Review

WINTER 1969

OAK RIDGE NATIONAL LABORATORY

State of the Laboratory 1968

Review

OAK RIDGE NATIONAL LABORATORY

VOLUME 2, NUMBER 3 **WINTER 1969**

FEATURED ARTICLE in this issue is the annual State of the Laboratory address as delivered in December by the Director. Its inclusion in the *Review* in its entirety, complete with the accompanying illustrations used in the original presentation, lends a documentary aspect to the quarterly that, it is hoped, will add to its historical value with the years.

Editor
BARBARA LYON

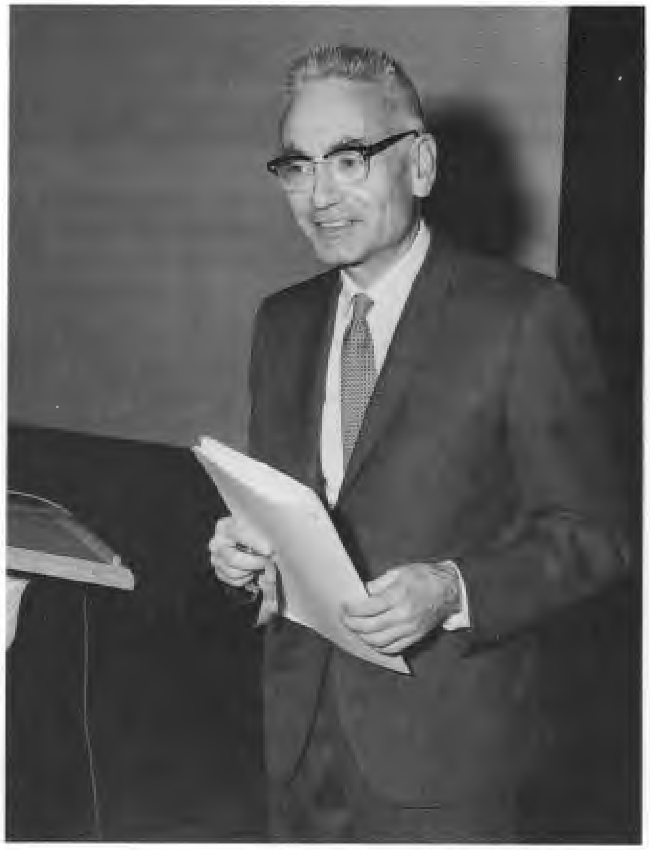
Consulting Editors
DAVID A. SUNDBERG
A. H. SNELL

Graphic assistance is provided by Graphic Arts and Photography Departments of the ORNL Division of Technical Information.

The *Review* is published quarterly and distributed to employees and others associated with the Oak Ridge National Laboratory. The editorial offices are in the Office of Public Information, Room 291, Building 4500-North, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tenn. 37830. Telephone: 483-8611, Extension 36510 (FTS No. 615-483-6510).

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION
UNION CARBIDE

Laboratory Director Alvin Weinberg has been delivering an annual State of the Laboratory address to the ORNL staff since 1951, when he spoke as Research Director. The message, given at the Oak Ridge High School, was classified for security reasons for seven years, and then open to attendance by invitation only until 1966, at which time the public was invited. This marks its first appearance in the ORNL *Review.*



STATE OF THE LABORATORY—1968

By Alvin M. Weinberg

THIS is a time of trial for science in the United States. For many years we had been warned that the expansion of science at the accustomed rate of about 10 percent per year could not persist much longer. In 1968, for reasons that are familiar to all of us, government science hardly expanded; some agencies, notably the National Science Foundation, spent less in 1968 than in 1967. The AEC has also had to retrench, and we at Oak Ridge National Laboratory have reduced our staff by about three percent.

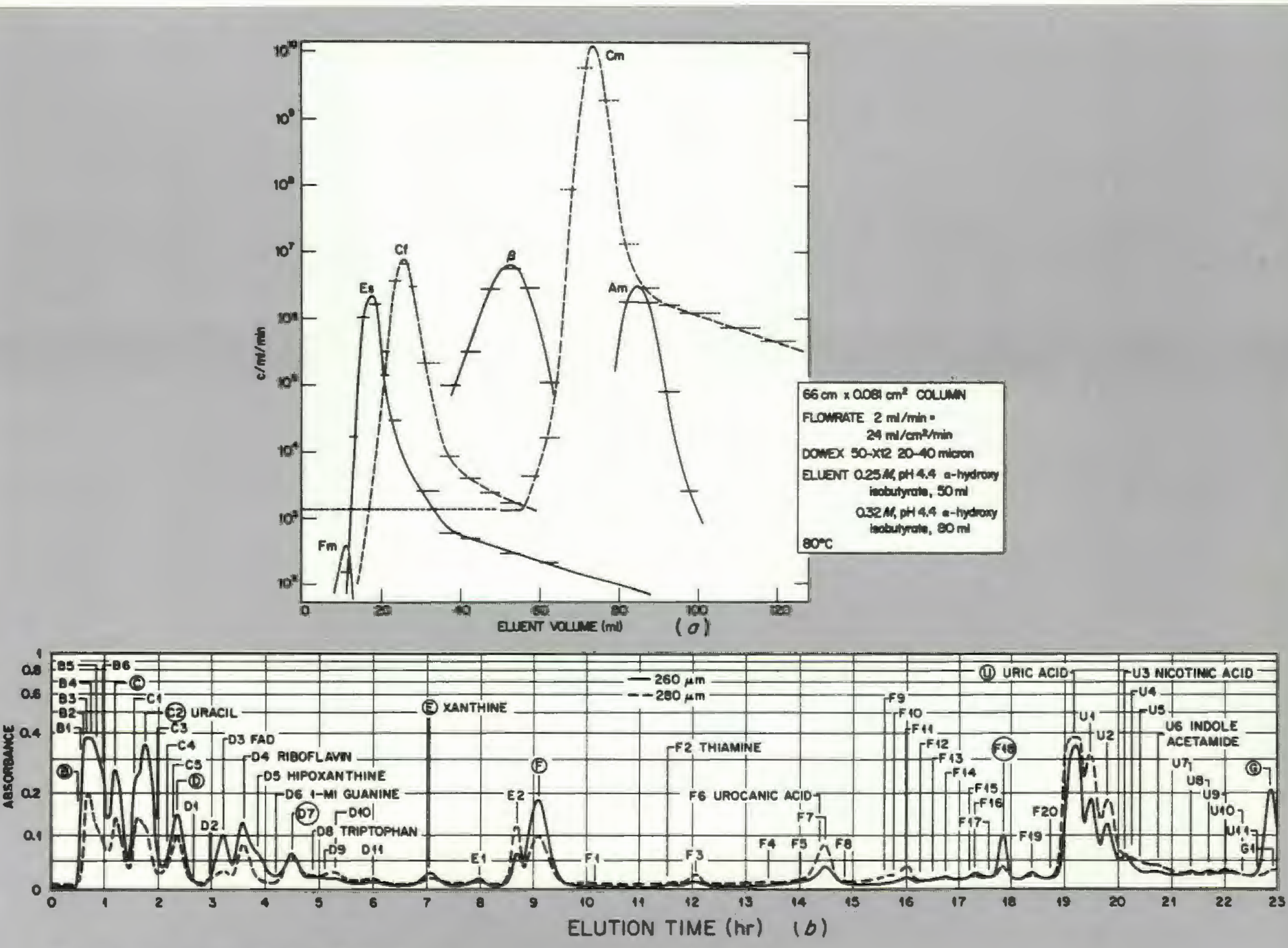
When money is short, competition naturally increases between the various claimants for scientific dollars. Each institution tries to advertise its virtues and particularly to rediscover those elements of uniqueness that insure an abundant future for itself. In describing our accomplishments during this past year, I shall therefore dwell on activities that illustrate two unique attributes of a national laboratory: our interdisciplinary style and our utilization of big machines in conducting basic research.

