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AUTHOR(S): David B. Harris
Donald J. Dudziak
David C. Cartwright

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INERTIAL FUSION IN THE NINETIES

David B. Harris, Donald J. Dudziak, and David C. Cartwright
University of California
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

ABSTRACT

The 1980s has proven to be an exciting time for the inertial confinement fusion (ICF) program. Major new laser and light-ion drivers have been constructed and have produced some encouraging results. The 1990s will be a crucial time for the ICF program. A decision for proceeding with the next facility is scheduled for the early 1990s. If the decision is positive, planning and construction of this facility will occur. Depending on the time required for design and construction, this next-generation facility could become operational near the turn of the century.

I. INTRODUCTION

The inertial confinement fusion (ICF) program has maintained level funding over the past few years, and is currently active at national laboratories, universities, and industries. Recent results in many areas have been very encouraging, giving indications that the ultimate success of ICF is achievable. The 1990s will most certainly provide even more progress towards achievement of the short-term military applications and the long-term civilian goal of energy production.

The U.S. ICF program currently has three major elements: capsule physics, driver technology, and driver-matter interactions. Other smaller components such as target fabrication and reactor studies are also being investigated at a lower level. The capsule physics effort is mainly in a classified program called Centurion/Halite, a theoretical and experimental effort to investigate the design characteristics of ICF targets. Excellent progress has recently been achieved, and has been said to be a turning point in demonstrating target behavior [1].

The 1980s has also seen new drivers being developed. At Lawrence Livermore National Laboratory (LLNL), the Nova solid-state laser has been constructed and is being used to implode targets. One significant result is the successful implosion of a target with a convergence ratio of 30 [1]. This demonstrates that compression of targets to high densities and small radius is achievable. At Los Alamos National Laboratory (LANL), the Aurora krypton fluoride laser system is currently under construction. When complete, this system will deliver ~5 kJ of 0.25-μm wavelength laser light to target. Aurora is the first end-to-end demonstration of an angularly multiplexed excimer laser for fusion. KrF lasers are an important laser driver because of their attractiveness for ICF commercial applications such as electric power production [2,3]. At Sandia National Laboratory (SNL), the particle beam fusion accelerator PBFA II has made significant progress. Light-ion accelerators such as PBFA II are attractive for ICF because of their low cost. These drivers and others will be described in more detail in Section II.

In 1986, the ICF program underwent a comprehensive review by a committee formed by the National Academy of Science (NAS) in response to a request by the White House's Office of Science and Technology Policy [4]. The results of the review stated that there is a strong motivation for continuing the ICF program with constant funding. The committee reported that, in their opinion, sufficient information will be available in the early 1990s to decide on the future direction of the ICF program. While the exact nature of the decision in the early 1990s has not been defined, it is probably a "go/no go" decision for a major new facility to achieve high gain [1]. A study led by the U.S. Department of Energy (DOE) of the next major facility, called the Laboratory Microfusion Facility (LMF), is currently underway [5-12]. This facility (also known as the Single-Pulse Test Facility, the High-

Gain Test Facility, or the Target Development Facility) is widely recognized as the next major step towards ICF commercialization. The conclusions of the NAS study will be discussed in Section III. The path to ICF commercialization will be reviewed in Section IV, and Section V will examine the Laboratory Microfusion Facility Scoping Study.

II. STATUS OF THE ICF PROGRAM

The national ICF budget has remained roughly constant over the last few years. Figure 1 shows the funding level and type of activity for each U.S. participant in the ICF program. An additional participant is the Lawrence Berkeley Laboratory heavy-ion fusion accelerator research program, which is funded out of the Office of Energy Research. The status of these activities will be described.

II.A. Drivers

The progress in the area of driver development is a good indication of the progress made towards ICF development. Four drivers are currently being developed in the U.S. It is uncertain which driver is the best for ICF commercial or military applications, and in fact the driver best suited for one application may not be suitable for another. Therefore, the four drivers are being developed in parallel. Each driver is in a substantially different state of development, and has its own set of issues. This will be described below.

