Dedication Week at GENERAL ATOMIC

The John Jay Hopkins Laboratory for Pure and Applied Science, home of the General Atomic Division of General Dynamics Corp., was formally dedicated on Thursday, June 25, 1959. Three years ago the late John Jay Hopkins broke the first ground on the site, located at the northern end of the city of San Diego, and a year and a half later construction was sufficiently advanced to permit moving into the new quarters. Since that time the laboratory's projects concerned with reactors, fusion and thermoelectric power, space ships, nuclear, atomic, and solid-state physics, radiation chemistry, and metallurgy have multiplied so greatly that it has become necessary to begin construction of additional buildings. The dedication ceremonies were followed by a week of talks and symposia attended by guest scientists from the US and abroad.

A Report by ***Martin O. Stern***

SOME random impressions of the week-long dedication program at General Atomic include the following: The talks had only the scientific approach as their unifying aspect; except for this, they had considerable range and diversity. There was the counterpoint of several different fields—physics, chemistry, metallurgy, even philosophy—and the harmony of different motivations, from the "purest" (philosophy of science and epistemology) to the immediately applicable (reactor engineering). This was appropriate, since the laboratory tries to encourage free interchange between disciplines and has the words "pure and applied" in its title. Further, the extremes of speakers' ages were striking, spanning, I believe, 28 to 75. There seemed to be little correlation between age and type of subject matter, the latter ranging from thoughts distilled over a period of many years to controversial theories on phenomena much discussed at this very moment.

The dedication ceremonies took place Thursday afternoon. A number of speakers gave short addresses, including General Dynamics corporate officers Frank Pace, Jr., Earl D. Johnson, and Frederic de Hoffmann, the late Commissioner Harold S. Vance of the U. S. Atomic Energy Commission, and Mayor Charles C. Dail of San Diego.

Niels Bohr came from his home in Copenhagen to deliver the keynote address, in which he stressed the unity of science and technology by historical examples and made a moving appeal for international collaboration to meet the challenges and opportunities of the nuclear age. In his own words, ". . . it may be appropriate to recall that through the ages science and technology always have interacted in a most fruitful way, that they never were separated and that their intimate relationship now is even intensified by modern developments in natural philosophy." In connection with these developments, he also examined the applicability of the complementary principle to domains of experience other than atomic physics. On the phenomenon of life itself Professor Bohr had this to say:

"The study of living organisms continually reveals a fineness of organization which goes down to the atomic level, and not least in the stability of genetic material we recognize typical quantum features. Still, in the description of biological phenomena, concepts foreign to physics present themselves under conditions of observation, which, as we say, allow 'the display of life'.

"Indeed, mechanistic analysis and so-called finalistic argumentation bear a relationship reminding us of the complementary descriptions in atomic physics. Also, in other fields of experience, as in the description of the state of our mind and social relationships, we recognize that the rich vocabulary of our language is used in a typically complementary manner."

Professor Bohr amplified some of his dedication-address remarks the following week, when he spoke before a small group on the subject of the epistemological implications of atomic science. These remarks were in close relation to his book, *Atomic Physics and Human Knowledge*, and he started out with a discussion of the complementarity principle as applied to the two-slit interference phenomenon to illustrate that the act of observing an atomic process renders it irreversible. He felt that this principle also plays a very meaningful role in other fields than physics, such as the life sciences and psychology, where quantum-mechanical effects and the complementarity inherent in them may account for the incredible richness of the phenomena observed, as well as for the stability of life itself. He suggested that the way we describe life processes (either using the everyday language defining "life" and what is living, or the mechanistic viewpoint of physics, the analytical methods of which destroy "life" in the process of investigation) itself exhibits a form of complementarity. A similar situation obviously occurs in psychology, where the

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Niels Bohr, Marshall N. Rosenbluth, and Hideki Yukawa inspecting torus at John Jay Hopkins Laboratory. Donald W. Kerst, in background, heads the fusion research program at General Atomic.

questions we ask influence the answers we get. Possibly such nonmechanistic terms as "free will" are subtly related to the play allowed by the uncertainty principle, and therefore meaningful. In fact, Bohr's argument was to some extent a plea for the usefulness of human language, which, having evolved pragmatically over thousands of years, may have become a more meaningful tool in describing our physical world than physicists realize. His talk was basted with a gentle, warm, and pertinent humor.

THE program of science talks arranged for dedication week began on Tuesday, June 23, the first speaker being Sir Marcus Oliphant of the Australian National University at Canberra, who discussed atomic energy developments in Australia. He reminded his audience that the practicality of atomic energy must be considered on a different basis in each country. Australia, in particular, has two outstanding problems: (1) Power is at present provided almost entirely by petroleum, which must be imported from Indonesia and the Middle East. Power comes dear in Australia—in some cities it is 5–8¢/kwhr! (2) Most of Australia is hot and arid. Agriculture and industry could thrive in these regions if water were available at a reasonable cost. Bringing water in from remote rivers or oceans is impractical because of the tremendous evaporation rate (8–10 ft/yr).

