analysis would reveal research areas in a dozen different disciplines that could much better serve as the test for a nation's "commitment to fundamental scientific research." Funding the SSC could result in abandoning fundamental scientific research in many fields and will certainly assure American decline in both science and technology in a dozen different fields of chemistry, biology and materials science. Indeed, it is obvious that funding the SSC is merely funding a public works project. There is absolutely no doubt that the SSC has survived only on its pork-barrel merit, and the scientists who use that route to advance their own tiny corner of science will no doubt rue the day, as the national technological capacity and wealth will slowly wither in their ability to support basic research at all. Only rich countries can afford esoteric research with no purpose connected to the public good.

The smaller, equally fundamental sciences are also quantifiably more meritorious in their value to society. The astonishing fact is that so few among the scientists in those fields have the intellectual fortitude to make their own case for being at least as fundamental as particle physics.

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Inertial Fusion Qualifiers and Qualms

I read with interest the article on progress toward inertial confinement fusion by John D. Lindl, Robert L. McCrory and E. Michael Campbell (September 1992, page 32).

In the paragraph preceding their equation 2, rather than defining ignition, as they claim, the authors have defined a fuel break-even condition. By picking the right value of "burn temperature" they can get any value for the fuel areal density ρr (ρ and r are the compressed fuel density and radius, respectively) that they want, and it was necessary for them to choose the temperature of 20 keV to get their "ignition" ρr value of 0.21 grams per square centimeter—a value more accurate than the method actually used to assess it can provide. Almost all quotes of the ρr value necessary for D–T ignition are based on numerical simulations, and most people are willing to venture only that the smallest value for which D–T ignition can occur is about 0.3 g/cm^2. (See the article by C. Martin Stickley in PHYSICS TODAY, May 1978, page 50.) Lindl has previously supplied all the equations needed to derive a reasonable minimum value of ρr for the case of volumetric ignition.[1]

Familiar examples of thermochemical ignition are striking a match and the combustion that takes place in a diesel engine. Thermonuclear ignition is similar. Prior to ignition in ICF the plasma state is determined mainly by the hydrodynamics of the implosion, but following ignition self-sustaining thermonuclear burn occurs and continues despite the expansion cooling that ensues. While it may be too involved for an article in PHYSICS TODAY to present the analysis that shows why ignition depends parametrically on ρr, the reader should understand that all historical definitions of fusion ignition are based on the concept of a threshold that is a dividing line between strikingly different behaviors of the thermonuclear plasma. The derivation of ignition conditions has usually been cast in terms of the rate of temperature increase due to the energy gain from deposition by the reaction products less the loss by thermal conduction, bremsstrahlung and other processes. For volumetric ignition, the condition of zero work rate by the confining shell (or "pusher") is appropriate for assessing the smallest values of temperature and ρr that allow ignition. In fact, in the absence of external support by compression, ignition can occur for a range of temperature and ρr pairs, but there is a minimum pressure P times radius r (proportional to the product of temperature and r) for which ignition can occur. For a given mode of ignition the Pr value ultimately required for ignition dictates what *initial* value of Pr is needed to insure ignition. An excellent illustration of the ignition process was given by Lindl.[1] However, for the dynamic case of hot-spot ignition, one must consider the residual velocity field in the hot spot. The physics of both volumetric and hot-spot ignition has been studied numerically by various authors.[2] More recently, the ignition conditions required for magnetized target fusion have also been discussed.[3]

References

1. J. D. Lindl, in *Proc. Int. School of Plasma Physics, Varenna, Italy, 1988*, A. Carnso, E. Sindoni, eds., Editrice Compositori, Bologna, Italy (1989), p. 617.
2. See, for example, R. E. Kidder, Nucl. Fusion **19**, 223 (1979); R. C. Kirkpatrick, Nucl. Fusion **21**, 1457 (1981); M. M. Basko, Nucl. Fusion **30**, 2443 (1990).
3. I. R. Lindemuth, R. C. Kirkpatrick, Fusion Technol. **20**, 829 (1991).

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I am very disturbed by the tenor of the two articles on inertial confinement fusion in the September 1992 issue (pages 32 and 42).

The authors of the first article, John D. Lindl, Robert L. McCrory and E. Michael Campbell, state that the attraction of the goal of controlled thermonuclear fusion is (among other things) the view of fusion as a safe, clean energy source. Immediately I started thinking about neutron activation and the danger of tritium leaks into the cooling fluid.

