

Nuclides Far Off Beta Stability Line

After some 50 years of development, starting with the naturally occurring radioactive nuclides early in the century and reaching a peak with the birth of the shell and collective models, radioactivity decay data, albeit fragmentary in many cases, now exist for roughly 1000 species, grouped around the line of beta stability. Extrapolations of energy and half-life systematics imply, however, that the number of nuclei available for systematic study could be more than doubled with new techniques.

Indeed, the experimental situation has largely changed in recent years. One can point to current advances in high-flux reactors, sector-focused cyclotrons and synchrocyclotrons, and other accelerators large and small, notably those delivering energetic heavy-ion beams. All of these machines can produce nuclei in fair yields out towards the limits of nucleon binding. But since the short-lived species must be isolated and investigated immediately after formation, on-line systems are called for. A basis for the application of such techniques has been laid by the spectacular developments in high-resolution detectors and data handling systems, as well as by the steady improvement of electromagnetic radioisotope separators and the invention of new rapid chemical separation procedures. In short, the tools exist for exhaustive, penetrating and systematic investigations of radioactive decay in essentially unknown regions of the nuclidic chart.

Although nuclear reaction studies have become a superior source of information on nuclear structure in the region close to stability, where beta and alpha decay lead mainly to a few low-lying levels, the significantly different situation to be expected in regions far from stability must be pointed out. In the latter case, the lack of suitable target nuclei will render nuclear-reaction work more difficult, but on the other hand, the rapidly increasing Q -values for decay as one goes further from the line of stability

will permit many more high-lying levels to be populated and studied. Moreover, there are effects that are specific for regions of sufficiently large neutron or proton excess, such as emission of beta-delayed neutrons, protons and alpha particles, two-proton radioactivity and superallowed beta decay. There may be a few surprises also waiting in this frontier land between bound nuclear matter and free nucleons. Nature is often like that.

A symposium, "Why and How Should We Investigate Nuclides Far Off the Stability Line?," held in Lys-ekil, Sweden, 21-27 Aug. 1966, had over 150 participants. The meeting came at a time when radioactive decay as a field of study is poised at the threshold of a new era of vigorous activity.

At the first session of the symposium, D. W. Dorn (Livermore) described the nuclear explosive as a high-flux neutron source. He pointed out that one of the essential features of this technique is the very short capture time ($\leq$ microseconds as compared with the order of months in a re-

actor). Since there is no time for beta decay between successive captures, the neutron captures must occur successively in isotopes of the same element, allowing one to bypass nuclides with high neutron destruction cross sections or short spontaneous fission half-lives.

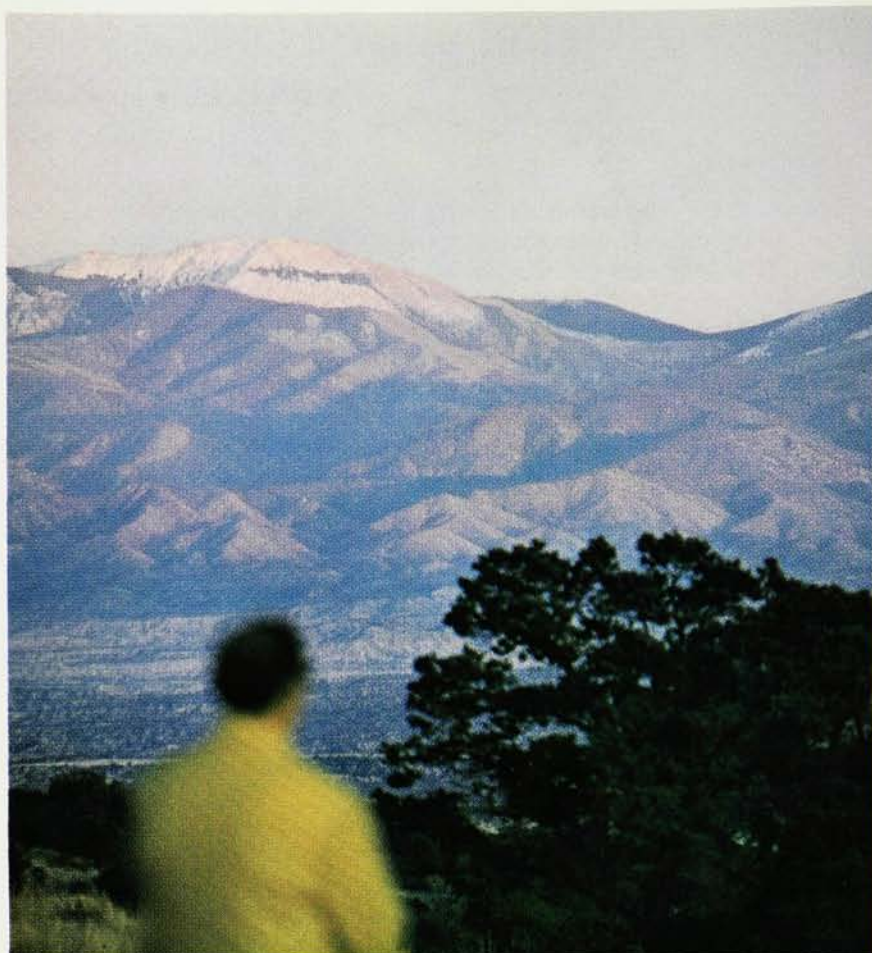
On-line techniques. One possible way to cope with the problem of rapidly selecting individual nuclides out of a reaction-product mixture is to connect a mass analyzer directly or via an element-separation step to the irradiated target to form an Isotope Separator On-Line System (ISOL). The table below summarizes the state of development in this field, which at present attracts considerable interest.

