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German Contributions to the Physics of Extreme States of Matter

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Extreme states of matter—what does this mean in the present context? For a nuclear physicist, a materials researcher, and a fusion scientist it has a different meaning. In the context of fusion we are, of course, concerned with matter, plasmas at temperatures of 1–100 keV. But then we must further distinguish between those scientists who confine their plasmas by magnetic fields at particle densities of 10^{12}–10^{14} particles/cm^3 from those who confine their plasmas for brief instants (smaller than 1 ns) determined by the inertia of mass. In these short times very hot and dense plasmas of 10^{22}–10^{25} particles/cm^3 can be investigated. This establishes a new field of physics and applied research.

The last example of matter research relevant to inertial confinement fusion will be the focus of my presentation discussing basic research in Germany (FRG).

The word "extreme" sometimes has an ambiguous connotation, but not so in the present context. Here it reminds us of the intellectual and technical challenge that the eventual goal represents, "the harvesting of fusion energy." We have been striving for this goal for many years already. Along this long and arduous road a push in the right direction will provide the incentive to remobilize our forces and move on.

Basic research related to fusion driven by laser beams started in Germany in the early 1970s, followed by particle beam fusion in the late 1970s. However, at the present time there still is no specific technical project labeled ICF-research comparable to the impressive efforts made in the U.S., Japan, or Soviet Union.

This situation is the direct result of the present German science policy which specifies that its fusion program should be imbedded in the overall European program as defined by the scientific council of Euratom. Its adopted position is that fusion research in Europe should concentrate on magnetic fusion with special emphasis on toroidal systems. ICF research should be conducted at a basic level only—with the sole objective of maintaining Europe's capability to judge and monitor international progress.

In view of the present budget constraints for fusion research, Euratom's policy may be wise. While it promotes concentration on advanced technical projects, it does leave some room for exploratory studies of less advanced approaches.

After this brief background information on Germany's science policies, let's focus on some specifics. In Germany there are presently three laboratories located in Karlsruhe, Darmstadt, and Munich. They function as lead laboratories in Germany, each working on a different approach to driver technology:

Light ion beam drivers:	Karlsruhe, KfK
Heavy ion beam drivers:	Darmstadt, GSI
Laser beam drivers:	Munich, MPQ

The work at these laboratories is, to a large extent, exploratory, concentrating on critical engineering and physics issues. With the available driver capacity hot dense plasmas are created and investigated. But no spherical implosions of pellets can be driven due to the present simple driver configurations.

In all three laboratories research on extreme states of matter in a narrow sense focuses on the following two topics: (1) The interaction of intense laser or particle beams hitting matter, and (2) the reaction of matter under such extreme conditions.

Over the last few years these activities grew to such an extent that there are between 15 and 25

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contributions at a typical meeting of the plasma branch of the German Physics Society. An annual workshop (in the Alps during the peak of the skiing season) further promotes the collaborative efforts of these three laboratories and their partners.

1. LIGHT ION BEAM PROGRAM AT KfK

Light ion beam research was started at the Karlsruhe Nuclear Research Center (KfK) in 1979. At that time it was and still is the only marked effort in Germany to catch up with the advances made in pulsed power technique in other parts of the world and its application to produce intense light ion beams in the Terawatt range. The major research efforts in this introductory period of the program concentrated on three subjects:

1. Production and focusing of intense light ion beams, i.e., research on various concepts of pulsed light ion sources (diodes).
2. Power conditioning in the vacuum section at the front end of pulsed power generators. Plasma opening switches are investigated and applied to inductive storage of electromagnetic energy.
3. Development of diagnostic tools suitable for the harsh environment in which intense light ion beam sources operate. The methods developed so far have primarily enhanced our understanding of the physical processes in the diodes for the production of Megaampère light ion beams. Experiments on the interaction of these beams with matter are in progress.

These efforts are supplemented by work in the field of high voltage, high power-production in tight collaboration with the high voltage laboratories of the universities of Karlsruhe and Braunschweig. Further partners in the physical program are the universities of Erlangen and Düsseldorf.

1.1. Most Important Results Obtained at KfK

1. Ion beam intensities with various diode concepts in the range of 0.2–0.5 TW/cm^2 on the 2-TW generator KALIF.
2. Pulse shortening using plasma opening switches by a factor of 2–3 and a corresponding increase of power up to a factor of 2 on pulse-power machines of the 0.1 TW class.

1.2. Future Goals

Expand the beam-matter physics experiments. Look for near-term applications like x-ray sources.

2. HEAVY ION BEAM PROGRAM AT GSI

Since 1979 heavy ion beam research is directly sponsored by the German government and administered by the Gesellschaft fuer Schwerionenforschung mbH (GSI) in Darmstadt. Involved are several laboratories and universities located in Frankfurt, Munich, Karlsruhe, Giessen, and, of course, Darmstadt.

The official title of the program is "The physics of generating in matter extreme energy concentrations by means of heavy ion beams." This title describes in short the present thrust of this collaborative effort.

The main goals of the German heavy ion beam program in its initial stage were:

1. To verify the feasibility of heavy ion beam drivers using RF-technology derived from conventional nuclear physics accelerators. Particularly high current, high brightness, heavy ion sources, and RF cavities had to be developed, which are the critical components of the injector system used with conventional LINACs.
2. To settle some atomic physics issues like the frequency of the charge exchange process for beams circulating in storage rings of finite rest gas densities.
3. To develop predictive capabilities like simulation codes required for system studies; particularly reinvent computational means for pellet calculations as required by the state of the art.
4. To develop strategies for future target experiments using existing or soon to be completed accelerator facilities at GSI in Darmstadt. These experiments should enable us to check our basic understanding of some physical processes like energy deposi-