusion and the 1970's

As the 1970's began, magnetic fusion in the United States was a modest, roughly $30 million per year research program administered by the Atomic Energy Commission. The program was headed at the AEC by Roy Gould, then on two year leave from Caltech. The positive results achieved in the mid-to-late 1960's with the T-3 Tokamak in Russia had just been confirmed by the Thompson scattering experiment of the British team, and the U.S. was in the process of converting its stellarator device at Princeton to the ST Tokamak. The laser fusion concept of isentropic compression, shock heating of a central core, and burn propagation through relatively cold fuel had not yet been discussed publicly. (This was to come in 1972, in the famous Nature paper by Nuckolls et al.) While funding in 1970 for inertial confinement fusion (ICF) research is not known, it was surely less than $10 million per year.

The sum of these MFE and ICF budgets, even in inflation-corrected dollars, is roughly seven times smaller than the combined budgets for fusion energy sciences and inertial confinement fusion research today. The facts that in 1970, the total funding for fusion research was less than $30-40 million per year, that fusion was part of the AEC's basic research portfolio, and that the AEC's fusion office was headed by an academic on temporary leave from his home institution, give a picture of the program's status as the decade began.

Activities underway included magnetic mirror research at Lawrence Livermore, the beginnings of tokamak research using ST at Princeton, theta pinch research at Los Alamos, Doublet research at General Atomic, and both magnetic mirror and bumpy torus research at Oak Ridge. Many universities had moderately-scaled experimental devices focussed on issues basic to fusion plasma science and there were many strong theoretical programs. Two of the larger efforts were at Wisconsin, where the program centered around the large octupole device, and at MIT, where Alcator A was under construction.

Laboratories such as Oak Ridge, Lawrence Livermore, Lawrence Berkeley and the MIT National Magnet Lab were developing technologies, such as neutral beams and magnet systems, that were critical for fusion plasma experiments. Groups at universities, particular at MIT and Wisconsin, and at several of the national laboratories had also begun to explore the technology needs and design issues of attractive fusion power systems. This emerging breadth, not fashionable at the time, would be important when the first unexpected external event was to hit in 1973, profoundly affecting the program.

Two national developments in the early 1970's should be mentioned, even though they were unrelated directly to fusion, because these developments (movements, really) have influenced fusion energy development ever since. The first is the emergence in full of the environmental movement, marked by the passage in 1970 of the landmark environmental legislation celebrated each year on Earth Day. This movement's roots go back to Rachel Carson and before, but the legislation in 1970 represented its "coming of age".

The second development was the emergence of the debate over nuclear power. An early manifestation of this debate was the call in the early 1970's for the breakup of the AEC. The objective was to separate the AEC's responsibility for the development of nuclear power from its responsibility to regulate that industry. This would eventually come about with the creation of the Nuclear Regulatory Commission as an entity separate from what today is the Department of Energy (DOE).

In short, as the decade of the seventies began, fusion research was focussed on basic magnetic confinement physics experiments, plasma theory, and technology development important for fusion experiments. Fusion reactor studies and environmental explorations were just beginning and laser fusion as we know it today was not yet out from under wraps. Concerns for the environmental impact of various industries had emerged as a national environmental movement, and the future of nuclear power development was heading towards a national debate.

II-A. The First Big External Event – The Oil Shock of 1973

In 1973, OPEC called for limitations on the production of oil and precipitated a worldwide energy crisis. The supply of oil was reduced, the price of oil increased, and the vulnerability and dependence of western-style democracies to such cartel action became evident. The response in the U.S. was immediate and uncomfortable. Gas lines became a common occurrence, driving and buying habits changed, and the government, recognizing the country's vulnerability in terms of national security and economic health, called for "energy independence". The entire episode changed the outlook of people with respect to energy and its use, producing much greater concern for issues such as efficiency and conservation. For a strategic viewpoint, the security of energy supply and the diversity of energy sources became national strategic objectives.

Over the next seven years, the government introduced programs and regulations that changed the way industry and private citizens used energy, changed the ways in which energy was produced (oil-based power stations were completely eliminated), changed the nature of our transportation fleet, introduced new research and development programs to develop new energy sources and promoted than energy conservation ethic. Generally speaking, the public's consciousness about energy's strategic role reached an unprecedented peak.

A-1: Consequences for the Magnetic Fusion Program

The effect of the 1973 oil shock on the fusion energy program was almost immediate. The primary AEC-supported program for new energy was focussed on the development of fission breeder reactors for self-sufficiency in electricity production. Yet while this program took on even greater urgency, the call came to the fusion community to answer the question - "What can you deliver, and on what timetable?" Clearly a major event, the oil crisis was about to have a major impact on the quest for fusion energy.

The fusion program organized to address this question. It was led by a new division office, created in 1974 by the AEC, for magnetic fusion research and energy development. During 1974 and 1975, the program zeroed in on an answer – it would propose a breakeven experiment based upon the tokamak concept. Breakeven, as contrasted with the "holy grail" of ignition, was defined as producing as much power in fusion reactions as is being injected into the plasma to maintain its energy content.

This decision followed long discussion and debate in the fusion community about the proper approach to follow. Design studies of devices ranging from what became the Tokamak Fusion Test Reactor (TFTR) to a superconducting machine aimed at achieving plasma ignition and long pulse burn were explored as part of informing the debate.

A fateful meeting occurred at the AEC during the period between Christmas and New Year, 1974. Program leaders were called to Washington to present their ideas. At the meeting, the AEC laid our a ground rule that the program must deliver a major facility capable of demonstrating fusion's potential while costing not more than $100 million. Oak Ridge had been studying a superconducting tokamak aimed at achieving ignition and reported its findings. It appeared to all that the price-tag would be well in excess of the allowable target, and that the degree of extrapolation from what was known experimentally at the time was rather large.