Solid-state lasers. The $176-million Nova laser at LLNL completed construction in December 1984. An artists drawing of Nova is shown in figure 2. Although rated for ~100 kJ at 1.06 μm and ~50 kJ at 0.35 μm, platinum particles in the glass disks have limited its performance to 15-20 kJ of 0.35-μm laser light in a 1-ns pulse. Within this capability, Nova accomplishments include [13]:

- Generation of 10^{13} neutrons, which is a gain of ~0.2%, from a D-T target directly illuminated with 17 kJ of 0.35-μm laser light.
- Demonstrated the drive conditions required for high gain with scaled indirect-drive targets.

- Propagated complex temporal pulse shapes of the type required for high compression through the laser chain.
- Started experiments for x-ray conversion efficiency and hot-electron production with plasma scale sizes greater than 5000 laser wavelengths.

KrF lasers. The Aurora krypton fluoride gas laser system at LANL is the first generation of KrF lasers for fusion (whereas Nova is the seventh generation solid-state laser at LLNL). Depicted in figure 3, Aurora uses four amplifier stages. The final amplifier, the Large Aperture Module (LAM) has already generated over 10 kJ of 0.25-μm laser light. A major milestone, propagation of laser light from the from end through the encoder, amplifier chain (bypassing the LAM), decoder, and target optics is scheduled for January 1988. The first multikilojoule experiments should occur late in FY 88.

Light-ion accelerators. Like KrF lasers, light-ion accelerators are not a mature technology. PBFA II, shown in Figure 4, first became activated in December 1985, and is in the middle of a substantial debugging period to improve two important areas; power concentration and beam focussing. This $45 million accelerator is eventually expected to deliver one to two megajoules of energy to a target and perhaps reach ignition.

Heavy-ion accelerators. The heavy-ion fusion accelerator research program is funded by the Office of Energy Research at a level of ~$5 million per year. The latest experiment is the Multiple Beam Experiment, or MBE-4, and is located at Lawrence Berkeley Laboratory (LBL). This accelerator propagates four beams from the cesium injector through acceleration modules to an energy analyzer. No target work is expected with this device. A next-generation device called the Induction Linac Systems Experiment (ILSE) is being planned. ILSE will address almost all of the remaining ICF driver issues [14].

Driver issues. Many issues remain to be solved for each of the drivers before a commercial-applications ICF facility can be built with acceptable cost and risk. For solid-state lasers, an acceptable lasing medium has not yet been identified that is acceptable for ICF commercial applications [3,15]. If a medium is identified, the energy scaling and cost scaling must be determined. Two key issues for solid-state lasers are the overall system efficiency and the ability to operate at high repetition rate. The yet-to-be-identified lasing medium must be able to satisfy these requirements.

For KrF lasers, amplifier module energy scaling and aperture combination must be demonstrated. Acceptable cost scaling must also be proven. Commercial drivers require high efficiencies (5-10%, depending on target gain). While KrF lasers appear to be able to satisfy the efficiency requirements, this too must be demonstrated. Finally, repetitive pulsing, an area that is not receiving much attention at this time, must also be developed.

Light-ion accelerators must develop repetitive pulsing for commercial applications. Focussing is another issue for light ions. This may be demonstrated on PBFA II, but also must be proved with a repetitive system with the diode much further away from the target than on PBFA II. Also, pulse shaping must also be demonstrated for light-ion accelerators to be considered for ICF commercial applications.

The main issue for heavy-ion accelerators may be their cost. Heavy-ion accelerators currently appear to be affordable but expensive for electric power production [16]. Another issue is the transport of the ion beam through the reactor cavity environment to the target. An additional issue is pulse shaping. Overall, heavy-ion accelerators are the least developed of the driver candidates. One issue may be the unknown issues that will arise due to current lack of knowledge. Further development will be required to fully determine all of the issues for heavy-ion fusion accelerators.

II.B. Capsule Physics

As mentioned before, much of the capsule physics effort is classified. Unclassified programs at the University of Rochester, Japan, and elsewhere have produced encouraging results, with higher target yields, higher compressions, and a greater understanding of hydrodynamics and instabilities. The reader is encouraged to examine reference 17 for more information on this subject.