MAN Program—An Example of Interdisciplinary Research

Our interdisciplinary style is nowhere better exemplified than in the Molecular Anatomy (MAN) Program, an effort jointly sponsored by the Atomic

Energy Commission and the National Institutes of Health. The aim of the MAN Program is nothing less than to establish the metabolic profiles and chemical constituents of all the moieties that make up the cell. To achieve so ambitious an aim requires biologists, chemists, physicists, and engineers all working together: this mobilization of the resources of K-25 as well as of ORNL is, I believe, unmatched in biomedical research. This year the MAN Program has been officially established as an interdivisional project under the direction of N. G. Anderson.

Before cell moieties can be chemically characterized, they must be separated from each other. The first task of the MAN Program is therefore the separation of cell organelles: nuclei, mitochondria, ribosomes, membranes, etc. To this end the zonal centrifuge was originally developed. This device is now used widely in biomedical research and in the production of various biologicals. During the past year nearly three million people have received flu vaccine that has been purified by the zonal centrifuge. Other applications continue to pop up. For example, during the past year the zonal centrifuge has been used to prepare experimental batches of clean rabies vaccine that ought to be much safer than the product now in use. It is also being used to purify viruses that are pathogenic for the tussock moth and therefore can be sprayed widely to control, by specific biological action, infestation of fir tree forests by this pest.



(a) ELUTION OF TRANSURANICS.

(b) "NORMAL" URINE PROGRAM (SAMPLE: N-2-C-FF; RUN: C-51) TYPICAL UV CHROMATOGRAM.

Figure 1. Use of high pressure ion exchange in biomedical analysis and in separation of transuranic elements.

Another separation method that has come out of the MAN Program is the high-pressure ion exchange column. Separation of biological molecules by ion exchange has been standard for many years; however, to get the ultimate in resolution, very small ion exchange resin beads (~10 microns in diameter) must be used. Since the pressure drop in such beds is very high, the columns must be operated at pressures up to 5000 psi. Anderson, C. D. Scott, J. G. Green, R. L. Jolley, all of ORNL, and R. H. Stevens of K-25 have developed these high-pressure columns. With them they have separated chemical constituents of body fluids such as urine and blood more sharply than could be done by conventional means. ORNL body fluid analyzers are now under test at the NIH Clinical Center and at Duke Medical School. Incidentally, these high-pressure columns have had an important reverse spin-off, again exemplifying the power of different disciplines interacting with each other. D. O. Campbell, S. R. Buxton, R. D. Baybarz, and co-workers of the Chemical Technology Division have this year found that these high-pressure columns will beautifully separate the higher actinides from each other. This method has been used for final separation of all trans-curium element products from TRU. Amusingly, this reverse spin-off completes a circle begun 25 years ago. Ion exchangers were introduced during the Manhattan Project to separate radionuclides produced in reactors; from there they found their way into biochemistry in the nuclear energy laboratories. Now the biochemists are returning improved ion exchangers to the chemical engineers, again to separate radioactive species produced in reactors, as shown in Figure 1.

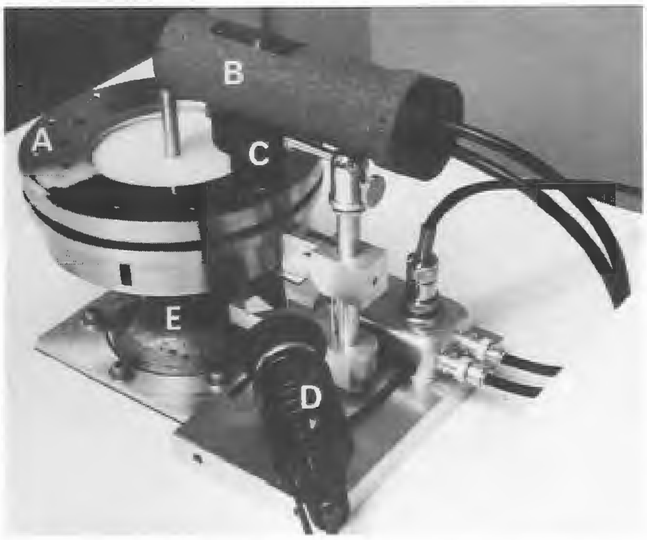


Figure 2. The GeMSAEC: (A) Cuvette rotor, (B) photomultiplier housing, (C) filter holder, (D) light source with diaphragm, (E) drive motor.

Devices such as the high-pressure ion exchanger, though developed as part of an effort to characterize cell constituents and body fluids without any specific regard for their medical application, may have importance in the practice of medicine. Every day medicine becomes more of a clinical science: treatment of serious disease requires increasing numbers of bioanalytical assays, and these assays become ever more complex. The sorts of analyses performed by the ORNL body fluids analyzer may well become standard in the general medical practice of the future.

