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# RESEARCH ACTIVITIES AT GENERAL ATOMICS

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## DISCLAIMER

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GENERAL ATOMICS

## ABSTRACT

General Atomics was founded with an initial charter to explore the peaceful uses of atomic energy. We currently play major roles in both magnetic and inertial fusion energy research and development activities in the USA. The long term goal of fusion energy development involves significant research challenges which in turn lead to the need for development of new technologies with potential for new business opportunities. Inertial fusion, with its need for extraordinary levels of power and precision in both space and time, is especially rich in opportunities for exciting new technologies. General Atomics' activities include exploration of high volume, high precision manufacturing techniques for inertial fusion target fabrication, precision cryogenic systems for target handling, and development of petawatt class laser technologies and their applications.

# I. INTRODUCTION

General Atomics was founded in 1955 in San Diego, California with an initial charter to explore the new and emerging field of peaceful uses of atomic energy. We contributed to the early research and development of nuclear power and as a result developed a number of products that are still important today. These include the TRIGA® research reactor (Fig. 1), which is the most widely used non-power reactor in the world, with 66 sold worldwide. Our products also include the High Temperature Gas-cooled Reactor (HTGR), with two built in the USA, and which has evolved into the high efficiency, passively safe Gas Turbine Modular Helium Reactor (GT-MHR), Fig. 2, a primary candidate to lead the resurgence of nuclear power throughout the world.

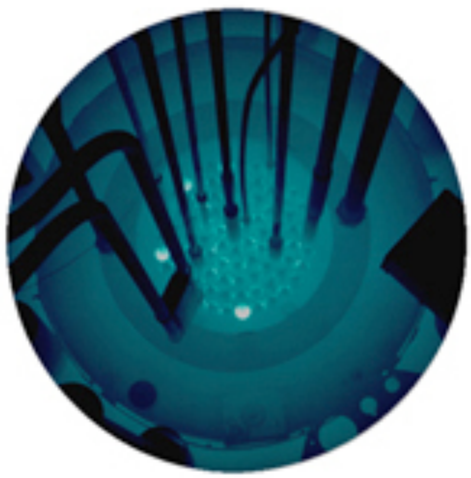

Fig. 1. TRIGA® Research Reactor.

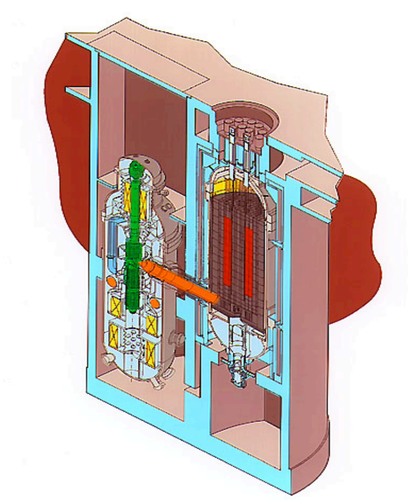

Fig. 2. Gas Turbine Modular Helium Reactor (GT-MHR).

General Atomics has had a serious research program in the field of fusion energy since the early 1960s. This program has focused on developing both the science and the technology needed to achieve practical energy production by fusion. As part of this program, we are a major participant in the US Magnetic Fusion Energy program. We built and operate the DIII-D Tokamak experiment (Fig. 3), the largest magnetic fusion experiment in the USA. Research is carried out on DIII-D by scientists from throughout the USA and the world. As part of our research into the challenges of magnetic fusion, we developed a number of cutting edge products. These include superconducting magnet technologies which we have applied to manufacture of more than 400 superconducting magnetic resonance imaging (MRI) magnets for medical diagnosis (Fig. 4), and high power microwave equipment such as waveguides, mode converters and beam combiner/splitters (Fig. 5) that we are applying to a variety of applications.

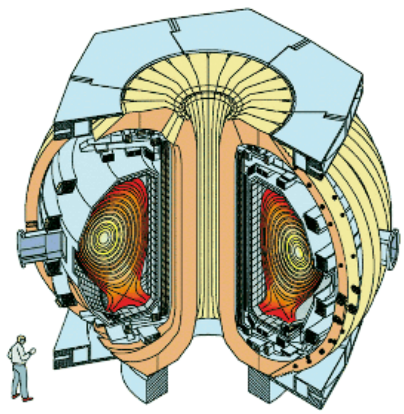

Fig. 3. DIII-D Tokamak.

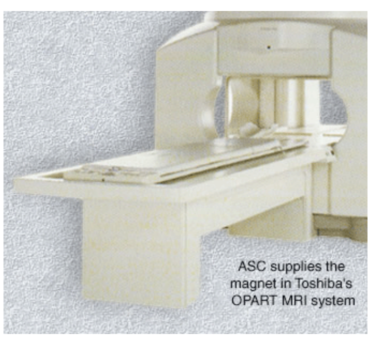


Fig. 4. MRI Imaging System.

Fig. 5. Microwave Components.