II.C. Driver-Matter Interaction

Significant progress has been made in the understanding of laser interaction with matter. Perhaps the most important aspect of this is the striking improvements in target physics when using short wavelengths. In an analysis or recent experimental data and theoretical modeling, it was determined that the broad bandwidth, short-wavelength KrF laser output offers considerable advantage over frequency-doubled Nd:glass laser light, and several slight or possibly significant advantages over frequency tripled Nd:glass laser light [18]. More work is needed to quantify the advantages of short-wavelength, broad-bandwidth light for both direct and indirect drive approaches.

II.D. Other Developments

Another significant development is the advantage of using induced spatial incoherence (ISI) for producing the beam uniformity required for direct drive [19]. This work, done mainly at the Naval Research Laboratory (NRL) and the University of Rochester, appears to have solved the most critical issue for direct-drive ICF.

A significant advance has been realized in the area of target manufacturing with the use of low-density foams. This allows the use of thick, free-standing liquid D-T layers, which are desired for high-gain targets [20]. Further development of foam targets is ongoing.

III. CONCLUSIONS OF THE 1986 NAS REVIEW OF THE ICF PROGRAM

The 1986 review of the ICF program by a National Academy of Sciences committee provided guidance to the U.S. Department of Energy. The following are statements from that study [4].

The rationale for maintaining an ICF program includes:

- "ICF addresses real weapons physics issues."
- "If pellet yields of 100 to 1000 MJ are attained, ICF microexplosions could replace certain underground tests and would allow studies of weapons physics and weapons effects to proceed much more quickly and inexpensively."
- "The challenges of ICF are providing unique new tools for the scientific and technological community, and for the other programs of national importance like SDI."

- "ICF could be especially important in the event of a comprehensive nuclear test ban."
- "ICF attracts talented people into the weapons laboratories and maintains high morale with its elegant and challenging problems."
- "ICF may eventually lead to commercial power."

The committee also listed priorities. They based their choice of priorities on the principle that the most urgent task is to study the physics involved in pellet compression and ignition. They defined the highest priority areas in the following statement:

> "In order to reach the five-year decision point noted in the previous section, the committee is unanimous in its view that Centurion-Halite and the efforts to exploit the capabilities of the major laboratory facilities, Nova and PBFA II, and maintenance of a vigorous program of smaller scale research activities are the top priority elements of the overall ICF program. Due to the critical contribution anticipated from each, we would prefer to view them as a single priority."

The NAS committee also identified a secondary priority:

> "We recognize that eventual success will ultimately depend on developing an affordable driver, but we accord that a secondary priority in present circumstances. Hence, we recommend only a modest exploratory effort in KrF and advanced glass laser development at this time."

Additionally, the NAS committee assessed five key ingredients to the next decision, which was previously stated to be in about five years. The following will need to be understood in order to make a decision:

- Centurion-Halite bounds on target gain (especially cryogenic targets).
- Control of critical laser-plasma and hydro instabilities.

- Determination of beam transport, focusing, and pulse shaping characteristics of PBFA II.
- Estimates of costs and capabilities of advanced short wavelength laser drivers.
- Assessment of the direct drive approach.

In summary, the NAS review indicated that "the ICF program has the essential structure and capabilities to permit a fairly reliable estimate of cost and specification of the required driver and targets in about five years, if the program if funded at about current levels." Only time will tell if their prediction holds true.

IV. LABORATORY MICROFUSION FACILITY STUDY

The LMF study is a multi-year, two-phase examination of a facility that will develop high-gain targets and perform weapons physics and weapons effects experiments. The main goal of the LMF is to achieve a target yield of 1000 MJ. The LMF study, led by DOE, has a steering committee made up of representatives of all of the institutions listed in figure 1 and Lawrence Berkeley Laboratory. The first phase of the study, currently under way, is driver independent and examines:

- The utility of the LMF, including ICF target development, weapons physics applications, and weapons effects simulations.
- Requirements of the LMF, including the driver, target fabrication, and in the experimental environment (in and near the target chamber).
- Siting, safety, and environmental considerations for the LMF.
- Cost estimates of the driver-independent components needed for the LMF and cost goals for the entire facility. Driver-specific costs will be examined during Phase II.
- LMF development issues common to all drivers.

The final report for the first phase is currently being prepared.