In his view, reactor technology is right now sufficiently advanced to make a contribution to Australia's development. Uranium and thorium ores are available. Needed are relatively simple reactors of a power in the 10–30-megawatt range that can be located in arid regions where no containment is required. He suggests that fuel elements could be ceramic, requiring little or no H_2O cooling; moderation could be D_2O. Power could be used to distill H_2O (at the same time enhancing the heavy water content), to provide air conditioning, to extract ores (large bauxite deposits have been found on the NW tip of the continent), to synthesize fertilizers, and to reduce oxides with hydrogen produced by the electrolysis of water.

P. Scherrer of the Eidgenössische Hochschule of Zürich gave a pellucid and exciting account of experimental proof of the existence of monoenergetic positrons emitted by some excited nuclei. The process comes about as follows: Nuclei excited by more than twice the electron rest mass can cascade to a lower state by means of a γ ray; this γ ray may escape, be "internally converted", or materialize into an electron-positron pair. If the original excited state came about by K capture, the electron of the pair may be captured by the K hole, so that only a positron of well-defined

Manuel S. Vallarta, Sir Marcus Oliphant, and Paul Scherrer listen as George de Hevesy lectures on the applications of isotopic tracers.

energy is emitted. The energy of the positron is higher by the K-binding energy than that of the upper energy limit of the continuous positron spectrum from pair emission. The theory of the process was worked out by Sliv, who showed that the probabilities of the two processes, pair production vs. monochromatic positron emission following K capture, are of the same order of magnitude. Professor Scherrer's group was able to demonstrate the existence of a monoenergetic group of positrons of about 590 kev in an excited state of Pb^{206} by means of extremely careful and well-thought-out β-ray spectroscopic work. The experimental results agree quantitatively with Sliv's work, provided the rapid decay of the K hole as compared with the time of γ-ray emission and materialization is taken into account.

G. C. Laurence, Director of Reactor Research and Development, Atomic Energy of Canada Limited, reviewed the impressive contributions that Canada has made to atomic energy, from ZEEP through NRX to NRU. He talked about several novel features of the NRU: shape of fuel, method of cladding, loading during operation, duplication of control and scram circuitry to eliminate shutdowns due to instrument faults, to help locate defects, and to allow testing during operation, etc. Canada has abundant water power, so the emphasis is on low fuel cost. Natural or slightly enriched fuel in ceramic form is favored. Laurence discussed the NPD (Nuclear Power Demonstration) reactor which will have fuel in the form of uranium oxide pellets in Zircaloy pressure tubing through which coolant is circulated. The moderator, D_2O, remains near atmospheric pressure and can be dumped to scram the reactor, which has no control rods.

J. J. Went, Director of Research of KEMA at Arnhem, Netherlands, talked on the KEMA homogeneous reactor experiments, which are intended to lead to a homogeneous, heavy-water-moderated, single-zone thermal reactor with a relatively high conversion ratio working either on U^{238} or Th^{232}. Because of the high concentrations of U or Th that are required, the homogeneous mixture is in slurry form. Such a reactor presents formidable problems and the Dutch are going about tackling these in a small aqueous critical assembly. A small test reactor and a later power demonstration reactor to be sponsored by EURATOM are planned for the future. Most of the problems of such a reactor arise from settling of the suspension, recrystallization of the suspended particles at higher temperatures, and removal of fission wastes—the latter being desirable to keep the conversion ratio high. Settling and variations in fuel concentration can be measured accurately by means of fluctuations in the multiplication or criticality. The particles must be larger than 1 μ to permit use of cyclones to adjust the fuel concentration, but smaller than 15 μ to allow fission products to escape. The manufacture of UO_2 and ThO_2 particles of uniform size within this range presents difficult and delicate problems. Accumulation of Xe and Kr radioactive gases in the vapor and decomposition of the heavy water must be prevented. Start-up in this device necessitates safety precautions because settling may have taken place so that shortly after circulation is started the core may be overloaded. A small reactor giving 750 kw heat is planned to explore possible solutions to these problems, especially the removal of fission products.