Princeton arrived at the meeting with something of a surprise, namely, its proposal for the Two-Component Torus, or TCT. By not aiming at Maxwellian fusion reactions and ignition, this concept had the virtue of permitting the achievement of breakeven at much reduced cost.

The decision was to proceed to develop the proposal for the TCT, and this effort led in 1976 and 1977 to the approval of TFTR. It was to be the first confinement experiment in the world to perform experiments using deuterium and tritium. The price of TFTR eventually came to more than $300 million, though it is important to recall that inflation during that period was very high. The value of the dollar decreased by about a factor of two from 1977 through 1982, the time of construction.

There were other major developments during the mid-to-late 1970's that together would drive up the budget for magnetic fusion energy research to greater than $300 million per year by the decade's end. In 1974-75, the magnetic mirror community proposed the superconducting MX experiment, a single-cell mirror device also aimed at breakeven plasma conditions, albeit on a equivalence basis, using only deuterium. This experiment was approved around 1976, and was later modified to become MFTF-B, the Mirror Fusion Test Facility. The MFTF-B was a tandem mirror device, one end of which was now the original signal mirror MX. The overall construction costs of this superconducting machine came to more than $400 million.

Many other experiments were approved during this period. New major tokamaks were built at MIT, the University of Texas, and the Oak Ridge National Lab, new tandem mirror devices were built and operated at both Livermore and Wisconsin, and many smaller machines of various concepts were built at universities around the country.

After 1973, fusion technology emerged as a strong component of the magnetic fusion energy program. The program was fortunate to have inaugurated reactor studies and technology development projects in the early 1970's. These programs and the results they produced provided the basis and the guidance for the development of a much more comprehensive program, one aimed at establishing the basic underpinnings for areas viewed as essential for practical fusion energy systems.

Two major examples were the Large Coil Test, a set of six superconducting magnets that established the basis for the construction of large toroidal field coil systems, and the Tritium Systems Test Assembly (TSTA), built to establish the basic experience and information needed about tritium handling, recovery, reprocessing, and recycling. Both these projects were international collaborations.

One could go through the complete catalog of such work but I'd be remiss if I did not mention the enormous progress made in the development of high power neutral beam systems, in the development and use of low atomic number materials for high heat flux components, in the development of plasma coating techniques and wall conditioning treatments, and in the significant effort to develop fusion materials capable of withstanding the environment seen by a fusion reactor chamber. It was during this period that the importance of low activation materials became evident as the key ingredient in making fusion power environmentally attractive.

The inertial fusion effort emerged in the U.S. in 1972 and, for reasons of national security and defense, was placed in the defense programs section of DOE. Immediately programs were begun to construct high power, short pulse lasers to test the basic concepts of laser absorption, plasma creation, isentropic compression, shock heating and ultimately net fusion energy gain. In particular, early prototype lasers and then the Shiva experiment were built at Livermore, the Omega laser was built at the University of Rochester, the Antares CO2 laser was constructed at Los Alamos, and a laser fusion effort was begun at NRL. Complimentary to the laser efforts were the particle beam pulsed power programs at Sandia and NRL, initially focussed on electron beam machines.

Technology development in ICF was wholly focussed on developing the drivers and targets needed to perform ICF experiments. However, the beginnings of energy studies emerged during this period, and the potential of heavy ions as efficient drivers of targets for power systems came under study. The first comprehensive reactor study, the SOLASE research and reactor study based on the use of lasers and carried out by the Wisconsin technology group, was carried out during the 1975-1978 period with support from the Electric Power Research Institute (EPRI). (The EPRI support was crucial, as the DOE was confined to supporting only defense-related ICF research, a situation that persists to this day. Encouragingly, the Office of Fusion Energy Sciences has supported the heavy ion driver program since 1992 and is now beginning to examine issues critical to the ICF approach to commercial fusion power.)

Several of the primary concepts introduced in the SOLASE study remain with us today. These include the use of gas-filled chambers to protect the walls from the initial X-ray pulse and the use of very low activation, carbon-composite materials to achieve environmentally attractive power systems.

I should mention that not all programs grew, or were even maintained, during the 1970's. In the MFE area, the proposal to build a large Theta Pinch was disapproved, based on experimental results that were not encouraging, and the program area was closed. A similar fate awaited the Elmo Bumpy Torus program shortly after 1980. In the ICF area, the CO2 laser program was discontinued when experimental results and theoretical understanding established that short wavelength light was key to deep coupling of the laser energy to the pellet, to minimizing backscatter and anomalous absorption (or the generation of fast electrons), and to good implosion dynamics.

In short, during the 1970's, the magnetic fusion program grew from $30 million per year to over $300 million per year while the ICF defense program grew from esssentially zero to close to $100 million per year. Worldwide, similar growth in fusion research occurred, especially in Europe, Japan and the former Soviet Union. During the late 1970's, Europe approved the Joint European Torus project (the JET tokamak), Japan approved the JT-60 tokamak and the 10 KJ laser program at Osaka, and the Soviets approved the T-20 tokamak (later to be modified to become the superconducting T-15 device). All these machines were supplemented by smaller devices, expanded theory and modelling programs, and new fusion technology research and development efforts. International cooperation abounded and the world program to develop fusion energy grew by 1980 to more than $1 billion per year.

A-2: External Developments Critical to the Development of Fusion

There were of course many consequences, in the United States and throughout the world, of the 1973 oil shock. I'd like to mention just two because they indirectly impacted the fusion program at the time and remain important for fusion's development today. The first consequence was the development of significant opposition to nuclear power. The second was the development of a strong movement focussed on energy conservation and what came to be called "appropriate energy technologies" or "green technologies". These developments were actually inter-related in that often, people and organizations opposed to nuclear power development and deployment were at the same time in favor of what Amory Lovins labelled "Soft Energy Paths".