The second phase of the LMF study will examine the driver-specific aspects. Four different drivers (KrF and solid-state lasers, light- and heavy-ion accelerators) and either (or both) direct and indirect drive schemes are being considered at this time. The second phase should produce conceptual designs of the drivers and specific estimates of the cost and driver and target performance. The second phase should last at least one year.

IV. PATH TO ICF COMMERCIALIZATION

One of the best descriptions of the path to ICF commercialization was done by Willke et al. in 1979 [21], with one exception. As it turns out, Willke was overly optimistic on projecting schedules and dates. His basic plan for ICF development is still valid. However, his first step is the equivalent of the LMF, which has not yet been reached. And, it may not be the next step towards commercialization. In the authors opinion, there is too great of a risk in building a (multi?) billion dollar facility with an ~10-MJ driver without an intermediate step. The intermediate step can appropriately be called an ignition physics facility. There are several reasons for the need for an ignition physics facility. First, target physics is too uncertain to determine the required driver energy for a 1000-MJ yield to less than a factor-of-two at this time. Therefore, the cost of the LMF is uncertain to approximately a factor-of-two owing to just the uncertainty in target physics. Perhaps PBFA II can resolve some of the uncertainties with respect to target physics if it can achieve ignition. Another high-risk area is driver technology. All of the drivers must solve all of their technical issues before the LMF could be built. The required scale-up in driver energy on target is a factor of 10 for light-ion accelerators (if PBFA II achieves its goal of ~1 MJ), 200 for solid-state lasers (if Nova achieves its goal of ~50 kJ of frequency-tripled laser light), 2000 for KrF lasers (if Aurora works as expected), and many orders of magnitude for heavy-ion accelerators. These scale-ups are too large and lead to an unacceptable risk of failure. It is impossible to determine what monster will rear its ugly head when extrapolations of this magnitude are needed. Finally, driver cost is a concern. With the exception of light-ion accelerators, the cost of all drivers have historically been much too high for the LMF. The cost goal of the LMF is less than $200/joule [5]. The Aurora KrF laser has a cost of several thousand dollars per joule. This is not unexpected or to be alarming because it is the first-of-a-kind system, and much of the cost is due to experiments with the laser and retrofits as more is learned on the system. However, the seventh generation solid-state Nova laser at LLNL has a cost of ~$3500/joule. Heavy-ion accelerators are also expensive in unit cost at their low energy levels. Cost reductions are clearly needed. An intermediate facility will allow driver technology to improve and mature, and hopefully result in an affordable LMF.

After the ignition physics facility, the next step is the multimegajoule single-pulse test facility, the LMF. The LMF will not only develop high-gain targets for commercial applications, but will also be used for military applications such as weapons physics research and weapons effects experiments. Either during or after the LMF, a small-scale experiment called (by Willke) the systems integration facility (SIF) will be needed. The purpose of the SIF is to develop the technology for target injection, tracking, and targeting by the laser system. Additionally, the SIF will aid in pulsed power supply development, require the construction and testing of a prototype driver, and allow beam propagation studies.

Following the LMF and SIF will be facilities such as the following:

- The engineering test facility (ETF), which is required to test ICF reactor concepts and reactor-plant equipment such as tritium recovery and handling
- The materials test facility (MTF), which is needed to test pulsed irradiation effects and to qualify materials for ICF applications
- The pellet fabrication facility (PFF), which is required to develop mass-production fabrication of targets, to serve as a prototype for a target factory for ICF commercial applications, and to provide targets for the above facilities
- The fusion pilot plant, which will serve as a prototype for an electric power plant. The pilot plant may be a fission-fusion

hybrid in order to lower the fusion requirements and still make the plant cost competitive.

Finally, after all of these intermediate steps, the technology will be available and the risk should be acceptable for construction of an ICF power plant operated by the electric power industry.