Wednesday morning was devoted to a discussion of fusion. Marshall Rosenbluth of General Atomic gave a very clear and comprehensive survey of the theoretical state of affairs in fusion. He pointed out that a plasma in a magnetic field is never in thermodynamic equilibrium, and that there are three broad processes leading to such an equilibrium that can defeat confinement. The first, that of two-body collisions, is not a serious troublemaker if the plasma is at 10 kev. The second process, radiation, may take at least three forms that one has to worry about. Bremsstrahlung may be on a tolerable level provided the impurities can be kept low. Synchrotron radiation, first treated by the Russians,[1] then Beard,[2] and most recently by Drummond and Rosenbluth,[3] can be quite alarming at high frequencies, and requires larger volumes of plasma than one had earlier hoped. Atomic radiation by high Z impurities may become a serious problem at high temperatures. The third process is, broadly speaking, concerned with diffusion of particles and stability of geometrical configurations, and much difficult theoretical work has recently been done in this area. The difficulties stem from the nonlinearity of the equations and the necessity of using approximations or dealing with simple geometries. The stability of the static equilibrium cases so far obtained has been tested under certain simplifying assumptions (linearization and low frequency). It has been found that stable equilibrium obtains in a certain regime of the general geometrical case provided Larmor radii are sufficiently small. For the infinite plasma in a uniform field it has been shown that four different kinds of waves can arise in the plasma, and that these are damped out, with resulting stability, provided the velocity distribution of particles is isotropic. Instabilities seem to fall into two classes: hydromagnetic (Taylor or Helmholtz type) and trapping of particles by waves such as the two-stream instability. The latter results when the velocity distribution becomes highly anisotropic due to "runaway" conditions. Actually not much is as yet known about what happens when these instabilities grow to the point where linear approximations are no longer valid. And much work needs to be done to explore starting conditions of a plasma such as breakdown and heating.

Donald Kerst of General Atomic talked about experimental work being done in fusion at the Laboratory on the joint General Dynamics–Texas Atomic Energy Research Foundation program under his direction. Most of this work presently comes under the heading of diagnostics. A shock tube, electromagnetically excited, is used to study the effects of impurity both on the shock

[1] B. A. Trubnikov and V. S. Kudryavtsev, "Plasma Radiation in Magnetic Field", *Proceedings of Second UN International Conference on the Peaceful Uses of Atomic Energy*, Vol. 31, pp. 93–98.
[2] David B. Beard, *Physics of Fluids*, 2, 379 (1959).
[3] Private communication.

parameters directly and via visible and rf spectroscopy. Particle pressures and temperatures are derived from magnetic and piezoelectric probe measurements. A "damage probe" is being used to study wall materials. In stabilized linear pinch discharges the tremendous amounts of energy being radiated in the ultraviolet during the later, "irreproducible" stages of the pinch, as well as the quantity and energy of runaway electrons, are being investigated. A toroidal discharge consisting of six independent linear-pinch type sectors is being put in operation. At the moment the experimental program, rather than involving the construction of large machines, is strongly oriented toward understanding some of the fundamental physics problems and investigating the difficulties that have beset all workers in the field in trying to heat up plasmas beyond 100 ev.

At the fusion meeting, Sir Marcus Oliphant briefly described some interesting experiments being done in Australia on carbon arcs in vacuo in a high magnetic field. The arc current, up to 300 000 amps, is furnished by the model of a homopolar generator. Its full-scale version, to be built to power a synchrotron, is to be capable of storing 6×10^8 joules and stopping in $\frac{1}{5}$ second, and may also be used to investigate plasmas of long duration.

Also on Wednesday morning, George de Hevesy of the University of Stockholm presented a very lively exposé entitled "Historical Survey of the Application of Isotopic Tracers". He traced the idea of labeling compounds from the year 1911 (in Manchester, when he proved to his landlady by means of some thorium that "she was serving remains of the Sunday pie in the Wednesday soufflé") through early solubility and self-diffusion studies, the beginnings of biochemistry with the study of the formation rate of organic compounds, the first pathological studies in 1923 concerned with the uptake of lead by cancerous tissue, to the discovery of heavy water and artificial radioactivity. He mentioned many applications of heavy water and radioactive calcium, phosphorus, and carbon for the study of metabolism and metabolic defects, permeability of capillary blood vessels, bone formation, etc.

Thursday morning was devoted to a technical review by General Atomic staff members of the TRIGA, a solid quasi-homogeneous reactor which is made up of Zr-H-U fuel elements. Mark Nelkin gave a review of the origin of the large prompt negative temperature coefficient, which makes the reactor shut itself down safely for very large sudden reactivity insertions. Ulrich Merten talked about the chemical structure and production of the fuel, while Richard S. Stone gave a brief résumé of experiments so far carried out to explore the behavior of the reactor under steady state conditions and step reactivity insertions. The reactor has so far been operated at steady powers up to 1.7 Mw and with step insertions up to 3% excess reactivity. The latter enable the reactor to go with complete safety on a 3 ms period to a power in excess of 1500 megawatts, then rapidly to return to a low power without the insertion of control rods.