The opposition to nuclear power emerged because of two main concerns: the contribution that know-how and enriched-uranium or plutonium diversion might contribute to nuclear weapons proliferation; and the assessment of some that nuclear power, as a technology, might be more difficult to operate and maintain safely than our social institutions could manage.

Concerns about proliferation of nuclear weapon materials were raised by Ted Taylor, then at Princeton, by Henry Kendall and the Union of Concerned Scientists, by John Holdren, then at Berkeley, and by Amory Lovins, among others. Some of their concerns were reflected in actions taken by the government at the time, most particularly the Carter administration's decision to cancel private industry programs engaged in the development of new uranium enrichment technologies. (This led, for example, to the cancellation of the Exxon Nuclear laser isotope separation program.) All enrichment programs would now be government-developed as reflected in the continuation of the laser isotope separation program at Lawrence Livermore.

Yet while this opposition developed, the nuclear industry, in my view, fought back without offering real accommodations to the concerns that were being raised. In particular, the program to develop the plutonium-based breeder reactor, embodied in the Clinch River Breeder Reactor (CRBR) project, continued apace with the unwavering support of the AEC and its sequel agencies, the Energy Research and Development Agency and then the Department of Energy.

The unwillingness to address the opponents concerns head-on and make accommodations would have consequences for the nuclear power program when the accident in 1979 occurred at the Three Mile Island nuclear power station. The growing opposition to nuclear power and the establishment by opposition groups of nuclear power as a symbol of technology-gone-amok would be confirmed in the minds of many by that accident.

This would have long term consequences not only for nuclear power development but for both the fusion energy and defense ICF programs. Though ICF proceeded apace, some groups that were opposed to nuclear power because of proliferation concerns would emerge, beginning in the mid-to-late 1980’s, as major opponents of the quest for ignition via the ICF route. Their argument is that such experiments may enhance the ability of the U.S. and others to develop more advanced weapons. In reviews of the ICF program conducted by the National Academy of Sciences, the NAS panels included members from groups opposed to ICF. This engagement was both proper and important.

Indeed, as we’ll discuss when we get to the 1990’s, the National Ignition Facility (NIF) project was eventually approved as a result of another major external event, the agreement to stop underground nuclear weapons testing. That unexpected event (it was first agreed to by President Bush in 1992) was powerful enough to ensure that NIF would go forward, despite strong opposition by antinuclear groups and years of proposals that went unheeded. The power of the external event of the early 1990’s and the ICF program’s readiness were the essential ingredients in gaining approval for this billion-dollar-plus project.

As for the development of “Soft Energy Paths”, great progress was made in areas such as transportation, lighting, heating, and so on. Conservation and improved efficiency efforts would have a significant long-term impact. In addition, the government established an array of programs to develop new energy sources as alternatives to coal and oil. In particular, as oil was phased out as a fuel for electric power plants, and as the supply of oil continued to be unstable, programs were put in place to demonstrate a panoply of alternatives.

Some of the major new programs started during this period included extracting oil from shale, MHD power conversion, wind energy systems, various approaches to solar energy, tidal energy, geothermal energy, fuel cells, and more. Many of these programs had the character of government-industry partnerships leading to a demonstration project. The “demonstration project” character would have consequences in the early 1980’s that were unforeseen in the 1970’s. Fusion energy development would in fact find that its scientific character and long time horizon would differentiate it in the 1980’s from essentially all other energy research and development efforts. This too is an important lesson.

II-B. The Second Big External Event(s) – The Crises of 1979 and their Implications and Impacts on Fusion

Three major events occurred in 1979. Two were global but with specific consequences for the U.S., and one was local. All would end up indirectly impacting fusion energy programs around the world, sometimes positively, sometimes negatively. The two global events were the Iranian revolution and its associated American hostage crisis, and the Soviet Union's war with Afghanistan. The U.S.-specific event was the nuclear power station accident at Three Mile Island. All these events had, of course, major and far-reaching consequences.

B-1: The Hostage Crisis in Iran

For the fusion energy program, the specific impact of the hostage crisis episode was both direct and indirect. The crisis induced a second oil shock and hyperinflation. The oil shock kept in focus the importance of energy and added to the view that the U.S. needed to continue its quest for energy independence. The Carter administration and the DOE called for, among other things, a review of the fusion program. The DOE review committee was chaired by Sol Buchsbaum, then of Bell Labs, and had a distinguished set of members including, among others, Johnny Foster, Pieff Panofsky, Guy Stever and Tom Cochran. (I was a member of the panel and its least distinguished member!) At the same time, Congress considered a fusion energy development act under the sponsorship of Rep. Mike McCormick of Washington.

The fusion energy development act passed by Congress in 1980 and was signed by President Carter. The bill explicitly called for increasing fusion energy development budgets and the construction, beginning in the early 1990's, of a fusion power demonstration plant. While the Buchsbaum committee did not go quite so far as the legislation, it was favorable to an expanded U.S. fusion program. Those were indeed heady days for the fusion program.

Implementation of the McCormick bill did not however take place. The second oil shock led to sharp increase in energy prices, and ultimately to hyperinflation. These and other difficulties in turn led fairly directly to a change in the presidency in the election in 1980. Fusion would not be alone in feeling the implications of this change, but let me return to this as we begin the 1980's.

B-2: The Soviet Union-Afghanistan War

The Soviet war in Afghanistan, as with the hostage crisis in Iran, did not have an immediate influence on the fusion energy program. However the Carter administration expressed surprise and dismay about this event, and expressed betrayal with respect to its relationship and "understandings" with the Soviet Union. What remained of détente came to a cold end.

