

but some of the more tolerant crops—generally the less leafy ones—would survive. Edgar Stephens (University of California, Riverside) tells us that during the Los Angeles “smog season”—June through mid-October—PAN levels comparable to or exceeding those predicted by Crutzen and Birks occur quite often. Although some plants exposed to these levels for just a few hours show markings on their leaves, the postwar PAN alone would probably not kill them, says Stephens.

It is difficult to estimate the combined effect on the food supply of reduced sunlight, aerosol deposits, acid rain, ozone, PAN and other air pollutants, radioactive contamination, and the disruption of cultivation and distribution systems. A further complication, say Crutzen and Birks, is that meteorological patterns of wind, temperature and rain would be altered for several weeks following a nuclear war. The absorption of most solar radiation in the atmosphere rather than at the ground would stagnate the flow of air below 10 km, and slow the removal of pollutants. The excess cloud condensa-

tion nuclei—up to 6×10^{10} per gram of wood burned—could narrow the range of sizes of cloud droplets and decrease the efficiency with which they coalesce and precipitate.

Crutzen and Birks conclude that the atmospheric effects of the explosions and fires would probably result in agricultural yields sufficient to feed only a small fraction of the initial survivors; many would die of starvation during the first year after the war.

Whatever the fate of life on Earth, the atmosphere and meteorology may return to prewar conditions after a few years, although one cannot rule out irreversible changes. One question, for example, is whether melting due to soot settling on glaciers or arctic ice and snow would cause permanent changes in important climatic parameters. We do have some data on the effect of atmospheric aerosol in nuclear-war quantities. The 1815 volcanic eruption of Mount Tambora in the Dutch East Indies (now Indonesia) was followed in the summer of 1816 by four waves of crop-killing snow and frost in New England and food shortages in parts of

Europe. The volcanic eruption at Krakatoa in 1883 lowered global mean temperatures, but for only a few years. One must be careful in using volcano data to generalize, however, because the physical characteristics of volcanic aerosol are not the same as those of fire-produced aerosol. —JDS

References

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French heavy-ion cyclotron facility starting up

At Caen, near the Normandy coast, construction of the French national heavy-ion accelerator facility, GANIL (Grand Accélérateur National d'Ions Lourds), has now been completed. GANIL is a tandem system of two large conventional (not superconducting) cyclotrons, designed to accelerate all ionic species from carbon to uranium. The maximum energy will be about 100 MeV per nucleon for the lighter ions, falling gradually to 10 MeV per nucleon at the heavy end of the periodic table. Thus GANIL will be, for the next few years, the most powerful heavy-ion cyclotron facility in the world.

The first beam was extracted from the first cyclotron in June. Argon ions were accelerated to 150 MeV. The next major testing step is scheduled for November; an argon beam will be accelerated to about 3 GeV in the full tandem system. Marc Lefort, retiring director of GANIL, told us that nuclear-physics experiments are expected to begin next January—with argon, krypton, and medium-mass metallic ion beams at energies from 20 to 60 MeV per nucleon. With the completion of GANIL, Lefort is returning to Orsay. His successor as director of GANIL is Claude Detraz.

A two-stage tandem configuration is nowadays a favored approach to the attainment of higher energies in heavy-ion cyclotrons. The maximum energy per nucleon that can be confined by the bending field of a particular cyclotron

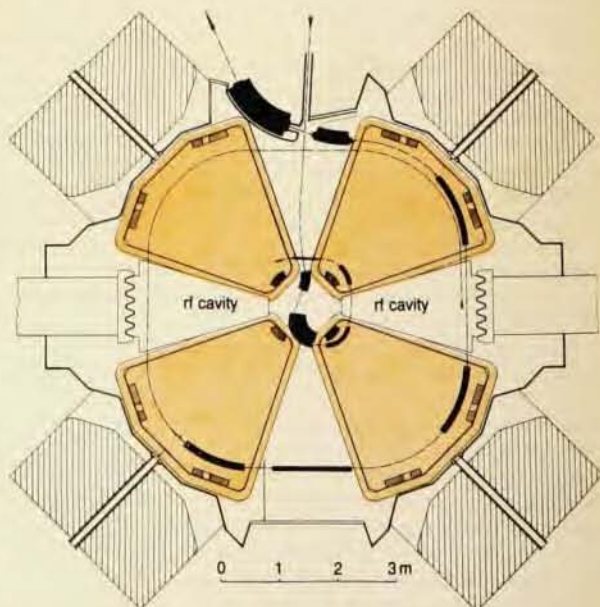
is given by $K(q/A)^2$, where q/A is the ion charge per nucleon and K is a characteristic parameter of the cyclotron, proportional to the square of RB , the product of the maximum orbit radius and the magnetic field at that radius. Thus one wants the highest attainable ion charge; one tries to strip off as many electrons as possible. For the lightest ions this is easily done, but for heavier species the attainment of a substantial charge-to-mass ratio becomes increasingly difficult. The trick

in a tandem cyclotron system is to accelerate low-charge-state ions to moderately high energies in a first-stage machine—a cyclotron or perhaps a Van de Graaff accelerator. Before injection into the second-stage cyclotron the ions are made to pass through a thin stripping foil. The higher the energy attained in the first stage, the more additional electrons are stripped off in the foil.

The two large GANIL cyclotrons are essentially identical, separated-sector,

The two large cyclotrons of the GANIL tandem heavy-ion facility are essentially identical. In the first large cyclotron we see the beam (dashed) from the small injection cyclotron injected into one of the inter-magnet gaps, and ultimately extracted at this same gap for injection into the second large cyclotron.

