Scyllac compression coil. Image-converter cameras (foreground) take streak photos of plasma through slots in front and top of coil. Five optical feedback detector stations are shown. Bundles of white cables power compression coil from capacitor banks in rear (not shown).

plasma is forced immediately in a helical shape.

Last month, as part of the plan developed with ERDA, Los Alamos experimenters under Warren Quinn were scheduled to begin a series of experiments as a result of collaboration with Garching, in which Scyllac's toroidal discharge chamber will be replaced by a helical one, in the expectation that transient disturbances of equilibrium will be eliminated in the formation of the plasma. Also, in a second experiment, Scyllac will start using an $l = 2$ field to produce equilibrium, instead of the $l = 0$ component.

If the Scyllac feedback stabilization succeeds, Ribe hopes to build a Staged Scyllac. This device would cost $10 million of operating funds, would have a 25-meter diameter and would be capable of feedback stabilization or wall stabilization. In the latter approach, the plasma is supposed to stabilize itself by having the $l = 1$ field interact with the wall. This will only work, Ribe told us, with plasmas much fatter (more dough in the doughnut) than presently available with Scyllac or ISAR T1.

Alternatives. In case Scyllac does not succeed, Hirsch and Kintner have asked Los Alamos to strengthen other parts of its program and introduce new concepts other than toroidal theta pinches. An existing Los Alamos program, under Don Baker, on toroidal z pinches will be expanded. Next year it is planned to use $2 million out of operating funds for a new and larger device (expanded from 15 to 40 cm in minor diameter), ZT-P, which will use a reverse-field toroidal z pinch (in which one applies a toroidal magnetic field but causes it to reverse its sign as it goes from the center to the outside). Another program that will be strengthened is the attempt to use end stoppers on the linear theta pinch.

In response to Hirsch's request for an alternative concept to toroidal theta pinches, Los Alamos plans to start experiments with liners, starting next year with $600 000. In this approach one uses a cylindrical copper shell (say 1 mm thick and with a 10-cm diameter), putting a cold plasma and a magnetic field into the shell. Then the shell is imploded in 3 microseconds, boosting the magnetic field to a few megagauss and producing a very dense, hot plasma. Because plasma burn is rapid, Ribe says, one can avoid problems with stability and confinement. The approach is not new. Liner work is going on at Los Alamos, at the Naval Research Laboratory and earlier, was done at Frascati, Italy. In the Soviet Union the liner concept is now the number-two concept in their magnetic-confinement program, according to Ribe. Soviet liner work is going on at a branch of the Kurchatov Institute—at Krasnaya Pochra (near Moscow) and the Efremov Institute in Leningrad. —GBL

Intense neutron sources for fusion studies

Steady-state sources of intense neutrons are under way at two US laboratories. They would be used to study radiation damage produced in controlled-fusion reactors. If funds are appropriated for the Los Alamos Scientific Laboratory's $25.4-million Intense Neutron Source, it would be expected to produce fluxes of 2×10^{14} 14-MeV neutrons/cm^2-sec after it became operational near the end of fiscal 1980. Meanwhile, Rotating-Target Neutron Source II, under construction at the Lawrence Livermore Laboratory, may begin initial operation leading to a maximum 14-MeV-neutron flux of 1.5×10^{13} neutrons/cm^2-sec as early as March of 1978; total cost of the RTNS-II is estimated at $5 million.

Design parameters for sources. The INS would employ a 300-keV tritium beam impinging upon a supersonic jet of deuterium gas to put out 10^{15} high-energy neutrons every second. The high flux thus produced would approximate expected conditions inside fusion reactors of the magnetic-confinement type. An additional use for the source, according to INS group leader C. Robert Emigh, will be to evolve techniques of tritium handling in pumping, purification, containment and cleanup operations. Two accelerators and two buildings are anticipated by INS planners.