Nonetheless, while the U.S. cancelled many programs with the Soviet Union, including our participation in the 1980 summer Olympic Games in Moscow, scientific exchanges with Soviet fusion scientists were allowed to continue. In fact, the initiation of the INTOR effort in 1982, under the auspices of the International Atomic Energy Agency (IAEA), was one outcome of the decision to allow certain ties to be maintained. Ultimately, the INTOR effort set the stage for fusion to play a role, perhaps small in the overall scheme of things but nonetheless important, in the rapprochement between Reagan and Gorbachev in the mid-1980's. The creation of the ITER project was the result. The fact that fusion science and energy research had been an international enterprise, with a history of successful international collaborations, served the program well during this period. It would however take another turn in the 1990's.

B-3: The Three Mile Island Accident

The Three Mile Island nuclear power plant accident, as with the two other events/episodes I've discussed, did not directly effect the fusion program. It did of course have a pivotal impact on the nuclear industry. No nuclear power plant has been approved since that accident, the concerns of opponents of nuclear power development appeared to be confirmed, and, when combined with the Chernobyl accident of 1986, served to create an environment of hostility to anything nuclear. To this day, nuclear power as a "technology of the future" has not recovered, and may never recover.

The consequences for fusion energy development were twofold. First, the fusion program from that time onward would be asked to establish its viability as a "pure" new energy source, without any firm connection to nuclear power. Indeed, fusion now needed to establish a set of objectives that would help show that fusion energy could be an environmentally and socially acceptable new energy source on its own. This gave great impetus to efforts to develop low activation fusion materials and the exploration of concepts for fusion power systems that could meet, at least on paper, stringent environmental goals.

This meant that certain natural applications of fusion energy no longer made sense, at least not politically. In particular, the fusion hybrid concept in which a fusion system would produce fuel for nuclear power stations was no longer studied or even discussed. Since such systems require reduced plasma performance as compared with the requirements for a pure fusion power reactor, a pathway somewhat easier for fusion to travel was now closed.

A lesson for the program here is that it is important at all times to maintain work aimed at studying and establishing fusion as an "appropriate technology" in a sustainable energy world - even in times of budget difficulties or calls for one type of emphasis or another.

Another lesson, perhaps much more widely applicable than just for fusion, is to engage the opposition as sensibly as possible and find a means of addressing their concerns. Of course, some may argue that those simply dead-set against nuclear power would never agree to compromise or reach accommodation. My sense is that history will show that people such as Ted Taylor, Henry Kendall, John Holdren, and the groups they represented, were not anti-nuclear per se, but would support a nuclear power program that addressed adequately their concerns, especially about weapons proliferation.

III. Fusion and the 1980's

Beginning in 1981, the Reagan administration and the Federal Reserve attacked inflation by raising interest rates close to 20%. Recession followed and unemployment rose to more than 10%. U.S. economic activity and consumption dropped sharply. At the same time, conservation efforts begun in the 1970's had taken hold and fuel-efficient cars had become ubiquitous. The combination of recession and efficiency led to a drastic reduction in the demand for oil. Indeed, the drop was so steep that the oil cartel cracked, various members lowered prices well below the targets set by OPEC, and the oil crisis finally ended.

By 1983, inflation had come under control and the price of oil had collapsed to levels not seen in a decade. Suddenly, in the minds of many Americans, the "energy crisis" had disappeared. Much later, in the 1990's, the lack of urgency about questions of energy would affect the fusion program during the crisis years 1995-97.

The Reagan administration also came to office with a very different view of the government's role in energy development and particularly its role in demonstration projects. It held the philosophic view that the government's proper role was to support long term research but not to support near term development projects. As expressed at the time, the view was that if a technology was close enough to justify demonstration, then private industry should be willing to pay for that demonstration. It was a point of view and it prevailed at the time.

Indeed, by 1983, most energy demonstration projects in other fields, such as oil-from-shale, solar energy, wind energy and geothermal energy, were cancelled or sharply curtailed. The major consequence for the fusion energy program was that the plans called for in the McCormick bill were largely ignored.

On the other hand, after almost two years of consideration and review, the Reagan administration did conclude that fusion energy research and development was indeed an area appropriate for government support. Fusion energy research was characterized as a program supporting an important field of science – plasma physics - and a program aimed at an important long-term national goal – the development of new sources of energy. The general balance of science and technology and the overall breadth of approaches being explored saved the program from a great fall. The years of ever increasing budget allocations did however come to an end.

The first major casualty of a leveling of the fusion energy research budget was the MFTF-B tandem mirror project. After an expenditure of close to $400 million, the machine was commissioned and the program immediately cancelled. There was no way that the magnetic fusion program budget, without further increases, could support the operating costs of two major devices such as MFTF-B and TFTR. And whereas results from tokamak research continued to generate strong results, the results from existing tandem mirror machines were fell below expectations. But the closure without operation of the MFTF-B was a black eye both for the program and the DOE, given the large expenditure of funds.

III-A: The Third Big External Event – The Gorbachev-Reagan Rapprochement at Geneva

After years of bitter exchanges, the U.S and the Soviet Union began in 1984 to discuss healing the breach in relations, though the U.S. expressed great caution about the possibility of any positive outcome. Among others, President Mitterand of France favored a rapprochement with the Soviet Union and engaged Chairman Gorbachev.

The decision in the mid-1980’s to re-engage the Soviet Union had major consequences for the fusion energy program. Crucially important for fusion’s ability to respond to an external event was that it was generally “balanced” in terms of the breadth and depth of research in fusion plasma physics, and “at the ready” with respect to work in fusion technology, reactor design and economic and environmental studies. It was in a strong position to respond to an unexpected call. That call came at the end of the Reagan-Gorbachev summit at Geneva in 1985.