V. CONCLUSIONS

Significant progress has been made towards ICF commercialization. Advances in target physics have been significant, including the compression of a target to a convergence ratio of 30, providing confidence that the compression of targets to high densities and small radius is achievable. Major new facilities have also been constructed or are soon to complete construction. PBFA II is a light-ion accelerator at SNL should eventually be able to deliver ~1-MJ of energy to a target and hopefully achieve ignition. Nova, a solid-state laser at LLNL, will ultimately be capable of delivering ~50 kJ of 0.35 µm laser light to a target. Operating at reduced energy due to platinum inclusions in the laser glass, Nova has still achieved a record number of neutrons from an ICF experiment. At Los Alamos, a first-of-a-kind KrF laser-fusion system called Aurora is nearing completion. When operational, Aurora should be capable of delivering ~5 kJ of near-ideal 0.25-µm laser light to a target. The Multiple Beam Experiment at Lawrence Berkeley Laboratory and the planned Induction Linac Systems Experiment will address most of the issues required for a heavy-ion driver for inertial fusion.

Uncertainty still exists on which method of target illumination--direct drive or indirect drive--is better. Significant progress has been made in illumination symmetry, the main issue for direct drive. The concept of ISI, developed mainly at NRL, has solved that problem. ISI will also provide some benefits for indirect drive schemes.

Though the ICF program is on the path towards commercialization, there is still a long way to go. The program is currently aiming for a decision and the beginning of construction of the next facility in the early 1990s. The driver energy and facility capability of this next-generation facility will depend on the choice of driver. The Laboratory Microfusion Facility Scoping Study is providing an early look at the different drivers in preparation for the upcoming decision.

The 1990s is sure to be an exciting period for the U.S. ICF program. Results from existing facilities will be continually reported, and the design and construction of the next step should occur. The next step will be somewhere between ignition and high gain, depending on the driver selected.

REFERENCES

1. S. L. Kahalas, "Remarks Prepared For Third Inertial Confinement Systems and Applications Colloquium", Third Inertial Confinement Systems and Applications Colloquium, Madison, Wisconsin, 9-11 November 1987. University of Wisconsin report UWFDM-748, December, 1987.

2. D. B. Harris et al., "Future Developments and Applications of KrF Laser-Fusion Systems," Fusion Technology, 11, 705 (1987).

3. D. B. Harris, L. A. Rosocha, and D. C. Cartwright, "Los Alamos National Laboratory View of Commercial Drivers for Laser-Fusion Reactors," Proceedings of the Third Inertial Confinement Fusion Systems and Applications Colloquium, 9-11 November 1987, Madison, Wisconsin.

4. "Review of the Department of Energy's Inertial Confinement Fusion Program," National Research Council, National Academy Press, March 1986.

5. D. J. Dudziak, D. B. Harris, and J. H. Pendergrass, "Goals, Requirements, and Desirable Characteristics of the LMF Inertial Fusion Driver," 12th IEEE Symposium on Fusion Engineering, Monterey, California, 12-16 October 1987.

6. R. E. Olson, "Conceptual Design of a 10 MJ Driver for a High Gain Target Development Facility (TDF)," 12th IEEE Symposium on Fusion Engineering, Monterey, California, 12-16 October 1987.

7. J. H. Pitts, "Using the Nova Target Chamber for High-Yield Targets", 12th IEEE Symposium on Fusion Engineering, Monterey, California, 12-16 October 1987.

8. M. T. Tobin, "Neutronics Issues for a Laboratory Microfusion Capability," 12th IEEE Symposium on Fusion Engineering, Monterey, California, 12-16 October 1987.

9. W. J. Hogan, "Design Issues for a High Gain Fusion Facility: Implications of Recent Program Results," 12th IEEE Symposium on Fusion Engineering, Monterey, California, 12-16 October 1987.

10. C. Orth, "Calculations of Ablated Mass and Ablation Momentum Transfer for the First Walls of ICF Facilities," Bulletin of the American Physical Society, 32, 9, 1788 (1987).

11. W. J. Hogan, "Target Chamber Design Issues for a High-Gain Inertial Fusion Test Facility," Bulletin of the American Physical Society, 32, 9, 1788 (1987).

12. D. B. Harris and D. J. Dudziak, "Major Cost Factors," Los Alamos National Laboratory report LA-UR-87-4142, December, 1987. Prepared for inclusion in the Laboratory Microfusion Facility Phase I Final Report.

13. "1985 Laser Program Annual Report," Lawrence Livermore National Laboratory report UCRL-50021-85, November, 1986.