Two groups contributed results of ISOL work. From Orsay, I. Amarel reported on fission and spallation studies, including the identification of $\text{Rb}^{96,97,98}$ isotopes, for which sample preparation was performed with a mass spectrometer with surface-ionization source on line with the 150-MeV synchrocyclotron. G. Holm (Stockholm) accounted for extensive studies

Isotope Separator On-Line Projects*

Location	Production machine	Mass-analyzer type	Startup
France			
Orsay	Synchrocyclotron	Nier spectrometer	1965
Grenoble	Reactor and neutron generator	CERN isotope separator	1967
	Isochronous cyclotron	Nier spectrometer	1968
Germany			
München	Reactor	Mattauch-Herzog spectrograph	1962
Jülich	Reactor	Cohen spectrometer	1965
Israel			
Yavne	Reactor and neutron generator	CERN isotope separator	1967
Netherlands			
Amsterdam	Isochronous cyclotron	CERN isotope separator	1966
Sweden			
Stockholm	Cyclotron	Scandinavian isotope separator	1963
	Neutron generator		1964
Studsvik	Reactor	CERN isotope separator	1967
Switzerland			
CERN	Synchrocyclotron	{ CERN (ISOLDE) isotope separator	1967
		{ Nier (Orsay group) spectrometer	1967
USA			
Ames	Reactor	Scandinavian isotope separator	1966
Princeton	Spontaneous-fission source	Scandinavian isotope separator	1965
USSR			
Dubna	Heavy-ion accelerator	Dubna isotope separator	1967

* These projects were operating or under construction in the summer of 1966.



LASL Photograph by William H. Regan

A View from the Mesa

Harold DeHaven, LASL technician, inspects the site for the proposed Los Alamos Meson Physics Facility (LAMPF), the world's first linear proton accelerator in the 800 MeV energy range. Now in design for construction on this scenic plateau, the 2,600-foot-long accelerator will produce an average beam current of 1 milliamper, manifestly higher than other machines of comparable output energy. If you would like to join LASL scientists and engineers in this and other exciting ventures opening important new avenues of basic and applied research, send your resume to:

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of Kr^{89-91} and $\text{Xe}^{137-140}$ carried out at Stockholm with the cyclotron as neutron source, where gaseous fission products were fed to the isotope separator through a long pipe.

Most of the on-line investigations conceived so far may be classified as straight-forward nuclear spectroscopy, taking over well developed techniques for energy, intensity and half-life analyses. Nothing, however, excludes more sophisticated on-line experiments. Thus for example, I. Lindgren (Göteborg) explained how the atomic beam technique may be used to determine spins and magnetic moments of short-lived nuclides, and B. I. Deutsch (Aarhus) discussed on- and off-line experiments with megagauss internal nuclear magnetic fields in order to measure g -factors of nuclear levels. A technique of considerable interest was treated by H. Daniel (Heidelberg and CERN), who described an inductive spark chamber built as a position-sensitive detector for a magnetic particle spectrometer. A FWHM resolution of 0.2 to 0.3 mm has been obtained in both the x and y directions.