In Livermore's new source, which constitutes an improved version of the RTNS-I developed in 1967 for radiation-effects studies, a 400-keV beam of deuterons is to strike the inner surface of a rotating titanium-tritide target in the form of a section of a sphere. This target, 46 centimeters in diameter and spinning at the rate of 5000 rpm, would contain materials to be tested. The samples would be bombarded by so-called "fusion" neutrons, 4×10^{13} neutrons/sec being produced at a beam current of 150 mA. Advanced development efforts, a long-term project for RTNS-II workers, might eventually enable them to produce 10^{14} neutrons/sec at 400 mA, with a maximum flux of 4×10^{13} neutrons/cm^2-sec for samples 1 cm in diameter.

Target lifetime short. One disadvantage of Livermore's technique is that the targets themselves wear out relatively soon in use. As the deuteron beam heats the tritium, the neutron yield decreases; the rotation method extends the target's lifetime by preventing overheating due to beam-incidence concentration at any one point, and it is also possible to rock the target up and down so that the beam may strike over a range of target radii. Normally, however, the beam remains incident at a fixed radius until neutron output declines substantially, at which time the target is adjusted and a new band is used. The neutron output of the RTNS-I during its early years dropped by half in 50 hours; performance has greatly improved since, and the loss in yield is now only about 15% in 100 hours. The same 100-hour period is expected to result in similar changes in output for the RTNS-II.

Both the INS and the RTNS-II are designed to operate in the steady-state, or DC, mode in order to facilitate their use for long-term applications. Most accelerators comparable with those to be employed in the Los Alamos and Livermore machines, with respect to beam energy and current, produce pulses rather than steady streams of particles, because steady-state usage involves serious cooling and power-dissipation problems. However, pulsed sources have low duty factors, about 2% on the average, whereas steady-state sources can irradiate samples continuously for many hours. The latter situation may correspond more closely to the situation in future fusion reactors.

Intended uses for the two facilities are quite similar to one another. The Los Alamos source would be employed to study bulk radiation-damage effects, some surface phenomena (including spallation), insulator problems and metallurgical properties, as well as to calibrate and correlate sample data. Since 1967 the RTNS-I has served to aid studies of surfaces, bulk-mechanical properties, the Mössbauer effect, electrical resistivity, sputtering and particle release, electron paramagnetic resonance, critical current in superconductors and so forth. It will continue to be utilized for these research efforts, and it is expected that the RTNS-II, when completed, will be used for similar projects.

The INS was first authorized by Congress in FY 1976, but no funds were appropriated for that period. FY 1977 construction funds have been sought, and ERDA issued a draft environmental statement on the source in February. The Office of Management and Budget released funds for the RTNS-II in March, and it is expected that building construction will be finished by May of 1977.

—FCB

Kondo

continued from page 17

low temperatures actually occurred, and many theorists worked on this problem. One school of thought was to try to select a certain number of diagrams in the perturbation expansion in which only one electron at a time was excited. These calculations were done, for example, by Harry Suhl (University of California at La Jolla), who used dispersion relations, Alexei Abrikosov (Landau Institute), who used Parquet diagrams, Nagaoka, K. Yosida, J. Zittartz (University of Cologne), P. E. Bloomfield (National Bureau of Standards) and Donald R. Hamann (Bell Labs). Although the theories worked very well above and around the Kondo temperature, it is generally believed that they are unsatisfactory below the Kondo temperature.

Meanwhile Philippe Nozières (Laue–Langevin Institute) and Cyrano de Dominicis (Saclay) had developed a solution of the x-ray problem, confirming a conjecture of Gerald Mahan (Indiana University). The x-ray problem deals with the singular edge of x-ray spectra of metals due to an "infrared catastrophe" similar to that of quantum electrodynamics. Both problems, according to Philip Anderson (Bell Labs), are examples of Fermi-surface anomalies or infrared (low-energy) divergences caused by interactions of a single scatterer with the large number of low-energy excitations provided by the Fermi sea of electrons.