Herein lies a frustrating dilemma. If each patient's disease becomes a research project requiring complicated analyses, how can our medical laboratories ever perform all of the time-consuming analyses; or, for that matter, how can the patient pay for all this testing? Automated, extremely fast, and inexpensive methods of chemical analysis will be required. The MAN Program has come up with an elegant, fast, centrifugal automatic analyzer, the GeMSAEC, that may be one key to swift, automatic bioanalysis. The GeMSAEC (Figures 2 and 3) is a small centrifuge carrying transparent cuvettes surrounding rings of concentric cups. Reagents and reactants (such as blood to be analyzed) are loaded into the cups. When the GeMSAEC spins, the reactant and reagent mix in the outer cuvettes; the course of the reaction is then followed by a spectrophotometer. With GeMSAEC, 45 assays can be performed, and the data recorded in less than two minutes. Medical spin-off of the MAN Program such as

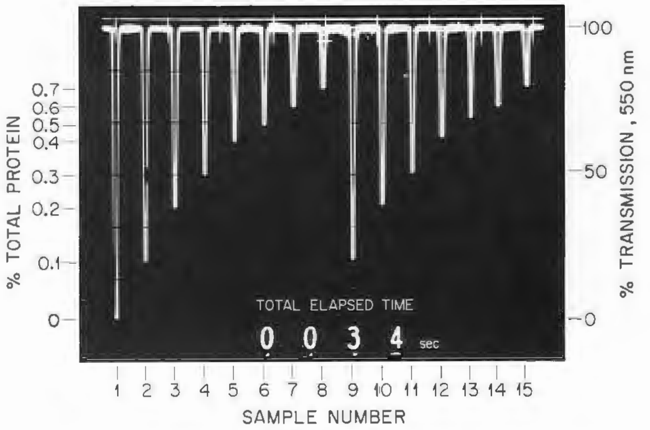


Figure 3. GeMSAEC fast analyzer: Absorbance curves measured automatically.

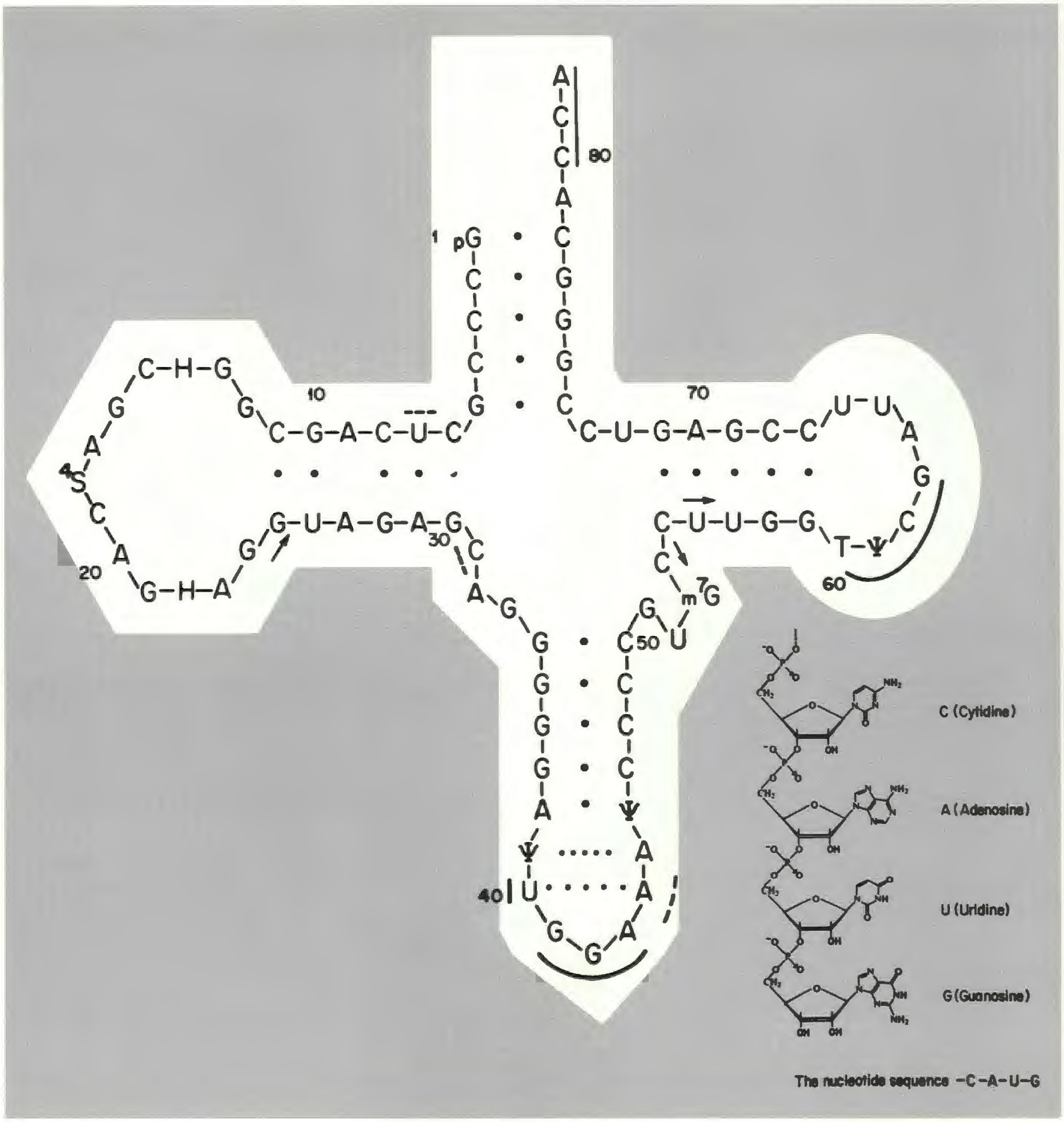


Figure 4. Phenylalanine tRNA.

GeMSAEC has so impressed the National Institute of General Medical Sciences that ORNL may be asked to go in a really big way into developing better techniques for clinical chemistry.

These rationalized, highly automated methods of biochemistry analysis obviously will have strong impact on basic structural biochemistry as well as on clinical medicine. For example, consider the base sequence in transfer RNA. (You recall that the bases referred to here are the four "letters" of the genetic code cytidine, adenosine, uridine, and guanosine; and that tRNA is the agent that escorts specific amino acids to their proper positions in proteins.) The first such structural sequence was determined by Robert Holley and his group at Cornell, a feat that took them about five years and won Holley a share of this year's Nobel Prize in Medicine. Since then the base sequences in eight other tRNAs have been determined, the latest, a phenylalanine tRNA, by M. Uziel and H. G. Gassen (a postdoctoral fellow from Germany) working in Waldo Cohn's laboratory here (Figure 4). The tRNA used by Uziel and Gassen was made available by the Macromolecular Separation Project, a joint enterprise of Chemical Technology, Analytical Chemistry, and Biology. This job has taken three man-years. Even this is a long time; and Uziel, J. X. Khym, W. F. Johnson (of the Instrumentation and Controls Division), and their co-workers have started to design an automatic nucleic acid "sequenator" whose use could significantly shorten the time and reduce the amount of starting material required for such analysis. One begins to see ways of establishing nucleotide sequences systematically for many RNAs—and possibly eventually relating anomalies therein to disease.