Following this discussion, Richard Ogborn of the Veterans Administration Hospital at Omaha (a "real doctor" as R. B. Duffield said in introducing him) presented an enthusiastic account of the medical frontiers that can be explored with a reactor such as the TRIGA that his hospital has just installed. He especially emphasized the many possibilities of neutron activation analysis. Not only can this technique be used to locate minute amounts of toxic substances, but also to discover possible subtle differences in composition of normal and pathological tissues. A most interesting application presents itself in the neutron activation of drugs

Above: Prof. Bohr in discussion with Director E. C. Creutz and Donald Kerst of General Atomic. At right: M. N. Rosenbluth discusses theoretical aspects of fusion; in front row of audience are J. J. Went, M. S. Vallarta, R. Courant, and N. Bohr.

A recent aerial view of John Jay Hopkins Laboratory, located in the northern part of San Diego, with fusion research center shown in right foreground. The large building in left foreground is the experimental building. Above it, on far left, is the administration building.

for metabolic study, namely, diagnosis and radiation therapy of malignant tumors. It has been found that certain antibiotic drugs of the tetracyclene family are taken up preferentially by rapidly mitotic cells with tremendous selectivity. Dr. Ogborn's talk brought out in many ways the degree to which this field is indebted to de Hevesy's researches.

Hideki Yukawa, director of the Research Institute for Fundamental Physics, Kyoto, spoke on Friday morning about the meaning of quantization in field theory. He pointed out that three years ago a unified description of elementary particles and electrodynamics was thought possible. Starting with nonrelativistic particle quantum mechanics, one could, on the one hand, use second quantization of the wave field to arrive at a description of a system displaying a nondenumerable infinity of degrees of freedom. Alternately, one could generalize the Schrödinger particle description to $N \rightarrow \infty$ particles in $3N$-dimensional configuration space. Relativistic invariance requirements tied these two descriptions together in a field picture involving negative as well as positive energy states. Divergence difficulties were encountered but gradually overcome. With the discovery of nonconservation of parity the situation has once more become confused. It has caused a return to the particle aspect through attempts at an axiomatic construction of field theories. The new methods have not been successful in describing the weak (four-fermion) interactions and the gravitational field, a new host of difficulties arising from the fact that the above interactions are nonlocal and nonrenormalizable. Yukawa discussed recent attempts to reconcile the two diverging approaches—particle vs. continuum—but was not optimistic of success.

The last speaker was Manuel Sandoval Vallarta, of the National Institute of Scientific Investigation and Institute of Geophysics and the National Nuclear Energy Commission of Mexico, who presented a tentative theory of the high-intensity radiation rings around the earth. Briefly, Professor Vallarta assumes that the earth's field in the region between two to ten radii from the earth can be approximated by a dipole. He then applies a theory of motion of charged particles in a dipole field developed by Stormer, which shows that at each energy, for a given component of angular momentum along the dipole axis, there may be two separate regions in which the particles are allowed to move; in particular, there exist two "principal periodic orbits" along which such particles can move periodically. According to a theorem of Poincaré, particles near these orbits move close to the PPO's, some of them oscillating stably about them, others approaching them, then gradually receding from them. Knowing roughly the spectrum of primaries incident, and making a simple assumption concerning direction and energy of secondaries, Vallarta has calculated the intensities to be expected in the two regions, and has obtained excellent agreement with the results reported by Pioneers III and IV and the Russian Mechta. He thinks that the inner ring consists mostly of primary particles temporarily captured; the outer one mostly of secondaries. If so, the persistence of these high-energy particles, with Larmor radii of the order of thousands of km, could not be due to their being trapped in the magnetic mirror of the dipole field as was the case in the Argus experiment. This theory is evidently much in conflict with the one that attributes much of the intensity in either belt to neutron decay products, either electrons or protons. The energy of the particles is quite different, and the effect of solar activity on the belts would also be different in the two cases. Needless to say, a very animated discussion followed.

Dedication week's talks were spelled by a number of other occasions, many of them social and held during evenings. Two daytime events stand out: On the afternoon of June 24, the visitors as well as a number of General Atomic staff members were guests of Scripps Institution of Oceanography for luncheon and a short cruise aboard the research vessel *Horizon*. The *Horizon* has recently been instrumental, on forays to the South Pacific, in providing new and revised estimates of the thickness of the earth's crust. The excursion through San Diego harbor to the tip of Point Loma and back was a delight in this balmy weather. And on Friday a similar group made a trip, over the Highway of the Stars, to Mt. Palomar, where we were allowed access to many of the laboratories, including the 200-inch telescope, with Drs. Jesse Greenstein and Horace Babcock as the hosts in this most impressive research establishment.