14. T. Fessenden, "Induction Linac Drivers for Commercial HIB Fusion," Third Inertial Confinement Fusion Systems and Applications Colloquium, Madison, Wisconsin, 9-11 November 1987. University of Wisconsin report UWFDM-748, December, 1987.

15. H. Lowdermilk, comments made at the 3rd ICF Systems and Applications Colloquium, Madison, Wisconsin, 9-11 November 1987.

16. D. J. Dudziak, W. B. Herrmannsfeldt, and W. W. Saylor "HIFSA Heavy-Ion Fusion Systems Assessment Project, Volume I: Executive Summary" Los Alamos National Laboratory report LA-11141-MS, Vol I, December, 1987.

17. The Program of the 29th Annual Meeting of the Division of Plasma Physics contains far too many significant papers to list independently. The reader is encouraged to examine this on their own. Bulletin of the American Physical Society, 32, (1987).

18. W. C. Mead, "Wavelength Scaling of Absorption, X-ray Conversion, and Hot Electrons," Los Alamos National Laboratory Memorandum X-1(1/88)67, 5 February 1988.

19. R. H. Lehmberg and S. P. Obenschain "Use of Induced Spatial Incoherence for Uniform Illumination of Laser Fusion Targets," Opt. Commum., 46, 27 (1983).

20. W. J. Hogan, "Progress in the ICF Program at the Lawrence Livermore National Laboratory," Lawrence Livermore National Laboratory report UCRL-94321, May, 1986.

21. T. Willke et al., "A Plan for the Development and Commercialization of Inertial Confinement Fusion," Argonne National Laboratory report ANL-79-41, 1979.

FIGURE CAPTIONS

1. The funding level and type of activity is listed for each participant in the U.S. inertial fusion program.

2. Artist's drawing of the Nova laser at Lawrence Livermore National Laboratory. Shown is the 10 beams leading to the main target area and two beams leading to a secondary target chamber.

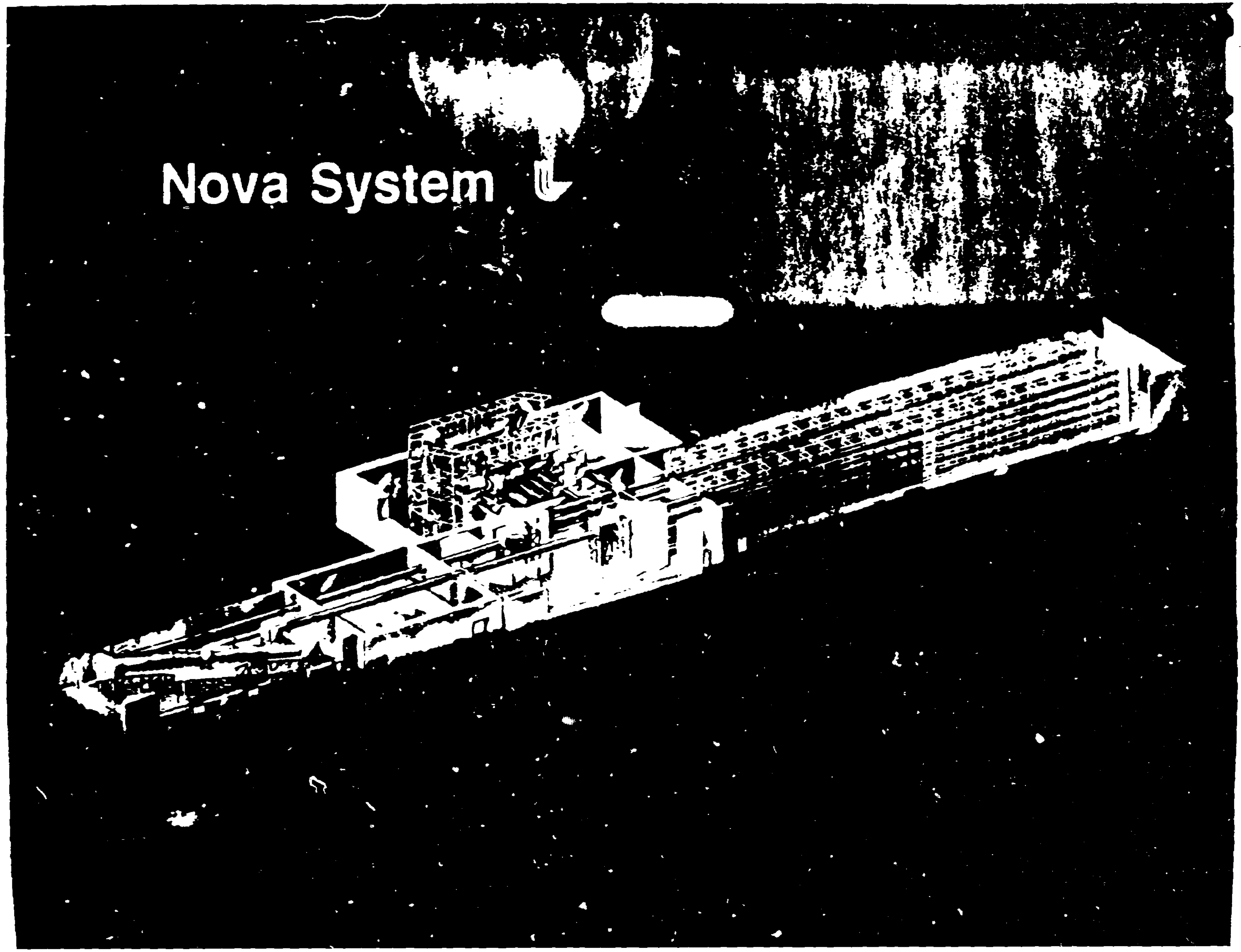
3. A conceptual layout of the Aurora laser system is illustrated. All of the main optical and laser elements from the front end through the final amplifier output and on to the target are shown. Stage gains, number of beams, and beam energy are indicated at various points along the beam path. A final output of 10-20 kJ in a 480-ns pulse composed of a 96-element train of 5-ns pulses is expected at the final large amplifier module amplifier. Typical delivered-energy at the target will be 5 to 8 kJ in 48 beams.