Heavy-ion induced reactions. R. M. Diamond (Berkeley) reviewed the special features of heavy ions as projectiles: greatly enhanced Coulomb-excitation probabilities, large transfers of linear and angular momenta (large recoil velocities for separating the reaction products, high-spin states formed and strongly aligned product nuclei), and excitation functions that allow considerable selectivity in the production of a particular nucleus. Since heavy-ion reactions bring in large amounts of angular momenta, high-spin states are produced along with a strong alignment of the product nuclei. The resulting gammas and conversion electrons show a marked angular distribution with respect to the beam direction, and this will permit a variety of new measurements. These characteristics make heavy-ion beams extremely suitable for "dynamic nuclear spectroscopy," as further exemplified by I. L. Preiss (Yale and RPI), who discussed in particular the high-spin isomers of $\text{Ba}^{125,127,129}$ and Cs^{123} . Reporting on the extensive heavy-ion work at Dubna, V. A. Karnaukhov accounted for the identification of element 104 by very fast and elegant chemical techniques. The

0.3-sec half-life was assigned to mass number 260 by the excitation function, indicating formation in the $\text{Pu}^{242}(\text{Ne}^{20}, 4n)$ reaction. Karnaukhov also reviewed Russian work on the systematics of spontaneously fissioning metastable states, giving data on Np, Am, and Fm isomers. A figure of 10^{25} is representative for the ratio of spontaneous fission half-lives of the ground and metastable states.

Radiation from fission fragments. S. G. Thompson summarized recent work at Berkeley using a Cf^{252} spontaneous fission source and a $dE/dx-E$ semiconductor-detector telescope.

The relative fission yields of fragments in the mass range 1-10 were determined, and experimental fission barriers of Hg^{198} , Tl^{201} , Bi^{209} , and $\text{Po}^{207,208}$ were also reported. The $K_\alpha-K_\beta$ x-ray energy differences taken in Ge(Li) detectors have proved highly specific in identifying products. It was shown that the fission process is capable of producing nuclei in hitherto inaccessible regions of the nuclidic chart. A Livermore program under development for separating and studying the primary fission fragments was presented by P. C. Stevenson. The recoiling fragments are to be stopped in a noble-gas mixture, the composition of which will determine the remaining ionic charge of the thermalized fragments. After transportation out of the reactor and through a differential pumping system into vacuum, the ions will be reaccelerated and subjected to magnetic mass analysis. Transport times from formation to detection are predicted to be a few tens of milliseconds.

A series of German contributions described direct mass analysis of fission fragments, with techniques using the ionization that the fragments receive when recoiling out of a target. P. Armbruster (Jülich) reported the first results obtained with a helium-filled Cohen-type mass spectrometer of low resolution ($M/\Delta M < 20$) on line with a 10-MW reactor. A careful calibration of the magnetic field facilitates the mass assignment of half-lives measured by means of the adjustable velocity of a moving tape carrying collected activities into the detector system, which includes a $\beta\text{-}\gamma$ coincidence arrangement. H. Lawin (Jülich) presented design studies for a focusing

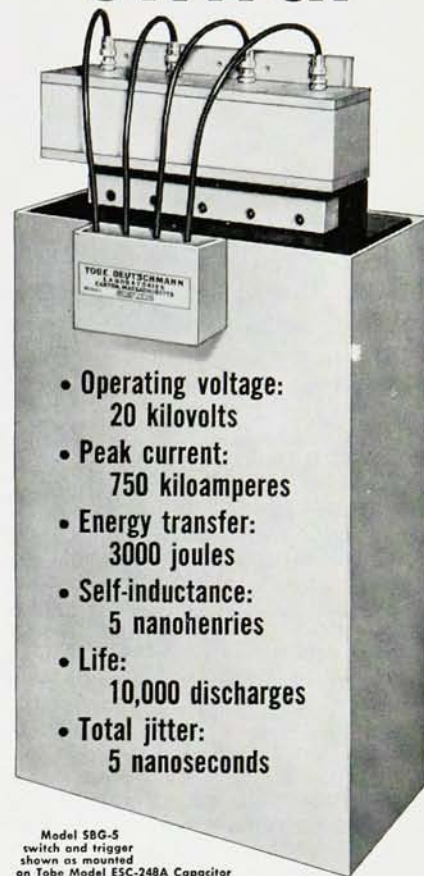
parabola spectrograph to be placed at a high-flux reactor, and H. Ewald (Giessen) compared this type of instrument with the modified Mattauch-Herzog spectrograph he has in operation at the Munich reactor. An improvement of the activity by a factor of 1000 should be possible by the combined action of higher spectrographic transmission and higher neutron flux.