At this point I would like to interject a report on a most remarkable finding by Oscar L. Miller Jr. and Barbara R. Beatty related to the synthesis of RNA. Miller and Beatty have for the first time been able to visualize clearly a functioning gene in the electron microscope (Figure 5). It has been known for some time that the DNA of the gene acts as a template to synthesize RNA molecules with a sequence of nucleotides complementary to the sequence of nucleotides in the DNA. This synthesis starts at one end of the gene and goes to the other. The picture shows a whole series of genes, each something like a conical bottle brush. The axis of the brush is the DNA of the gene; the "bristles" are the RNA molecules in the process of being synthesized. Many RNA molecules are being synthesized; the longest ones have just finished synthesis. As the finished RNA molecules are released from the DNA, the others move along, copying the nucleotide sequence as they move; and new molecules start synthesis at the origin.

In a sense the MAN Program is a speculation: we

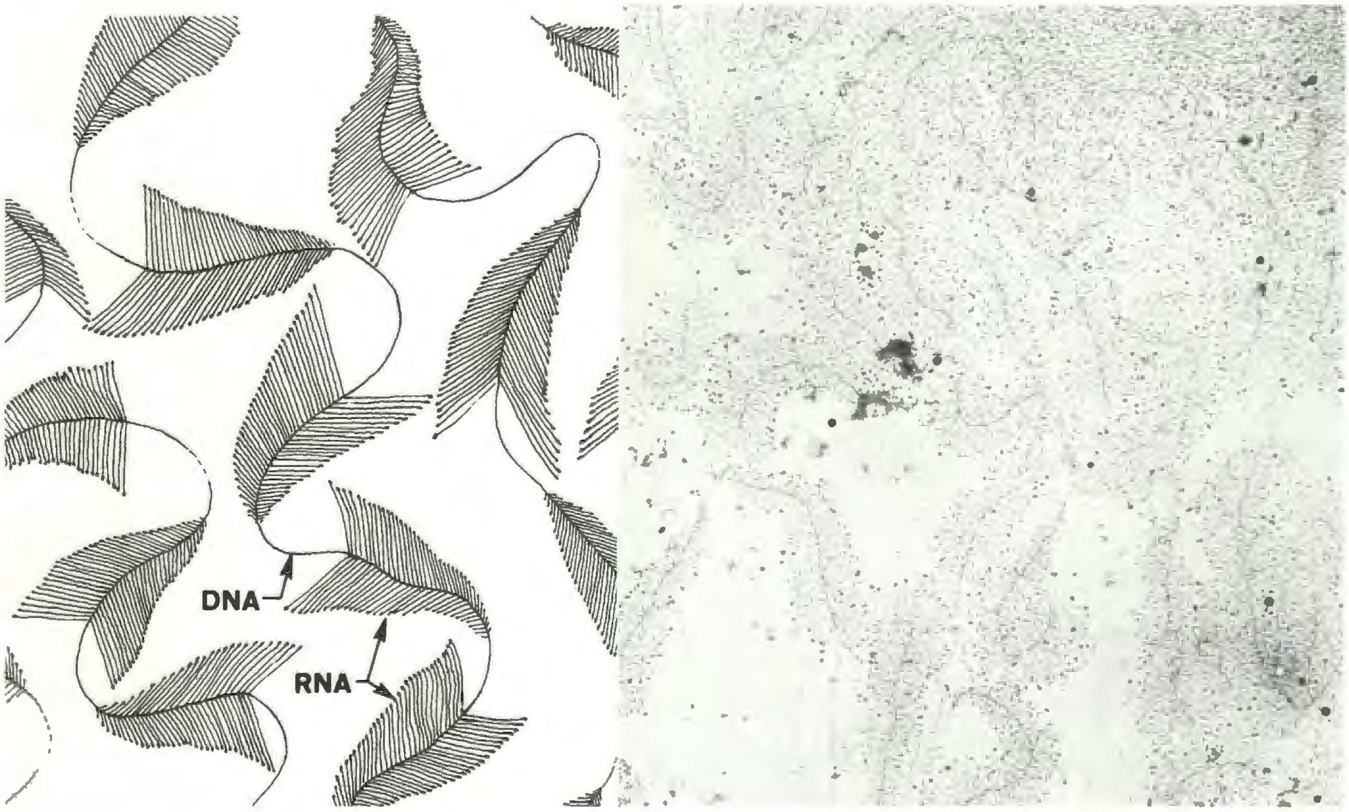


Figure 5. Genes in action: Synthesis of RNA on DNA strand.

are gambling on the idea that subtle metabolic deficiencies underlie many human diseases, and that in order to understand and then control them it will be necessary, first, to develop a very sophisticated bioanalytical technology that can detect small metabolic anomalies. Though it is too early to say how well this gamble will pay off, there have been several findings both at Oak Ridge and elsewhere which suggest that this approach may be fruitful. First there is the discovery, largely by workers at the Sloan-Kettering Institute, that acute leukemia (the sort that attacks children) can often be controlled temporarily by injecting the enzyme 1-asparaginase. Apparently the leukemic cells require the amino acid 1-asparagine, whereas this amino acid is not generally needed by the rest of the body; in consequence an enzyme such as 1-asparaginase that reduces the level of 1-asparagine in the blood might be expected to inhibit the growth of leukemic cells. This has indeed been observed, and 1-asparaginase now is taking its place as a useful agent for the control of acute leukemia.

At Oak Ridge, Stanfield Rogers has observed that the Shope papilloma in rabbits, a malignant skin tumor caused by a virus, has an anomalously high arginine requirement. Rogers has invented an ingenious scheme for lowering the level of arginine in the blood. He dialyses the subject's blood in an artificial kidney against arginase. The blood is thereby depleted of its arginine, but it is otherwise unaffected. With this technique Rogers has apparently caused a rabbit papilloma to regress (Figure 6). He is now trying to apply the scheme to the treatment of histidinemia, a disease of children, caused by excessive histidine. And finally I mention the finding of James Regan and William Lee of ORNL, in cooperation with Susumu Takeda and Helen Vodopick of ORAU, that granulocytes, both leukemic and normal, have a special requirement for serine that is not shared by other cells in the body. Thus growth of granulocytes conceivably could be selectively inhibited by depleting the blood of the amino acid serine, and this conceivably may find some use in the control of granulocytic leukemia.