The U.S., as I mentioned, had maintained scientific contacts with the Soviet Union in the fusion energy area after 1979 and the INTOR project, begun in 1982, was one manifestation. In late 1984 or early 1985, the idea of an East-West project to establish the feasibility of fusion energy was discussed by Mitterand and Gorbachev, and both were positive. Their discussions were instigated in large part by Evgeny Velikhov, a plasma physicist, director of the Kurchatov Institute in Moscow, and a close advisor of Chairman Gorbachev. Velikhov was also a strong supporter of INTOR, having helped establish that activity.

In 1985, President Reagan and Chairman Gorbachev met for their first summit in Geneva. Their final communiqué dealt with matters of relationships between the two countries, world security, and certain plans and projects for the future. One of those projects turned out to be about fusion energy – a remarkable and unexpected event! The communiqué stated that the two leaders had agreed that their countries, joined by others, should and would work together to establish the feasibility of fusion energy for “the benefit of all mankind.”

This clarion call led two years later to the birth of the ITER fusion program, the largest international design project for a scientific enterprise ever undertaken. A consequence of this national commitment was that the U.S. magnetic fusion program would receive close to full support for its part of the ITER program. Indeed, as a result of this presidential commitment, the fusion budget in the mid-to-late 1980's generally faired quite well. Even the Soviet nuclear power accident at Chernobyl in 1986 did not weaken U.S. support for the ITER program, and for fusion generally. In a way, ITER insulated fusion from the anti-nuclear sentiment, already strong following Three Mile Island, that grew even more so after Chernobyl.

At about the same time as the call came for an international effort on fusion, the national magnetic fusion program began formal studies for a new, domestic tokamak experiment aimed at reaching plasma ignition, or at least high energy gain. Calls for such an experiment had be made earlier, such as the proposal by Bruno Coppi and colleagues in 1978-79 for the Ignitor concept as a high field, compact tokamak path to ignition. But preoccupation in the early 1980's with the construction of many large fusion projects around the world made it seem premature to embark on the ignition path at that point. We shall never know if that decision was the right one.

However, by the mid-1980's, construction of TFTR was complete and plasma experiments had begun. The same was true for the JET experiment in Europe and the JT-60 experiment in Japan. The general view now was that the time had come to prepare for the next domestic step in fusion's development – and ignition or high gain experiment. For the next eight years, a national team centered at Princeton developed designs for various versions of a burning plasma tokamak experiment.

In the end, none would be approved. Energy did not have the urgency of the past, budgets became tighter in the late 1980's and especially in the early 1990's, and no external event, other than the Geneva Summit (which called for an international approach), arrived to drive a decision for a domestic machine. The needed external episodic event eluded the program.

Indeed, funding for magnetic fusion peaked at about $450 million around 1984 (following completion of TFTR construction) and moderate budget reductions in the late 1980's brought the budget back down to around $360M. The situation was not helped when the a new Director of the Office of Energy Research at DOE, Bob Hunter, proposed moving about $40 million from the budget for fusion energy to the budget for ICF.

All this caused pressures to mount within the magnetic fusion program. There was the pressure to maintain our commitment to the stated program goals of achieving a demonstration of the feasibility of fusion power (represented now by the ITER program) and pressures to meet our international commitments. As a result, the U.S. program began to narrow towards work focussed primarily on the tokamak concept and on technological work in support of ITER. This would cause the program to lose its sense of balance, and there would be major consequences in the mid-1990's.

During the 1980's, the ICF program grew at a reasonable pace and budgets reached about $200M per year by the end of the decade. New facilities were built and new approaches, such as KrF laser drivers and light ion beam pulse power systems, came into operation. As the decade came to a close, the Nova laser program at Livermore would be the U.S.'s largest ICF experimental facility, rated nominally at 100 kJ. It operated routinely with around 60 kJ of frequency tripled light delivered to targets. Scientific understanding and target designs continued to advance, giving the sense in the community that a major new facility aimed at ignition might be reasonably justified.

Calls began coming in the mid-1980's for a megajoule-scale laser capable of driving targets to ignition, and studies were initiated. These calls were persistent from the program and just as persistently resisted by the defense community and the DOE. However, unlike the situation in the magnetic fusion area, a major and unexpected external event would occur in the early 1990's (the agreement to stop underground nuclear weapons testing) that would change the situation dramatically.

III-B: The End of the Cold War – The Ultimate Unexpected Event

The end of the Cold War in 1989 and the ultimate collapse of the Soviet Union were historic events unparalleled in the century for their "unexpectedness". No one at any time prior to the actual collapse foresaw the dissolution of the Soviet Union. The implications for the world were and are obviously profound. The end of the Cold War and the almost simultaneous and coincidental emergence of the internet age have changed the world in which we live.

Since we are focussing on fusion energy development in this "reflection", I'll simply note that fusion, like most things, would not go unaffected by these dramatic events. But again, because fusion energy development is a rather modest activity on the world stage, the impact would be somewhat indirect and understanding the impact requires careful tracing.

IV. Fusion and the 1990's

As the 1990's began, the world was becoming a profoundly different place, mostly because of the end of the Cold War. The quest for fusion energy will surely be affected and the question is not whether but how it will be affected. Unfortunately, not many of us at the time recognized that the key for the program would be whether, and how well, it was positioned and structured for the coming unexpected events. As we'll see, one unexpected event will drive the ICF program forward towards its "ignition dream", while another unexpected event will drive the magnetic fusion program downward, taking its dream of ignition with it.