Mass formulas. The theorist W. J. Swiatecki (Berkeley) emphasized the difference between microscopic and macroscopic approaches to the description of the nuclear-mass surface; these became known as the respective views of "cartographers" and "astronomers." Placing himself among the astronomers, Swiatecki went on to discuss anomalies in nuclear masses—that is, systematic deviations of calculated trends from experimental evidence. A mass formula has been constructed so as to eliminate such overall anomalies and is available, with complete mass and Q -value tabulations, as a Berkeley report.

An essential difficulty in the application of shell-model formulas to regions far from stability was pointed out by N. Zeldes (Copenhagen): It is not known to what extent the magic numbers remain magic at high excess or deficiency of the other kind of nucleon. Experiment alone can settle this question. A very impressive piece of work was the calculation of nuclear separation energies by K. Bleuler (Bonn). Rather than construct a mass formula and fit it to experimental masses, he started from fundamental interactions and used various empirical results mainly to determine parameters in the expression for the nuclear potential.

Delayed particle emission. A. Sivilola (Helsinki) reviewed alpha and proton activity at mass numbers below $A = 200$. Included was the discovery of about 30 new alpha-active nuclides in the region from Ir to Hg from heavy-ion work at Berkeley. Details about alpha and proton emitters near the double closed shell of 50 protons-50 neutrons, also largely from Berkeley studies, were given by R. D. Macfarlane (McMaster University). Te^{107} and Te^{108} were found to be alpha active, whereas delayed proton emission was ascribed to Te^{108} and Te^{110} . This turned out to be in disagreement,

LOW-INDUCTANCE triggered discharge SWITCH



Model SBG-5 switch and trigger shown as mounted on ToBe Model ESC-248A Capacitor

- Operating voltage: 20 kilovolts
- Peak current: 750 kiloamperes
- Energy transfer: 3000 joules
- Self-inductance: 5 nanohenries
- Life: 10,000 discharges
- Total jitter: 5 nanoseconds

The TOBE Model SBG-5 Switch is a multi-channel enclosed spark-gap switch supplied with its own high-voltage trigger. The user must provide only a 250-volt positive pulse and a trigger-charge input of 5 kv which may be taken from the storage-capacitor charging supply through a dropping resistor.

The switch is designed to mate, as pictured, with a TOBE 5-nanohenry, 3000-joule, 20-kv capacitor or to any 10-inch-wide parallel-plate transmission line. Common trigger circuitry is available to facilitate banking.

Detailed information about dimensions, acceptance tests, and mountings is given in Bulletin EB365-60 available, on request.

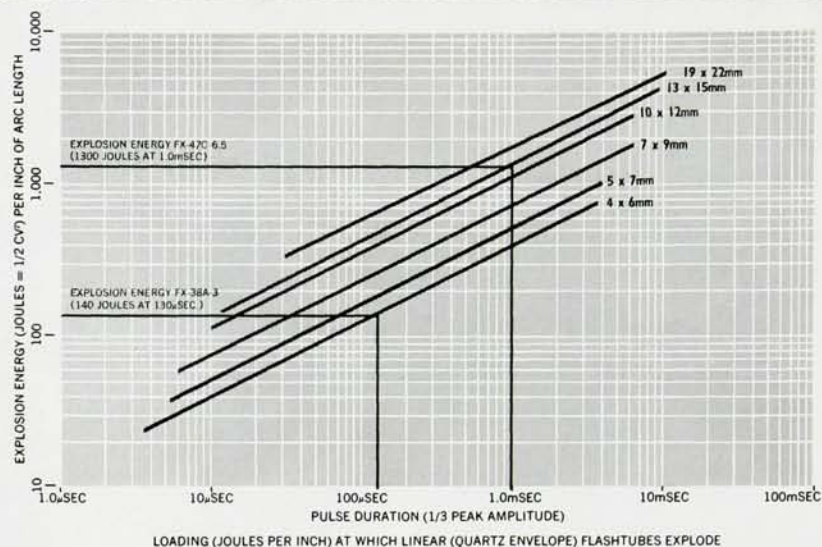
• And write or call whenever you have a requirement for energy-storage capacitors, discharge switches, pulse-forming networks, or low-impedance pulse lines.