In reviewing the MAN Program and the work on amino acid requirements of tumors, one is struck by the role that is being played by the analytical chemists in such enterprises. Increasingly modern biomedical research, as exemplified by the MAN Program and other big biological projects, seems to be dominated by analysis. In this respect our Laboratory is very fortunate. We have one of the most powerful groups of analytical chemists to be found anywhere. The excellence of our analytical chemists is something I need not stress to all you who have for so long depended on them. It is gratifying therefore that in April of this year H. A. Laitinen, Editor of *Analytical Chemistry,* devoted an editorial to analytical chemistry at ORNL. In this editorial he pointed out that over the years from 1955 to 1966 ORNL was the leading source of papers in *Analytical Chemistry;* and that "the Division represents a fine example of the contributions that can be made

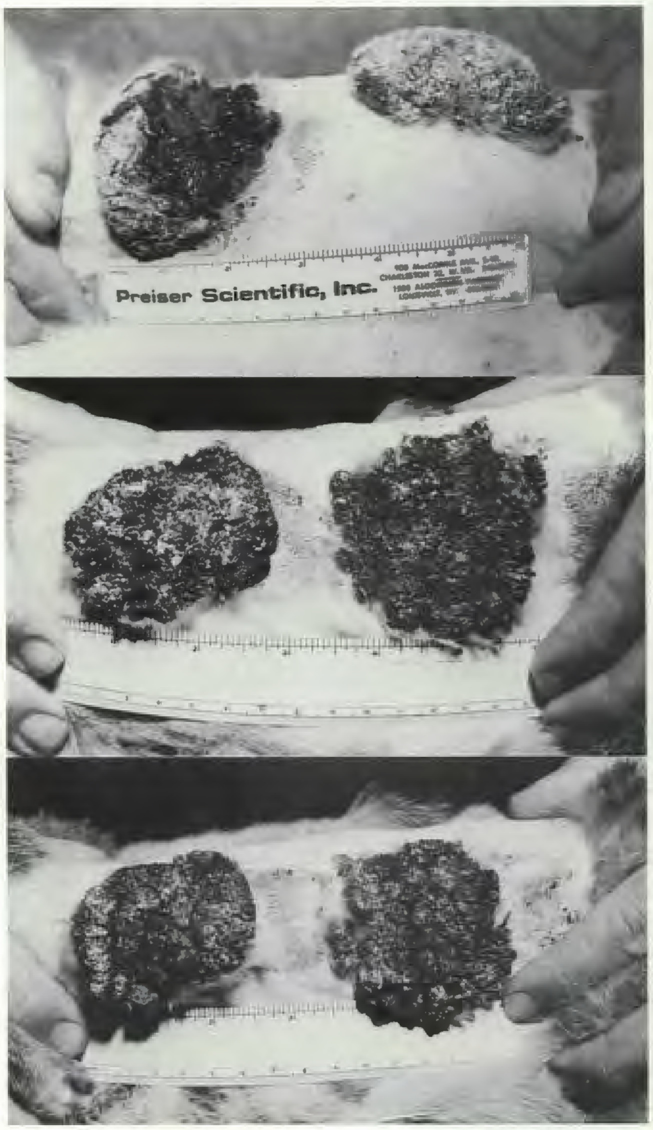


Figure 6. Shope papilloma in rabbit: Top, before treatment, tumor is bloody and 1 cm thick; middle, after 7 days' treatment with artificial kidney, it has dried and is less than 3 mm thick; bottom, after treatment has stopped, tumor has rethickened.

by a strong analytical chemistry group to a complex . . . operation." That the analytical chemists, particularly W. C. Butts, G. Goldstein, D. W. Hatcher, and I. B. Rubin, are becoming increasingly involved in our biomedical research is I believe a good thing both for the biologists (who typically have done their own analyses) and for the analytical chemists.

This interaction, between the analytical chemists and the biologists, illustrates the power of our interdisciplinary style in a way peculiar to Oak Ridge. There are few institutions, outside the AEC laboratories, where biologists interact so closely with chemical engineers, analytical chemists, and even metallurgists. This unusual interaction, which we perhaps take for granted, is now being discovered by NIH. I would expect that we can look forward to much further interest by NIH in these peculiarly Oak Ridge ways of injecting into our biomedical research our physical and engineering know-how.

Isotopes—Particularly in Medicine

The interaction between biomedical science and physical science at ORNL is further exemplified by much of the work of our Isotopes Development Center. The traditional core of the ORNL isotopes program has always been the development of special radioisotopes for medicine, and 1968 was a very good year in this regard.

I shall illustrate what we did by mentioning briefly the gallium-67 project carried out at the ORAU Medical Division. Gallium-67, which decays by electron capture and emits medium energy photons, was produced in the ORNL 86-inch cyclotron for the ORAU Medical Division. Looking for localization of gallium in bone, Drs. C. Lowell Edwards and Raymond L. Hayes of ORAU were surprised to note the very good localization of the carrier-free gallium-67 in soft tissue tumors. This lead is now being followed up because of the importance of finding new or improved agents for soft tissue tumor localization, especially in connection with radioisotope scanning.

The gallium story gives only a small inkling of the enormous impact that isotopes continue to have on medical research and practice. Perhaps a better measure of the isotopes' role is given in a report issued last July by the National Center for Radiological Health in which we learn that isotopes were used in the treatment or diagnosis of 1.7 million patients last year.

Fundamental Research Based on Big Machines

I turn now to another characteristic of places like ORNL—the exploitation of very big scientific machines for basic research. Of the large machinery at ORNL, the High Flux Isotope Reactor remains unique. It continues to operate well at 100 Mw, creating the highest thermal neutron flux in the world available for research. A reactor very much like HFIR is being built jointly by France and Germany in Grenoble; a replica of HFIR had been scheduled to be built at Argonne but unfortunately was canceled early this year.

As was expected, HFIR has provided the world with more heavy transuranics than had ever been made before. During the past year from the HFIR-TRU complex have come 840 μg of ^{249}Bk, 6 mg of ^{252}Cf, 58 μg of ^{249}Cf, 43 μg of ^{253}Es, and 8×10^7 atoms of ^{257}Fm. These have been distributed to transuranium chemists everywhere, as well as being used at our own TRL.

With thermal neutron beams of the intensity available at HFIR, it has been possible to greatly refine our studies of inelastic scattering of neutrons from crystals, and of the magnetic interactions of neutrons with paramagnetic materials. The point is that with so many neutrons available it is possible to scatter the neutrons three times before detecting them: once to monochromate, or polarize; once to interact inelastically, or magnetically; and a third time to measure their resulting energy or polarization. At each scattering, intensity is lost; hence for this sort of work extremely high flux is particularly important (Figure 7).