Between 1990 and 1992, three major events occurred – two of which were unexpected. The somewhat predictable event was the economic recession of the early 1990's. The unexpected events, of course external to the fusion program, were the Gulf War of 1991 and the decision by President Bush in 1992 to halt all underground nuclear weapons testing. This latter event was reinforced by President Clinton when he signed in

1996 the Comprehensive Test Ban Treaty (the CTBT). Though not confirmed by Congress, the U.S. remains committed to the terms of the Treaty, at least for now.

I've mentioned earlier that at the beginning of the Bush Administration, a new DOE director of energy research, Bob Hunter, reviewed both the MFE and ICF programs and proposed an increase for ICF and a decrease for MFE. In particular, funds from one program were to be transferred to the other, with no net change in the overall combined funding. Of course, the request to reduce funds for MFE was gladly approved by Congress, but the funds requested for ICF were not forthcoming.

In 1990, Admiral Watkins, then Secretary of Energy, asked Guy Stever to chair a committee to review both the magnetic and inertial confinement fusion programs. The charter was to assess the status and prospects of these programs, determine if the plans of the programs were reasonable, and recommend to the DOE how the two programs should be managed and placed within the then-developing National Energy Strategy. The DOE published its National Energy Strategy report in 1991 and included most of the recommendations of the Stever committee.

Stever's committee was supportive of the magnetic fusion effort and recommended that it maintain its focus on demonstrating the feasibility of fusion power. The committee saw the ITER international effort as the primary vehicle for achieving this end but it also supported the need for a domestic magnetic fusion high-gain burning plasma experiment and the need to develop fusion technologies that would be central to achieving an attractive as well as a workable fusion power system.

The committee was likewise complimentary about the achievements and potential of ICF. It noted the energy potential of the ICF approach and recommended a degree of coordination and integration between the two programs in order to gain synergies with respect to energy-oriented research important to both approaches to fusion power. Recall that ICF was, and still is, managed by the defense programs office at DOE while magnetic fusion was, and is, managed by the energy research office. One administrative arrangement that did result from the committee's recommendations was the transfer of the heavy-ion accelerator program to the office of energy research, where it remains today.

However, to achieve all that the Stever committee recommended would have required continuing increases in both the ICF and magnetic fusion program budgets. In the magnetic fusion case, estimates were that the budget would need to increase from around $360 million to ultimately more than $700 million per year. This would not be practical as a result of the economic recession of the early 1990's and the Gulf War and its consequences.

IV-A: The Economic Recession of 1990-93 and the Unexpected Event – The Gulf War

The end of the Cold War and the proclamation of a new era called into question the need to continue the defense buildup of the 1980's and the need for the scale of the defense industry that came along with that buildup. The President and the Congress agreed to reduce defense spending sharply in the early 1990's. These and other factors, including the very long economic expansion from 1983 to 1989, led to a significant economic recession. Anyone living in California south of Silicon Valley might describe the period as approaching true economic depression. Indeed, for the first time since the 1930's, the faculty and staff at the University of California had their pay actually reduced. Unemployment nationwide grew, though not to the levels of the early 1980's.

Nonetheless, the economic downturn was so strong that it is generally cited as the reason for the loss by President Bush of the 1992 election, despite the victory of the U.S.-led alliance in the Gulf War of 1991. Throughout this period, attempts to gain control over federal deficits continued and this began to exert a strong pull downward on any proposals to increase federal spending.

The second event, quite unexpected, was the invasion of Kuwait by Iraq in 1990 and the resulting 1991 Gulf War. A direct and immediate effect of this action was the stabilization and ultimate depression of world oil prices. Those prices would not recover to the $20 per barrel level until just this past year, and at one point during the decade, the price of oil fell to as low as $10 per barrel. Just as critically, in my view, the war guaranteed that energy prices in the developed economies would remain stable and not be subject to large, arbitrary and unilateral changes.

The recession and the Gulf War would effect the economy generally, government spending in particular, and attitudes towards energy and risk. The recession produced a tightening of government spending and programs such as fusion received constant or modestly decreased funding. The magnetic fusion program now had to address the question – How can it continue to move towards its energy oriented objectives without the funding recommended by the Stever committee?

The program chose to narrow its approaches in the area of magnetic confinement research to an almost singular focus on the tokamak, and it chose similarly to narrow its efforts in fusion technology research to work almost singularly focussed on the stated needs of the ITER program. The program itself chose to cancel the ZT-H reversed field pinch construction project, then underway at Los Alamos, thereby eliminating the largest non-tokamak U.S. experimental program. The DOE, in its efforts to lower budgets, then cancelled the national program aimed at designing and constructing a burning plasma experiment (the BPX program), which itself would have been a tokamak device. Research of a more basic nature in plasma physics became somewhat more difficult to sustain and work in basic fusion technology, important for fusion's ultimate attractiveness but not needed for the ITER approach, was redirected, reduced or stopped.

The program was able, in this way, to maintain its focus on the goal of establishing the feasibility of fusion, albeit now for a particular approach to fusion, the tokamak. It was also dependent heavily on international efforts to construct ITER. The research effort continued to produce strong scientific results (for example, the emergence of the advanced tokamak regimes of operation) but the overall fusion program remained far from its ultimate goal, and many felt that the narrowing induced by the budget constraints was premature. Tensions grew, and the lack of balance among program elements would make the whole magnetic fusion program vulnerable to the next major episodic event, the unexpected Republican victory and "revolution" of 1994.

Of course, hindsight is 20-20 and the community made decisions in the early-to-mid 1990's that it believed were the right decisions at the time. The program was in a state of frustration over being forced to narrow its options and over being thwarted in its long-standing ambition to construct a burning plasma experiment. Burning plasmas and ignition have been the scientific "holy grail", the "next frontier", for fusion physics research for a very long time.