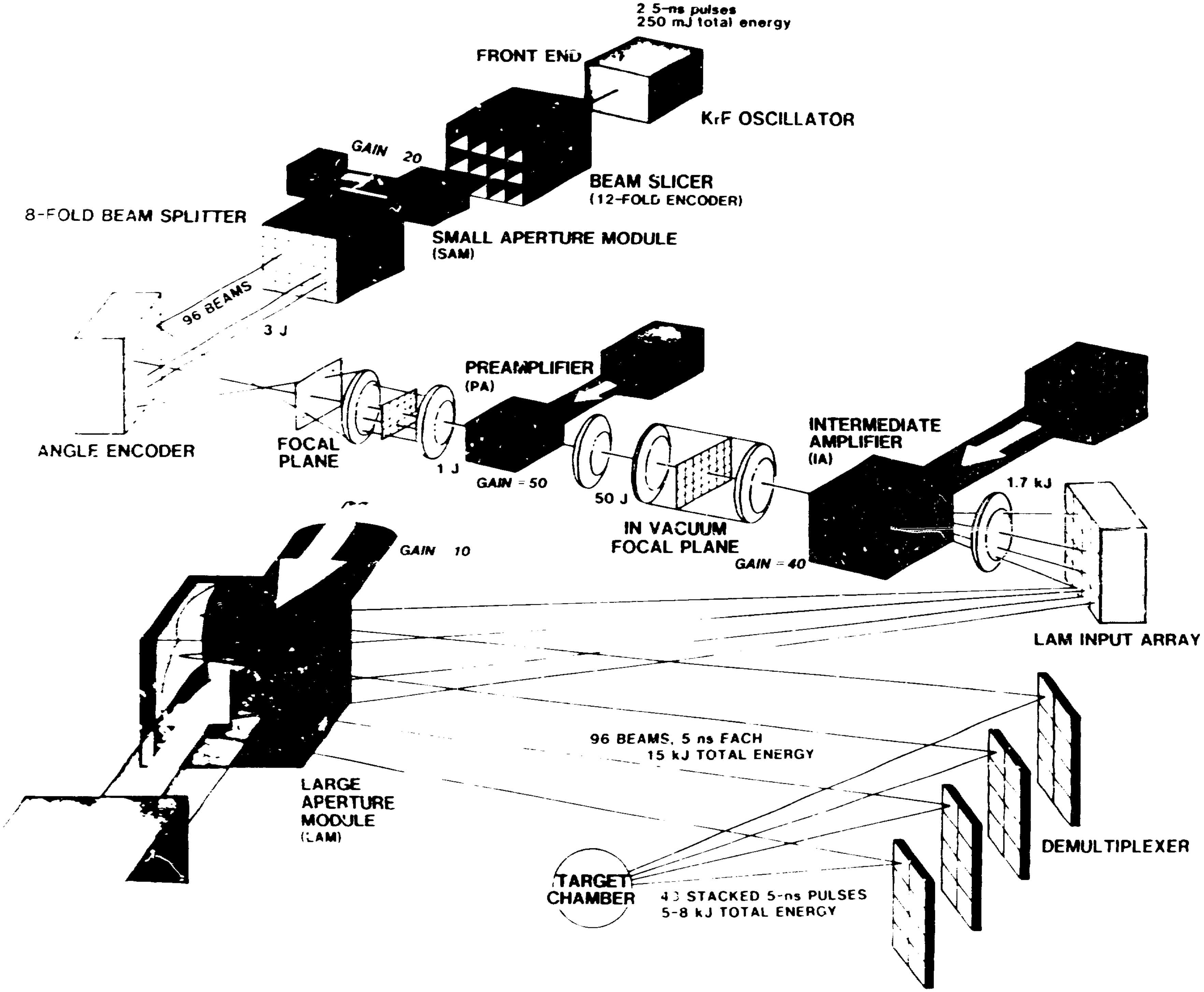
4. Photograph of the PBFA II light-ion accelerator at Sandia National Laboratory. Marx generators form the outer ring of the circle, followed by a pulse compression ring, leading to the diode at the center.