To illustrate what can be done with triple axis spectrometers, I mention the observation, by R. M. Nicklow, P. R. Vijayaraghavan, H. G. Smith, and M. K. Wilkinson, of localized vibrations of aluminum atoms dispersed in a Cu–4% Al alloy. In Figure 8 the neutrons inelastically scattered from the vibrating aluminum atoms are easily seen as the small peak against the five times greater inelastic scattering peak attributed to the vibrations of the host lattice of copper. In the same vein, R. M. Moon, T. Riste, and W. C. Koehler have been able to measure the paramagnetic scattering of polarized neutrons by MnF_2. Here the magnetic interaction ("flipper on" in the figure) gives a signal only one-fifteenth as large as the main diffraction peaks, and the experiment would be all but impossible without the flux available at HFIR (Figure 9).

The success of the HFIR has encouraged us to begin asking whether we should plan yet another research reactor, one that exceeds HFIR flux by, say, a factor of five. That there are new scientific worlds to conquer with superfluxes seems to be beyond question. The issue is whether we see ways of achieving substantially higher flux at a reasonable cost; for this we have no clear answer. Since a new superflux reactor would be a very major undertaking that might require eight to ten years, I believe it is not premature for us to begin to look now into the possibility of a superflux research reactor at ORNL. An informal group including D. S. Billington, R. D. Cheverton, T. E. Cole, W. K. Ergen, and J. A. Cox is thinking about this very important matter.

Turning to our big accelerators for nuclear physics, our new linear accelerator—ORELA—is almost complete (Figure 10). The electron gun has given 15 amperes, 3 nanosecond bursts; the klystrons perform well; and in every way we expect the machine to achieve its expected rating of 140 MeV and 10^{11} neutrons per 24 nanosecond pulse. This will make ORELA the world's most intense pulsed neutron source designed for neutron cross section measurements. The remarkable smoothness with which the ORELA project has been completed on time and within budget is a tribute to the engineers such as J. A. Murray and others of the General Engineering and Construction Division and A. L. Boch, as well as to the scientists who will be using the machine.

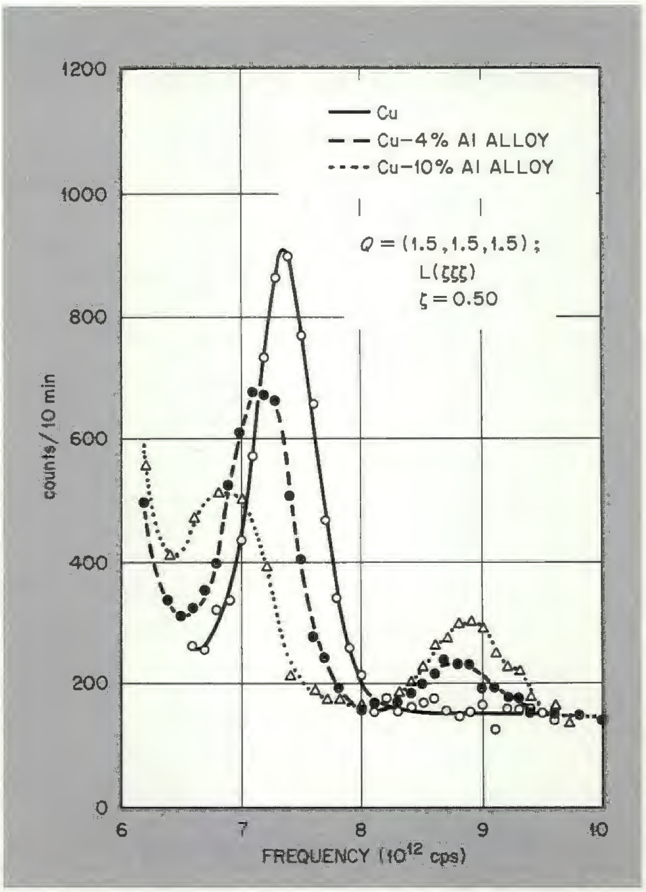


Figure 8. Localized vibration of aluminum atoms dispersed in Cu-Al alloys.

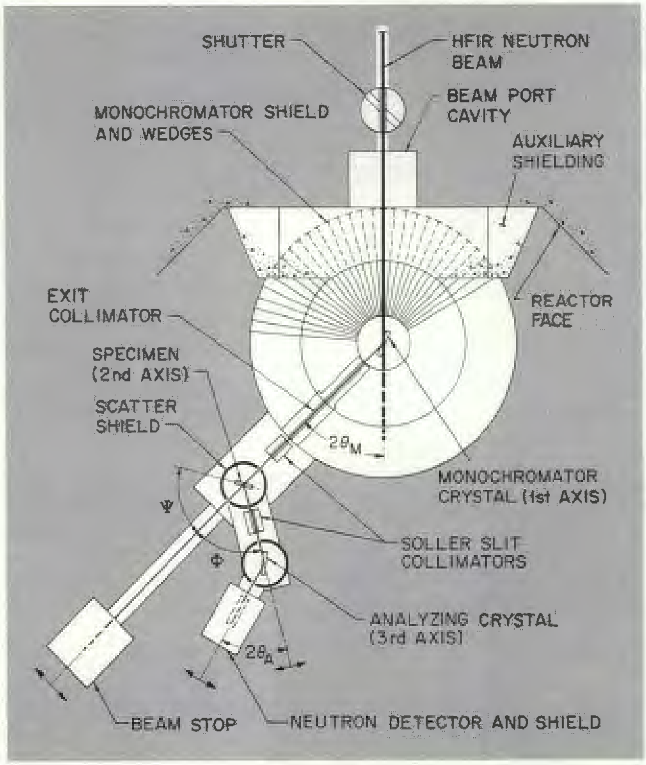


Figure 7.
Triple neutron spectrometer.

ORELA is aimed both at understanding nuclear structure and at measuring neutron cross sections relevant to reactor design. In this latter connection, G. de Saussure, R. Gwin, and L. W. Weston, with the help of R. W. Ingle, J. H. Todd, and F. E. Gillespie of the Instrumentation and Controls Division, and in collaboration with people at Rensselaer Polytechnic Institute, have this year found that α, the capture-to-fission ratio of plutonium, in the energy range from 1 kev to 20 kev is higher than had been assumed in reactor calculations (Figure 11). These results imply that the breeding ratios of fast breeder reactors based on plutonium may be somewhat lower—perhaps by five percent (rather than the 15 percent predicted by earlier British work)—than had been previously estimated. This loss in breeding ratio is unimportant for liquid metal fast reactors where the breeding ratio is comfortably high, but is of the highest significance for the steam-cooled plutonium breeder where the margin for breeding is all but eaten up by the higher value of α for plutonium.