Nonetheless, history does inform us, and if we do not examine what might have done differently, mistakes of the past will likely be repeated. It is clear now, and was apparent then, that the lack of increases in funding in the early 1990's (through the fiscal year 1995 budget), without associated changes in program goals, would lead to large tensions. Those who felt the program was narrowing too fast were inevitably at odds with those who felt that the results from tokamak experiments, strong as they were, when combined with the stated goals of the program and our international commitments, justified the decision to narrow the program.

The other, less visible, impact on the program would play an important role after the next crisis, and this was the growing sense that energy, and particularly the development of new energy sources, was simply not a major issue for the U.S. This sense was enhanced by the outcome of the Gulf War and the subsequent drop in oil prices. At various times in the 1990's, the price of a gallon of gasoline was less in real terms than at any time since the early 1960's. Congress and the President simply could not find sufficient reasons, in this circumstance, for large increases in energy research expenditures.

IV-B: The Unexpected Decision in 1992 to Halt U.S. Nuclear Weapons Testing

In 1992, President Bush agreed with Congress and signed legislation halting underground testing of nuclear weapons. Subsequently, President Clinton signed the Comprehensive Test Ban Treaty and while its ratification was rejected by the Senate, the policy remains to abide by the terms of the treaty. Since 1992, the U.S. has not carried out any underground tests of nuclear weapons. While such a moratorium had been a goal of many groups, there did not seem to be an overwhelming consensus at the time for such a moratorium, and the decision by President Bush has to be characterized as "unexpected". Certainly, no one, even after the fall of the Berlin Wall, would have predicted this decision to have come as early as it did.

Suddenly, the job of insuring the viability of the nuclear stockpile took on a new and different flavor. Without the ability to perform the ultimate integral test, the nuclear weapons community, particularly at Los Alamos, Livermore, and Sandia, began investigating how to ensure that the stockpile would remain, and could be confirmed to be, viable.

New programs emerged under the umbrella of "Science-Based Stockpile Stewardship". These included experimental facilities and major commitments to enhanced computational modeling, as expressed in the ASCI program. One of those major experimental facilities, which had been waiting in the wings for many years, was the proposal from the ICF community to build a multi-megajoule laser with the aim of achieving ignition, burn and moderate energy gain for ICF targets. This placed the ICF program in a good position when this "surprise" event occured.

The ICF community, led by Livermore, began an enlarged design effort and ultimately proposed to build a 1.8 MJ laser National Ignition Facility (NIF). The key to approval, however, was not that the scientific results from ICF experiments were suddenly so spectacular, though the results were very good. As I've said before, no major programmatic advance has ever been the result of the program's scientific achievements alone. In this case, the moratorium on nuclear testing caused weapon's designers, who historically (and today) prefer real underground tests and who had in general opposed funding an NIF on grounds that those funds would be better spent on underground tests, now turned into NIF supporters. Further, as part of President Clinton's decision in 1996 to agree to the CBTB, he also agreed that the nuclear weapons lab directors would each year verify the viability of the nuclear stockpile. This became a necessary condition for the ban on underground testing to continue.

The lab directors agreed that one of the major facilities needed by the nuclear weapons community and the stockpile stewardship program was NIF. Today, the ICF budget is larger than $500 million per year, more than two and a half times its steady-state level throughout the 1980's and early 1990's.

In a sense, the ICF community's reaction to the opportunity presented by the Nation's decision to halt underground nuclear tests was similar to the MFE community's reaction to the opportunity presented to it by the first oil shock. Both events were unexpected, external to fusion itself, and of global import. Both events led to the construction of major facilities and to a sharp increases in the respective program's research budgets.

A lesson here for the magnetic fusion enterprise is that it should maintain some level of study regarding an ignition/high gain plasma experiment. There is no predicting when the next call may come, and the maintenance of such studies in the early 1990's was an appropriate part of "staying at the ready". Unfortunately, budget reductions came before a major event arrived that could generate an upturn, and those studies were discontinued, at least officially.

It is also interesting to note that the timetable to bring new facilities such as NIF and TFTR into operation appears to be similar, and that such projects are highly stabilizing to the general program. TFTR came into operation in late 1982 and real operation in 1983, about ten years after the oil shock of 1973. NIF is to come into operation in 2006, about 10 years after President Clinton signed the CTBT and 14 years after President Bush's initial decision. The long timeframes associated with the buildup of such facilities and their experimental campaigns generally leads to long periods of program stability.

The key point in closing this story is that NIF, as with TFTR, would not have been approved merely on the basis of the scientific results of the program itself. A major external event was needed to catalyze the program's move to the next level of funding and experimental machines. The ICF and MFE programs each needed to be balanced and ready when opportunity came knocking, and they need to remain balanced and ready now.

IV-C: The Unexpected Republican Congressional Victory in 1994 and the Budget Battles of 1995 and 1996

In 1994, the U.S. elections took an unpredictable turn when the Republican Party won a large majority of the seats in the House of Representatives. Already a majority in the Senate, this meant that Congress as a whole was now Republican while the President was a Democrat. Here again was an external event, mostly unexpected, that turned out to have a great impact on the magnetic fusion program, this time in a negative way. Clearly, nothing fusion had done was related to the unexpected event itself.

After the 1994 election, the focus turned even more strongly to reducing the federal deficit, achieving a balanced federal budget, reducing federal spending, and reducing or eliminating programs not viewed as essential, especially if such programs might require significant funding in the future. Programs of this latter kind were said to carry a "mortgage for the future" and were seen as a threat to the ability to balance the budget.