# II. INTERNAL FUSION

General Atomics has been involved in the inertial fusion research program in the USA since the 1970s when we began investigating the potential for inertial fusion energy applications. In 1990 GA was chosen as the US inertial fusion target development and fabrication laboratory, manufacturing targets for experiments in all the US inertial fusion experiments. We are now also carrying out research and development efforts related to inertial fusion's needs for high volume, high precision manufacturing techniques for inertial fusion energy (IFE) target fabrication, for the cryogenic target handling systems and IFE power plant will require and development of petawatt class laser technologies for IFE drivers. Each of these challenging research and development areas, because of the technical challenges involved, has opportunities for new product development.

## 2.1. Inertial Fusion Targets

Inertial fusion targets must meet exacting specifications for their dimensions, surface finish and materials composition. Dimensions must be controlled to sub-micron levels, surface finishes to ~100Å, and compositions to ppm levels. Currently, their production is a slow, labor-intensive process with a significant effort required for manual characterization of each target and costs of ~$2000 each [1]. This is acceptable today when only a few thousand targets are needed each year and when the constantly changing target designs and specifications require a great deal of development for each small delivery order. For inertial fusion energy, however, each power plant will need about 500,000 target per day and to achieve reasonable economics, they must cost no more than about 30 cents apiece. GA is currently carrying out a target development program with four major tenets. [2] We will eliminate the current high development and first-of-a-kind costs by standardizing on a limited number of target designs. We will reduce the current high characterization costs by automating the characterization processes and using statistical sampling to adjust process parameters. We will increase batch size from the current levels of ~10 targets per batch and increase yield to the needed 95+% level by development of fabrication processes better suited to automated mass production, such as microencapsulation and fluidized bed coating as illustrated in Fig. 6. These processes of high precision mass production with automated high accuracy characterization will have application to other manufacturing processes such as manufacturing microelectro-mechanical systems (MEMS).

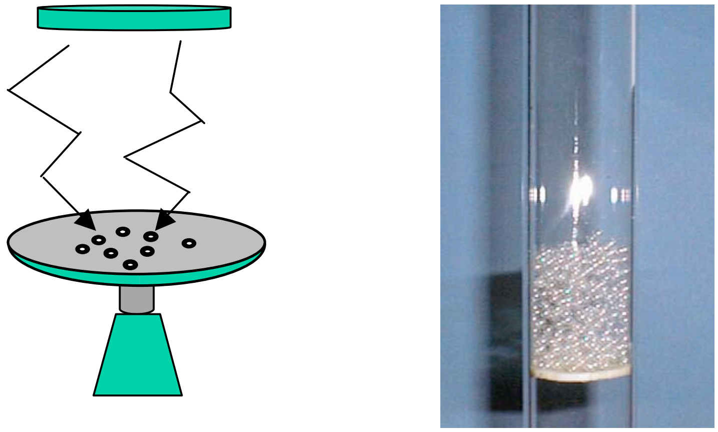

Fig. 6. Bounce pan coating few capsules vs fluidized bed coating of many.

## 2.2. Cryogenic Target Systems

Current targets for ignition experiments and future IFE targets must be filled with DT fuel and cooled to cryogenic conditions near 20K. They must be held under precise thermal conditions, possible with additional heating by infra red radiation, to achieve a smooth, uniform DT ice layer. They must be transported to the target chamber and injected at the rate of about 5 per second. All of this must be done with extreme accuracy (~0.1 K) and uniformity (~25 μK) of temperature control and high precision (~20 μm) of placement. GA developed the cryogenic target handling system with the University of Rochester for their Omega laser (Fig. 7), which must shoot about 4 targets per day [3]. We are now developing the technologies to do this for IFE power plants which must shoot about 5 targets per second. The challenges of high precision thermal and mechanical measurement and control at cryogenic conditions and high speed will provide opportunities for spin-off technologies.

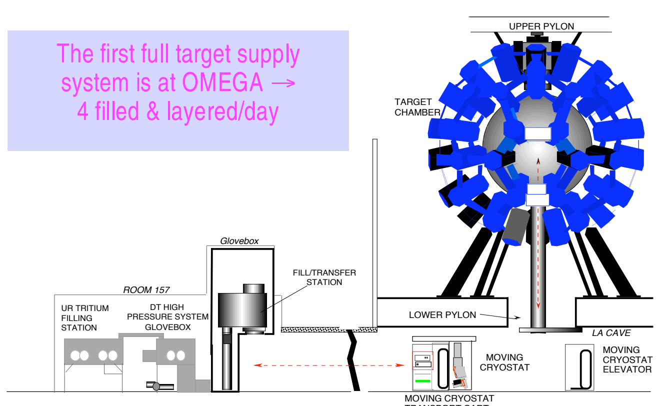


Fig. 7. Omega Cryo Target System.