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ONCE OVER LIGHTLY

Vol. 1, No. 3

PRODUCTS TO GENERATE, DETECT & MEASURE LIGHT



FLASHTUBE LOADING CHART

As determined experimentally by our staff, the above chart indicates (in joules per inch of arc length) the loading at which linear quartz flashtubes will explode. For a flashtube with a specific bore size and arc length, this explosion point is a function not only of the energy input per flash but also of flash duration. For optimum performance in free air at a given pulse duration, it is recommended that the energy per flash into a flashtube not exceed 70% of the explosion level. By operating below the 70% level, the life of a flashtube is increased substantially. For flashtube operation in a cavity, the energy input per flash should not exceed 40% of the explosion point. A copy of the chart can be found in Data Sheet 1002-B, Linear Xenon Flashtubes.

WITH AN EYE TOWARD SAFETY

More industrial firms, government and university laboratories are using Model 580 Radiometer and Model 580/585 Spectroradiometer System to detect, measure and monitor hazardous levels of ultraviolet, visible, infrared and laser radiation. These systems offer a convenient means for detecting and measuring both continuous and pulsed radiation over the spectral range from 0.2 to 1.2 microns (ultraviolet to near infrared). Safety engineers can then issue precautionary procedures and equipment to protect personnel operating in the area.

The Model 580 Radiometer, designed primarily for use with monochromatic sources such as lasers, has a wide dynamic range for measuring both low-level diode lasers as well as high-power solid-state

lasers with peak powers as high as 10 GW. The Model 580/585 Spectroradiometer measures broad-band (chromatic) light sources. With a monochromator grating system, the power and energy of a source at a given wavelength can be measured and then repeated at various wavelength settings over the spectral band of interest. The 580/585 can also operate into an external X-Y recorder for a direct plot of output vs. wavelength.

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The major improved SGD-444 specs for this large-area, 1.0cm² photodiode include a reduced maximum operating voltage of 150 volts (we determined higher operating bias levels are not required in 95% of the applications), a 10-nanosecond rise time, typical leakage current of 0.5 microamps at 100 volts, NEP equal to 5.9×10^{-13} watts, and quantum efficiency greater than 70% over a range from 0.6 to 0.9 microns. Take pen in hand, if you're interested, and request a copy of the new SGD-444 Series

data sheet and detailed applications note.

FLASHTUBE NEWS FLASH!

Six new tube types have been added to the standard line of high quality EG&G linear xenon flashtubes. They are: FX-98-3 (5mm bore, 3" arc length, 400 joules); FX-81-4 (10mm bore, 4" arc length, 3000 joules); FX-47C-3 (13mm bore, 3" arc length, 2250 joules); FX-47C-12 (13mm bore, 12" arc length, 9200 joules); FX-77-4 (19mm bore, 4" arc length, 7700 joules); and FX-77-8 (19mm bore, 4" arc length, 15400 joules).

Complete ratings on these types as well as updated information on older linear types are given in the recently data sheet 1002-B, Linear Xenon Flashtubes. It's yours for the writing.

ON COOLING PMT'S



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Standard temperature controllers are available for stabilizing the temperature of the PMT from $\pm 0.5^{\circ}\text{C}$ down to a proportionally controlled $\pm 0.01^{\circ}\text{C}$. The standard EG&G chamber, which is $7\frac{3}{4}$ " square by $12\frac{1}{2}$ " long, is adaptable to any end-on PMT with a tube envelope up to 2" in diameter and up to 6" in length. All chambers have magnetic shielding around the tube, interchangeable tube sockets, dynode resistors, a double window to eliminate fogging, and a thermal limit switch for automatic power cutoff.

Applications include scintillation counting, star-tracking systems, photometry, flying spot generators, Cerenkov radiation measurement, laser detection, industrial controls, colorimetry and timing measurements.

All models of the standard chamber are available for delivery within four weeks.



EG&G INC.

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however, with results obtained at Dubna. According to Karnaukhov, 4.2-sec Te^{109} and 19-sec Te^{111} are the delayed proton precursors. Further work is required to resolve this question; it would seem that an ISOL system should be desirable in work of this type.

T. Tunaal (Oslo) discussed the systematics of delayed neutron emission. Each of the six half-life groups found in fission are now known to be composite, with $\text{Kr}^{92,93,94}$, $\text{Rb}^{92,93}$, As^{85} and possibly Sb^{135} reported to be delayed neutron precursors in addition to the familiar series of Br and I isotopes. Spallation has added He^8 , Li^9 , C^{16} , N^{17} and Ti^{210} to the list.