FUNDING LEVEL AND TYPE OF ACTIVITY FOR EACH U. S. PARTICIPANT

PARTICIPANT	FY85	FY86	FY87	TYPE OF ACTIVITY
LLNL	68.0	66.0	62.4	NOVA (GLASS; ≤60 kJ (0.35μm) 10 BEAMS; HALITE; SOLID STATE LASERS; HEAVY IONS
LANL	41.2	31.0	28.6	AURORA (KrF;≤10 kJ (0.25μm) 1-SIDED; CENTURION; GAS LASER DEVELOPMENT; HEAVY IONS
SNL	20.0	23.0	26.1	PBFA II (LIGHT IONS; ≲2 MJ) -LIGHT ION DRIVERS/PULSED POWER
KMS	13.0	13.8	12.9	CHROMA (GLASS;≤1 kJ (1.06μm) 2 BEAMS -SUPPORT TO LLNL; TARGET FAB. TO NAT. PROGRAM
UR	8.0	7.8	7.9	OMEGA (GLASS; ≤2 kJ (0.35μm) 24 BEAMS -DIRECT DRIVE; SYMMETRY; HYDRO;USER FACILITY
NRL	2.7	2.5	3.5	PHAROS II (GLASS;≲1kJ (1.06 μm) 2 BEAMS -DIRECT DRIVE; HYDRO EXPTS.
TOTAL	152.9M	144.1M	141.4M	

Nova System




2 5-ns pulses
250 mJ total energy
FRONT END
KrF OSCILLATOR
GAIN 20
BEAM SLICER
(12-FOLD ENCODER)
8-FOLD BEAM SPLITTER
SMALL APERTURE MODULE
(SAM)
96 BEAMS
3 J
PREAMPLIFIER
(PA)
INTERMEDIATE
AMPLIFIER
(IA)
ANGLE ENCODER
FOCAL
PLANE
1 J
GAIN = 50
50 J
1.7 kJ
IN VACUUM
FOCAL PLANE
GAIN = 40
GAIN 10
LAM INPUT ARRAY
96 BEAMS, 5 ns EACH
15 kJ TOTAL ENERGY
LARGE
APERTURE
MODULE
(LAM)
DEMULTIPLEXER
TARGET
CHAMBER
48 STACKED 5-ns PULSES
5-8 kJ TOTAL ENERGY