The Laboratory is continuing to examine its future in nuclear structure and heavy element physics and chemistry. The massive effort in nuclear structure at ORNL has become a model for the rest of the world. But this is a fast moving business. Devices such as the tandem Van de Graaff and the ORIC, which were unique when they were installed several years ago, are no longer very unusual. True, the ORELA does confer a measure of uniqueness on our work on low and intermediate energy neutron interactions. But there is more to nuclear structure physics than neutron interactions, and we shall want new and more powerful Van de Graaffs and cyclotrons if we are to continue our broad exploration of nuclear structure.

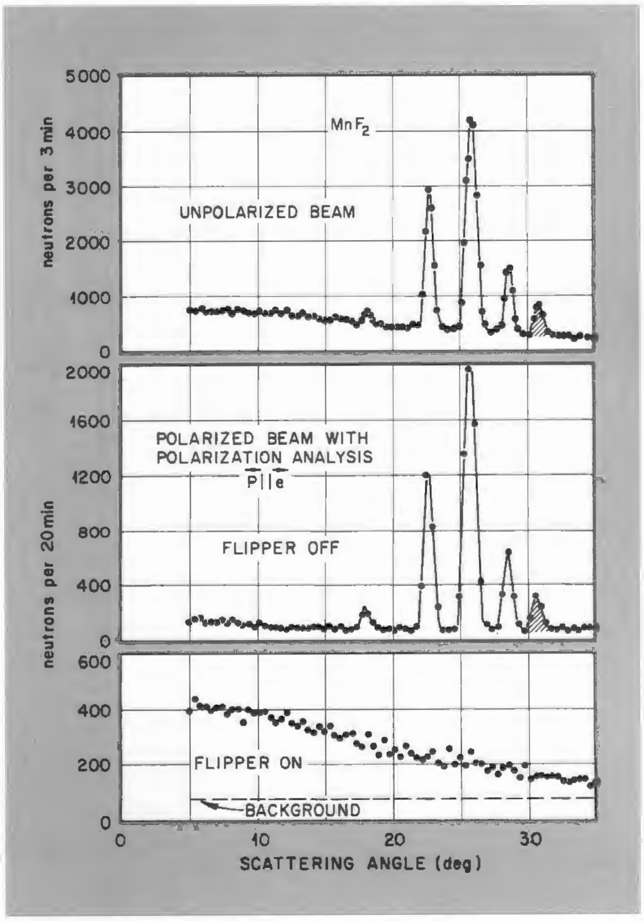


Figure 9. Magnetic interaction between polarized neutrons and MnF_2.

There may be some philosophical objection to our moving aggressively into this next phase of nuclear structure physics, since we would be moving into an energy range—100 MeV protons—that goes beyond what is obviously relevant to power applications of nuclear physics. But I believe in this instance we must recognize our broader scientific responsibility, spelled out precisely in the original atomic energy act: "The Commission is directed to . . . conduct research . . . relating to nuclear processes." And, with our traditional strength in nuclear structure and our newly found competence in heavy elements, it seems natural to probe further into these subjects. We have the setup and the environment to look into these matters more efficiently and professionally than most other places, and this is ample reason to keep moving aggressively.

We have therefore re-examined the proposal we presented to the Commission in 1966 for a TU Van de Graaff. This giant among Van de Graaffs was to have accelerated protons to 30 to 40 MeV, as well as accelerate heavier ions, but the energy would have been sufficient barely to get bromine ions into a uranium target nucleus. We now propose adding a separated-sector cyclotron as an energy booster (Figure 12). To take the extreme example, uranium 9+ ions would be accelerated in the TU to about 150 MeV, and then would pass through a foil where an appreciable fraction of them would be stripped to the +36 ionization state. They would then enter the cyclotron and be accelerated up to 1800 MeV, or 7.5 MeV per nucleon, which is sufficient to react uranium with uranium. With an auxiliary injector, the cyclotron could accelerate protons to 180 MeV—three times the top energy of ORIC.

Thus the whole periodic table would be opened to reaction studies, as well as the fascinating transuranic region where current speculation suggests a group of quasi-stable elements grouped around atomic number 114. Such an accelerator would have an advantage in beam current compared with other machines being considered elsewhere, and would keep us busy in nuclear structure work for a long, long time.

Energy Sources—Thermonuclear Energy

I shall touch now on two aspects of the work of the Thermonuclear Division. The first of these concerns the discovery in DCX-2 of a generalized form of the negative mass instability. G. G. Kelley made the

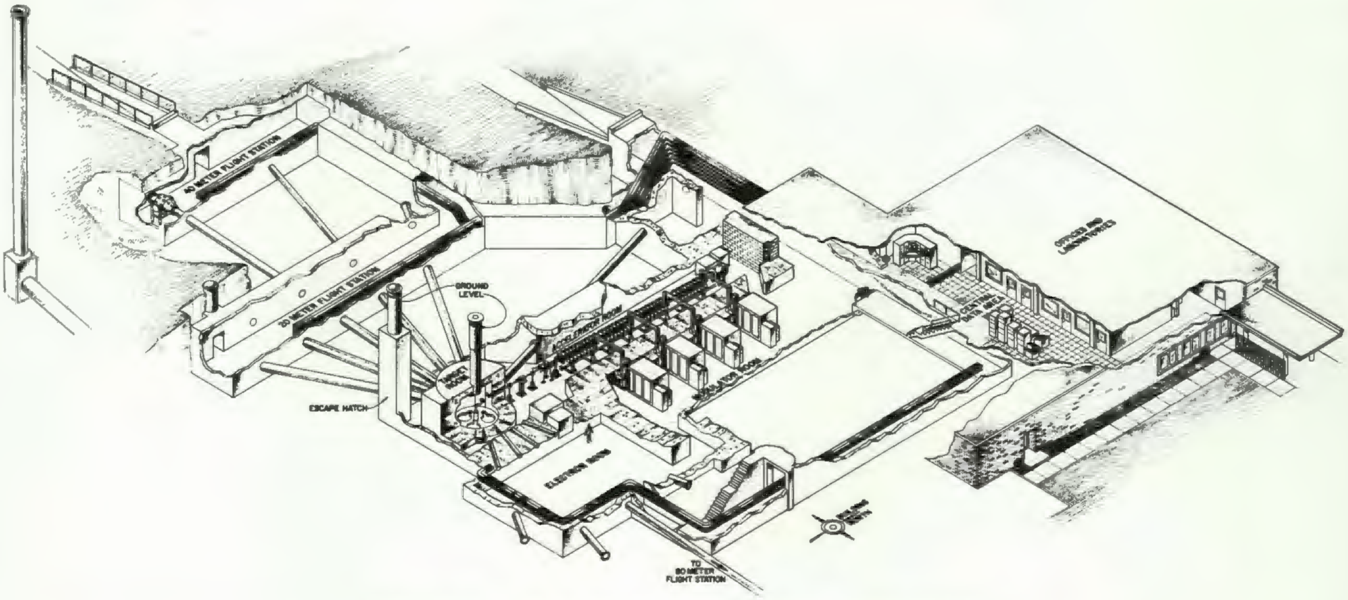


Figure 10. Oak Ridge Electron Linear Accelerator.