Since the end of the Gulf War, all energy programs had become vulnerable to budget reductions. It was very difficult to explain the strategic importance of energy when the price of gas at the pump had fallen to historic lows. Furthermore, while the issue of greenhouse gases and global warming was intensely discussed, the political debate about these issues was still at an early stage. Indeed, after the 1994 election, these issues became very contentious politically, and the matter of climate change was simply not at the point where it could be an argument for supporting programs in energy development or greenhouse gas management. At best, the climate debate would stabilize some energy programs while awaiting a clearer resolution of the issues involved.

Magnetic fusion, now narrowed mainly to research surrounding the tokamak concept, was focussed on two major activities. These were the proposal to participate as a partner in ITER, estimated to be a roughly $10 billion construction project, and the proposal to build a significant new fusion experiment, the Tokamak Physics Experiment, estimated to cost in the range of $1 billion.

Both ITER and TPX were moving forward based upon the tokamak line of research, leaving the program vulnerable to two charges. The first charge was that the program had not spent sufficient effort to find the best approach to fusion, i.e., that it had prematurely focussed on the tokamak. The second charge, which really was stated as a budget matter, was that ITER and TPX represented significant mortgages for the future, and that without a compelling justification for the timetables proposed (as external events had provided in the past), both these proposals were ripe targets for elimination. The situation was not helped by the fact the ITER program was coming to the end of its formal agreement phase, and would require a renewed agreement among the parties to continue.

Over a two-year period, funding for TPX was eliminated and the program cancelled, and funding for ITER was discontinued at the end of its engineering design phase. Other program activities were also cut, including the shutdown of TFTR after more than a decade of operation. The result was a loss of one third of the funding for the magnetic fusion program. Over the two year period covering the fiscal years 1996 and 1997, funding was reduced from about $360 million to around $240 million.

In its fiscal year 1996 appropriation, Congress called for the DOE to re-examine its fusion program goals, and to consider restructuring the program more along lines appropriate for a long term research effort, rather than along lines of an energy development program. In essence, after 20 years of being organized, approved and described as an energy program with a strong scientific mission (the stewardship of plasma physics), the fusion program now needed to reorient. It needed to begin a restructuring process where the focus would be more on the science of the program and less on the mission of energy.

The DOE charged its Fusion Energy Advisory Committee (FEAC) in 1995 to address this issue and to recommend a new program strategy and new policies and organizational changes consistent with its recommendations. (In the spirit of full disclosure, I was chair of FEAC at the time.) The committee formed a series of panels and engaged a broad cross section of the community to carry out its work. The result was the 1996 report, “A Restructured Fusion Energy Sciences Program”. The committee’s recommendations were accepted by the community and the DOE, and the program has been on that recommended path ever since.

In essence, the recommendations call for creating a fusion research program that can be characterized as “Science with an Energy Goal”. When the recommendations are examined closely, one sees that they amount to a call for balance among areas such as fusion plasma science, confinement research, and new confinement approaches, and to research in technology, engineering, and design that will help keep the program "at the ready".

In the intervening years, the program has indeed broadened its scientific content while including research on fusion technology that is critical for the long-term attractiveness of any fusion power system. Support in Congress did stabilize, though the program budget declined a bit more over the next two years, to about $220 million. This year, for the first time in five years, Congress approved an increase of about 14% in the budget for fusion energy research, to $250 million. It expressed pleasure with the changes that have been made programmatically and my sense is that the new balance everyone worked so hard to achieve is being recognized and rewarded.

V. History's Lesson to the Fusion Community

Let me close these reflections with a reprisal of the lessons history has taught us. First and foremost, history shows that all the major opportunities to advance fusion research came about as a result of a major external event – often one of a global nature. The same is true for the downturns the program has experienced. Scientific progress and achievements made in fusion research have never been sufficient, in and of themselves, to create a major and sustained upturn in support for the quest for fusion energy. The program's scientific and technical progress has at best led to incremental gains over time, and may have helped place a floor beneath the program's budget during times of funding cutbacks. The program's "degree of readiness" at the time of an episodic opportunity has similarly been critical in determining the extent of the upturn.

The key lesson I hope the fusion community draws from this history is that the program should, as a matter of policy, be organized to respond effectively to a major unexpected external event. That response needs to be a credible one, one where the program can defend its plans to move the field sharply forward when that opportunity arises. Similarly, the program must be able to defend itself scientifically and technically against arguments that it is ineffective, unproductive or unbalanced when it comes under attack.

In the end, this means the fusion program must continuously aim at achieving a solomonic balance between its often competing desires: to gain further basic understanding of fusion-grade plasmas; to demonstrate optimal magnetic or inertial confinement configurations; to demonstrate performance capability at burning plasma conditions; and to develop and demonstrate the technologies and designs needed for an attractive and practical fusion energy system. These tugging desires, sometimes expressed as the tension between a science-oriented program and an energy-oriented program, can lead the program to overly focus on one of these sub-objectives. That, history suggests, will leave the program vulnerable to downturns and less than optimally prepared for upturns.

The key for the future is to sustain support in the community of fusion scientists for the twin principles of "balance" and "staying at the ready". With each large decision, one should ask how it enhances “balance” and what it contributes to “staying ready”. These then become checks on decisions.

The ICF program showed in 1997 that it was sufficiently “balanced” and “ready” to take advantage of a major opportunity to build NIF. The fusion energy sciences community likewise should take great pride and pleasure in the fact that over the past five years, it has changed, sometimes with considerable pain, into a forward looking and balanced enterprise. The research efforts in inertial and magnetic confinement are, this year and for the first time, growing together in many ways. Keeping it that way is everyone’s task, and keeping in mind the twin principles of “balance” and “staying at the ready” will serve the community well over the long haul.