William J. Hogan, Roger Bangerter and Gerald L. Kulcinski start the second article with the statement, "Fusion is potentially a safe, clean energy source." Yet later they state, "All the studies cited here employ *low-activation structural materials and blankets*" (emphasis mine). They show graphs indicating the expected radioactivity of an inertial confinement fusion reactor as a function of time after shutdown. While considerably smaller than that of a fission reactor, it is still sizable. Also, one has to keep in mind that the graphs show calculated values for the ICF reactor but, presumably, hard experimental values for the fission reactor.

In reading both articles I had to constantly remind myself that many of the references were to calculations of expected results, not to hard experimental facts. The first article states that the newest version of the Nova laser delivers 40 kilojoules of light onto a target, while the Omega laser delivers 2–3 kJ. The estimates of the required energies for indirect- and direct-drive inertial fusion shown in figure 7 give requirements of 0.3–2 megajoules for the former and over 1 MJ for the latter. Thus an increase in laser power by a factor of about 7.5 to 50 is required for practical ICF. Remembering the time when lenses were badly damaged after three laser shots, I wonder whether the behavior of the optical focusing elements can be predicted safely.

The last paragraph of the second article states the goal of these articles: to gain support, if not for the continuation of the ICF work as a whole, then at least for the development of powerful enough lasers. While I recognize that enthusiastic writing is necessary for that purpose, I am afraid that the tenor of these articles may defeat the purpose and even may not be in the best interest of the physics community.

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THE AUTHORS OF THE TWO ARTICLES REPLY: All energy sources involve materials or processes that, if not properly controlled, can be hazardous to humans or the environment. When the magnitudes of the risks and the means of controlling them are considered, we believe that inertial fusion indeed does have the potential to be safer and cleaner than today's fossil and fission power plants. Our articles clearly point out the magnitude of the design and development tasks that must be done to assure this. Hans Meissner has not identified any new mechanisms that would affect safety or cleanliness. The specific reactor studies referred to in our second article (references 4, 5 and 12) do not ignore the possibility of tritium leaks into the cooling fluid or any other identified source of leakage. Our "calculated" total radioactivity estimates are based on a very large number of measured cross sections, and the neutronics codes used have been used in current fission reactors to estimate other integral results that have in turn been verified by experiments. It is not likely that integral experiments done when fusion facilities are available will find that the calculated results are in error by the several orders of magnitude that would be required to reverse our conclusions.

Regarding the issue of optics damage, the ten-beam Nova system, which was originally designed in the late 1970s using the then current technology and began operation in 1984, operates at about 3–4 kJ per beam in the blue (0.35 μm) and provides about 1400 system shots per year on a two-shift-per-day, five-day-a-week schedule. In addition, high-power laser and optical materials technology has made significant and in some cases revolutionary progress in the past 15 years. Based on these advances, a National Academy of Sciences review group (reference 1 of our first article) concluded in 1990 that a megajoule-class solid-state laser was technically feasible with present technology.

Finally, we do not apologize for the fact that we are advocates of inertial fusion energy. We believe it is in the best interest of the physics community that advocates be as enthusiastic as they can be so long as they do not ignore the difficulties that must be overcome to realize the benefits of their ideas. We are certainly not alone in our assessment of the promise of fusion. DOE's Fusion Policy Advisory Committee[1] found that "fusion reactors will have substantial advantages over fission reactors with respect to the consequences of severe accidents and the magnitude of radioactive-waste burdens. This is true even in the unfavorable case of fusion blankets that use nonoptimal structural materials such as stainless steel, which becomes highly radioactive under neutron bombardment. The volume of waste produced by a 1200-MW_e fusion reactor, if diluted to the levels required for shallow land burial under US Federal Regulations, is at least a factor of one million lower than that produced by a fission reactor of the same size. The maximum plausible critical dose at the site boundary for a severe fusion accident is two to three orders of magnitude less than that for a severe fission accident."

Reference

1. Fusion Policy Advisory Committee final report, September 1990, NTIS-PR-360, available from Natl. Technical Inf. Service, US Dept. of Commerce, Springfield VA 22161.

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News from the Nuclear-Pumped Laser Forefront

The Russian Institute of Physics and Power Engineering (IPPE) hosted NPL-92, an international conference on nuclear-pumped lasers, in Obninsk during the last week of May 1992. Scientists from the former Soviet Union, the United States, Germany, China and South Africa attended, including scientists from American and Russian nuclear weapons laboratories. The openness of the FSU participants was remarkable, considering the relationship of the conference topic to nuclear directed-energy weapons programs. The changing political climate allowed the Russian organizers to welcome foreign participation; previous NPL conferences had been