Nuclear structure. One of the highlights of the symposium was the talk by R. A. Sorensen (Copenhagen) entitled "Spherical and Magic Nuclei." In a perspicuous way he summarized many of the reasons we have for wanting to study nuclei far from stability. A principal group of experiments aims at broadening the area of the (Z, N) plane in which nuclear properties are known. At present, information on ground-state spin, excited states, magnetic and electric moments, transition rates, etc. of true single-particle nuclei is largely missing, except around O^{16} and Pb^{208} . The new techniques may bring several other doubly-magic regions within reach. But there is again the question whether the trends in single-particle orbits responsible for the large energy gaps (that is, closed shells) persist for instance, to $N = Z = 50$ (Sn^{100}) and $N = Z = 40$ (Zr^{80}). It thus is important to follow the shifts of single-neutron and proton levels with N and Z over an extended area. This information is needed for various theoretical calculations, including those of nuclear shape and nucleidic masses. Nuclei near $N = Z$ in general offer several features of interest, particularly due to the expected isospin structure of their low-lying levels. One implication is the occurrence of superallowed beta decay for $Z \geq N$ nuclei. When N approaches Z , further consequences occur for the theoretical treatment of quasi-particle spectra of heavy nuclei. It is no longer possible to neglect n - p pair correlations as in current approximations. Deviations of experimental spectra from calculations based on p - p and

n - n pairing will be interesting to follow as the neutron excess decreases.

As for the second main group of far-from-stability experiments, those involving essentially new phenomena, Sorensen spoke of (1) beta decay to states of high excitation, perhaps more than 10 MeV, in the daughter nucleus and (2) fast or delayed neutron or proton emission. From a single-particle point of view, a detailed study of proton decay is of particular interest, since it is a fairly simple process to tackle theoretically.

Deformed nuclei were the subject of several interesting papers, including extensive theoretical calculations by S. G. Nilsson (Lund) and V. Strutinski (Moscow). S. A. E. Johansson (Lund) presented a semiempirical criterion for nuclei to have a nonspherical shape and used this criterion to define the boundaries of new regions of deformation. Two of these may become accessible to systematic experimental study, one consisting of neutron-deficient nuclides around $A = 125$, the other of nuclides around $A = 110$ on the neutron-rich side. The latter region can be reached in fission. Calculated deformability parameters of fission fragments were shown by H. W. Schmitt (ORNL) to be compatible with recent experiments. Experimental approaches to the study of new regions of deformation were discussed by H. Morinaga (Tokyo). He also described a so-far unsuccessful search for the trineutron, n^3 , a very far-from-stable nucleus.

Although a fair number of suitable reactors and accelerators already exist and some on-line work is being done or has been prepared, it is difficult to avoid the impression that while many nations are involved in major efforts to unravel nuclear structure *close to stability* by nuclear reaction studies the efforts and funds going into the study of nuclei and nuclear structure *far from stability* by means of on-line techniques have been minimal. In the US there is only one on-line isotope separator system for reactor studies in operation (Ames) and one under design study (Livermore), and no systems concurrent with cyclotrons, heavy-ion accelerators or other machines seem to be in the course of realization, although this represents a

major opportunity. Progress in this field in the next few years will come largely from the various European on-line projects now operating or shortly to come into operation. The full proceedings of the symposium will be published as a special issue of *Arkiv för Fysik*.

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Helsinki Conference: Low Temperature Calorimetry

Prior to and associated with the Tenth International Conference in Low Temperature Physics (meeting report to appear in *PHYSICS TODAY*, April), a conference on low-temperature calorimetry was held at the Technical University of Helsinki, 26-29 Aug. 1966. It was organized under the auspices of the International Union of Pure and Applied Physics and was sponsored by the Technical University and the Finnish Physical Society.

The communications presented can be grouped into five sections: calorimetric techniques, superconductors, alloys, magnetic transitions and other topics. In the first section J. C. Wheatley presented an invited paper on calorimetric techniques in the millidegree region. He discussed thermometry and suggested that the magnetic temperature, as obtained with powdered cerium magnesium nitrate, is equal, within a few tenths of a millidegree, to the absolute thermodynamic temperature down to 3 millidegrees Kelvin. He also presented data on the heat capacity of cerium magnesium nitrate and discussed thermal contact, thermal resistance and thermal isolation for making sure that heat-capacity measurements are done under equilibrium conditions.

Special experimental methods for investigating several specimens simultaneously and for measuring small heat capacities were discussed in the techniques section by A. Arrott and S. S. Shinozaki. Data on the performance of a mechanical heat switch were presented by R. W. Hill and G. R. Pickett. The measurements show that a switch with gold-plated contacts is useful down to at least 0.1°K. Germanium resistance thermometers, their