## 2.3. Petawatt Class Lasers

Inertial Fusion research has been particularly demanding on the technology of lasers. Not only must extraordinary levels of power and energy be delivered, but it must be delivered with extraordinary precision in both space and time. These demands have resulted in the development of new laser technologies for laser materials, laser and optics fabrication, and beam smoothing and control that have already provided business opportunities outside fusion research. The current interest in fast ignition as a pathway to a better inertial fusion energy power plant with a faster development pathway is now pushing these demands to new heights [4]. Fast ignition promises to achieve higher target gain at lower laser input energy than hot spot ignition (Fig. 8). This means it would lead to a more affordable, more efficient power plant, and it means that a first minimum sized pilot plant will be smaller and cheaper to build than currently envisioned for hot spot ignition. However, fast ignition will require laser beams that can deliver several petawatts of power for ~ 10 picoseconds, focused to a ~25 μm spot to ignite the pre-compressed fuel. This laser will need precision beam control and high damage threshold diffractive optics to produce the ignitor beam. We are working to develop these technologies (Fig. 9), with will have numerous other high power laser applications, including grating based multiplexers for ultra-broadband optical communication, and short pulse laser machining.

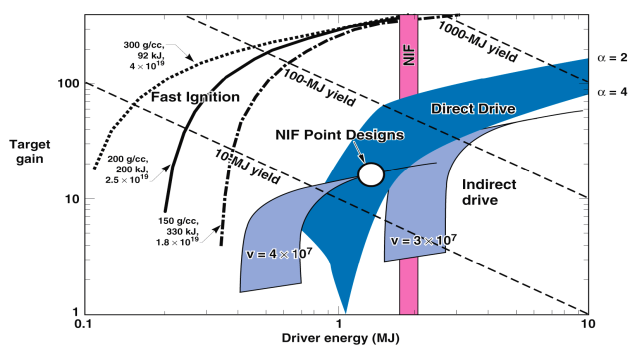


Fig. 8. Gain curves for hot spot and fast ignition

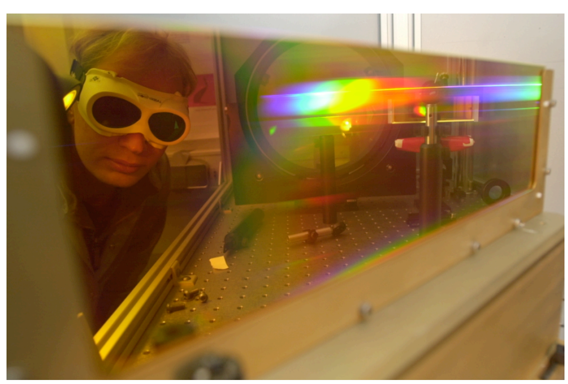

Fig. 9. GA-built pulse stretcher for Jena petawatt class laser.

Perhaps the most exciting applications for fast ignition research will come in the use of the products of the interaction of lasers and matter at very high power densities. At intensities of 1 □m laser radiation above $10^{18}$ W/cm$^2$, relativistic effects occur that produce intense beams of electrons and ions at high energy. [5] These ions have very low beam divergence and may enable whole new fields of ion beam science for diagnostics and accelerator research as illustrated in Fig. 10 and 11.

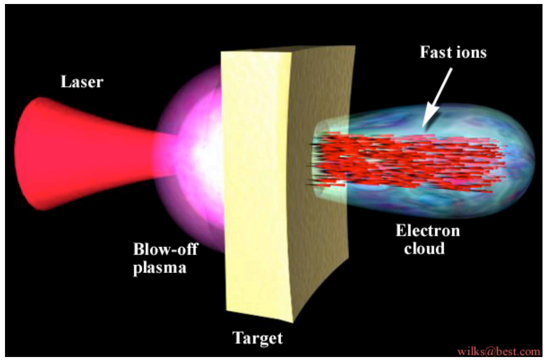


Fig. 10. Laser acceleration of ions.

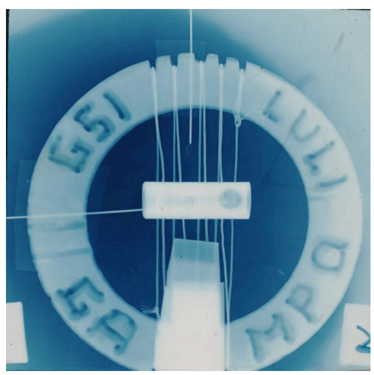


Fig. 11. Laser-accelerated proton radiography.

## III. CONCLUSION

Challenging research activities require the development of innovative new technologies to carry out the research and implement the results. These technologies in turn enable new areas of science and technology development, and new opportunities for exciting new products. These opportunities provide incentive to stick with long term development programs like fusion energy. General Atomics has pursued fundamental research into the peaceful uses of atomic energy for 46 years and has discovered, developed and implemented many new technologies in the process. The scientific challenges of fusion energy — which has been called one of the Grand Challenges of Science — will provide many opportunities. General Atomics is actively involved in the development of high volume, high precision manufacturing techniques for inertial fusion target fabrication, precision cryogenic systems for target handling, and development of petawatt class laser technologies for fusion and many other applications.

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