Building on this idea Anderson and Gideon Yuval (Cambridge University) showed that the x-ray problem could be used as a guide for a reformulation of the Kondo problem as a Feynman path integral over all possible temporal histories of the local spin. In 1969 Anderson, Yuval and Hamann used a method of solution that would now be called "block spins;" they derived a set of "scaling equations" by starting at the molecular scale and eliminating the individual spins step by step by grouping them together and replacing them by a lower density of effective spins. Thus, Anderson told us, a problem with one Hamiltonian can be scaled continuously into a different, and often easier one. They showed (or conjectured, depending on one's standards of proof, Anderson notes) that there is one value of the coupling strength where this different problem is solvable. Anderson and his collaborators scaled to this strength where they could solve the problem to study properties at lower temperatures. Anderson notes that they gave no numerical values for any parameters, because the method (in contrast to Wilson's later work) is formal rather than numerical and does not lead very easily to precise calculation.

Later Anderson, in a paper called "A Poor Man's Derivation of Scaling Laws," found a simple perturbation method to replace the original problem, which is characterized by a strength and a cutoff, with a problem in which the cutoff is lowered as the temperature goes down, causing the effective strength of the interaction to increase. Thus from a weak-coupling problem at high temperature one reaches a strong-coupling problem at sufficiently low temperature. However, on the way down in temperature, one must cross a No-man's land where no perturbation theory will help. This method closely resembles, Anderson notes, the conventional renormalization group of field theory, which was soon applied to this problem by Alfred Zawadowski (Budapest) and Michael Fowler (University of Virginia), who developed the formula:

$$T_K \cong E_F J^{1/2} \exp(-1/\rho J)$$

At about the same time a very different set of perturbation methods was developed by K. Yosida and A. Yoshimori (University of Tokyo).

Nozières points out that there is no doubt Anderson and his collaborators had a correct physical picture as early as 1969. The weak-coupling case, he remarks, is very simple. And the strong-coupling case again becomes very simple because the impurity traps an electron, making a frozen singlet which has too much energy to be broken. However, Nozières does not believe that the Anderson solution provides a strictly exact method to treat the crossover region. Anderson, on the other hand, feels that some aspects of the crossover, especially the ratio of specific heat to susceptibility, could be carried out in detail following work that had been done by Anderson's student, John Armitage (Cambridge).

Crossover region. In 1973 Wilson reported at the Nobel symposium and the Cargese summer school that he had devised a numerical algorithm to treat this crossover region.[1] The technique is an outgrowth of his work on the renormalization group, which is having wide applications in critical phenomena and particle physics. As Nozières remarked about Wilson's 1973 algorithm, the method is the first scheme that in principle allows one to describe the crossover from weak to strong coupling in many-body physics.

One way of looking at the Wilson renormalization-group approach was explained by Nozières not long ago. Think of a single spin inside an onion. Around the original spin, add a shell of two electrons, around that add a shell of four electrons, then a shell of eight, a shell of sixteen, until before long, you have 10^{23} electrons. In a sense, Wilson always coupled the spin in the center with a finite number of other electrons and considered the effect of adding new electrons beyond it as one in which the Hamiltonian is changed step by step. Then he looked for the nature of the change in the Hamiltonian as he went from a weak coupling between the original spin and the electrons to a strong-coupling problem in which the original spin was very strongly coupled, producing a singlet state.

As Wilson explained the recursion technique to us, he treated the electrons near the Fermi surface as a perturbation on electrons far from the Fermi surface. That is, one treats the small energy excitation near the Fermi surface relative to the large energy excitation for electrons far from the Fermi surface. This is done repeatedly. He treated as unperturbed the energies of order 1 eV, then treated the energies of order ½ eV as a perturbation on 1 eV, then treated energies of order ¼ eV as a perturbation on ½, and so on. Subsequently he did a more complete calculation. At each stage of the perturbation calculation, instead of just using the ground state (as in ordinary perturbation theory), he made use of the first 1600 excited states as well. When he moved to the next lowest energy scale, more states were added to the system; Wilson threw out all but the first 1600 states. By this technique, he reached a final answer that was accurate to a few percent.