Two other gaps provide the rf acceleration. The four separate magnet sectors (color) provide the azimuthal field variation necessary for beam stability with a radially increasing magnetic field.



isochronous cyclotrons, each with a K of 400 MeV. (A much smaller third cyclotron serves as an injector into the first large accelerator.) GANIL was authorized by the French government in 1975 (PHYSICS TODAY, March 1976, page 20). Although there was by then considerable enthusiasm for superconducting cyclotrons, the French opted to build large, conventional, room-temperature cyclotrons rather than risk the chancier new superconducting technology.

Other laboratories have in the meantime committed themselves to the more compact, and thus significantly less expensive, superconducting-cyclotron designs. Michigan State University is building a tandem system of two superconducting heavy-ion cyclotrons, designed to achieve 200 MeV per nucleon for light ions and 20 MeV per nucleon for uranium. The first-phase cyclotron ($K = 500$ MeV) began operation last fall, and the second-phase machine ($K = 800$ MeV) is scheduled for completion in 1984 (PHYSICS TODAY, August 1981, page 21). Because the 5-tesla mean magnetic field strength of the MSU cyclotrons is about three times that of GANIL, the superconducting MSU facility should achieve twice GANIL's energy with a third of its 3-meter extraction radius and about half its cost.

The University of Milan is also building a $K = 800$ -MeV superconducting heavy-ion cyclotron, to be fed by its existing tandem Van de Graaff accelerator. But like the MSU facility, its completion is several years down the road. Thus GANIL will have the field to itself for at least two years. The Chalk River (Ontario) Van de Graaff-superconducting-cyclotron tandem facility is scheduled for completion next year. But its maximum energy will be only 50 MeV per nucleon.

The Berkeley Bevalac, a tandem union of the Superhilac and Bevatron, has recently completed modifications that will permit the acceleration of uranium to almost 1 GeV per nucleon (PHYSICS TODAY, July 1982, page 22). But because the Bevatron is a pulsed synchrotron designed primarily for relativistic energies, its beam intensities are rather limited at the intermediate energies that GANIL and the MSU facility are designed to explore.

The UNILAC at GSI (Gesellschaft für Schwerionenforschung, in Darmstadt, Germany) has recently been upgraded to accelerate all ionic species up to uranium to about 20 MeV per nucleon. Unlike cyclotrons, heavy-ion rf linacs such as UNILAC accelerate all ions to roughly the same velocity, irrespective of mass or charge state. Thus, while UNILAC achieves significantly higher energies than GANIL for the heaviest ions, it is limited to the same 20 MeV



The GANIL heavy-ion facility is a tandem system of two large room-temperature cyclotrons capable of accelerating light ions to 100 MeV/nucleon, and uranium to 10 MeV/nucleon. Each has an extraction radius of 3 meters. Shown here is the first cyclotron.

per nucleon for light ions, where GANIL can do five times as well.

GANIL was originally scheduled for completion in 1980 or 1981, but it was delayed by the competing budgetary requirements of the French effort in high-energy physics in the late 1970s. The laboratory is sponsored jointly by the Commissariat à l'Energie Atomique and the Institut National de Physique Nucléaire et de Physique des Particules (often abbreviated IN²P³). Caen was chosen as the site of this national facility in an attempt to decentralize French physics (which is largely concentrated around Paris) and to support the economic revitalization of this city.

Each of the large GANIL cyclotrons is *isochronous*; that is to say a constant orbital frequency is maintained, despite the relativistic mass increase of the energetic ions, by having a stronger bending field at large orbit radii. However, such a radial magnetic-field growth tends to destabilize particle orbits. In separated-sector cyclotrons such as the GANIL accelerators, this destabilizing effect is countered by segmenting the magnet to provide a compensating azimuthal field variation. Each GANIL cyclotron has four separate pie-shaped magnet sectors separated by four 38° gaps. Radio frequency accelerating fields are provided in two of these gaps.

A small ($K = 30$ MeV), flat-pole cyclotron serves as an injector into the first of the large GANIL machines. At its center is a Penning ionization source. The stripping foil between the two big cyclotrons increases the net charge of heavy ions by about a factor

of four. There is always a trade off between stripping and intensity. When an ion beam traverses a thin foil, numerous charge states are generated, of which the subsequent cyclotron can accelerate only one (at a given frequency). For example, a uranium beam traversing the GANIL foil will emerge with a distribution over about ten charge states. Choosing one of them for acceleration in the final stage thus reduces the beam intensity by an order of magnitude.

The first experiments at GANIL will avail themselves of beams of about 10^{11} ions per second—"an intensity that has never been obtained before" at these energies and masses, Lefort told us. Experimental proposals have already been submitted by 45 nuclear-physics teams from France and other European countries. "GANIL is a very well equipped facility," we were told by Hermann Grunder of Lawrence Berkeley Lab. "But," he added, "the nuclear-science community would like to have seen it in operation two years earlier."

GANIL should achieve energies of 100 MeV per nucleon for masses up to about $A = 40$, above which the stripped charge-to-mass ratio, q/A , begins to fall rapidly. At these masses GANIL will have no serious rival until phase II of the MSU facility is completed. At GANIL energies the primary physics interest is the study of nuclear matter at higher than normal densities. Above the typical kinetic energy of nucleons bound in nuclei (the Fermi energy, about 36 MeV), the exclusion principle no longer prevents high nuclear densities from occurring briefly during heavy-ion collisions. —BMS □