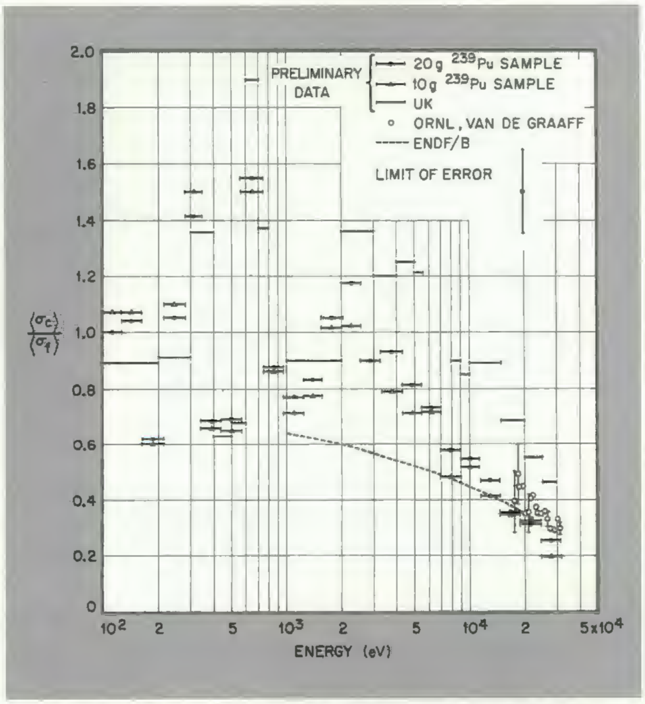


Figure 11. Capture-to-fission ration in ^{239}Pu.

discovery, and J. F. Clarke supplied the numerical evaluation. The physics can be easily explained in a simplified drawing of DCX-2, as shown in Figure 13. Consider the ring of ions at the left, rotating in a magnetic field, and suppose by chance a slight overpopulation of ions occurs at A. Then ions at C will feel an electrostatic repulsion from the cluster at A, and consequently they will gain orbital speed. Similarly, trailing ions at B will also be repelled from A, and they will *lose* speed. Let's follow those at B, and recall that in DCX-2 the ions actually spiral in helical paths between mirror coils as shown at the right. When the ions at B lose circular speed, the pitch of their spiral increases because their longitudinal speed remains practically unchanged. When the pitch angle is increased, the ions will penetrate more deeply into the stronger field in the mirror coil before they are reflected back. In the stronger field their angular velocity increases, so when they are reflected back out of the mirror they have caught up with the cluster A. Similar reasoning shows that the leading ions at C fall back into A. Thus the cluster grows and you have an instability. Also you see that the name "negative mass" comes from the fact that the ions at B move *forward* as the result of being forced *back*.

You will note also that this kind of instability is not peculiar to DCX-2, but will occur in any plasma device that relies upon magnetic mirrors for confinement. As it turned out, the Russians had also discovered the instability, so at the triennial international fusion conference held at Novosibirsk last summer where the generalized negative mass instability was unveiled, the work of Kelley and Clarke prevented another major Russian scoop in the atmosphere of friendly confrontation that pervades those conferences.

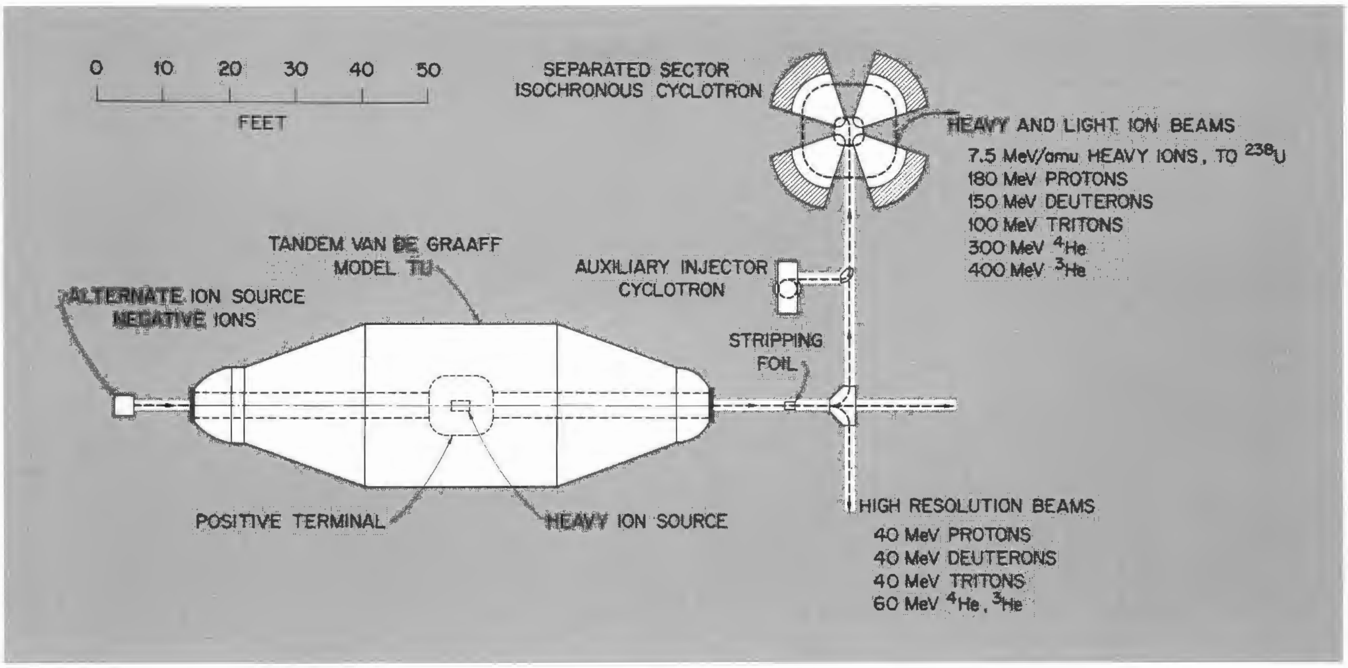


Figure 12. TU Van de Graaff and cyclotron.

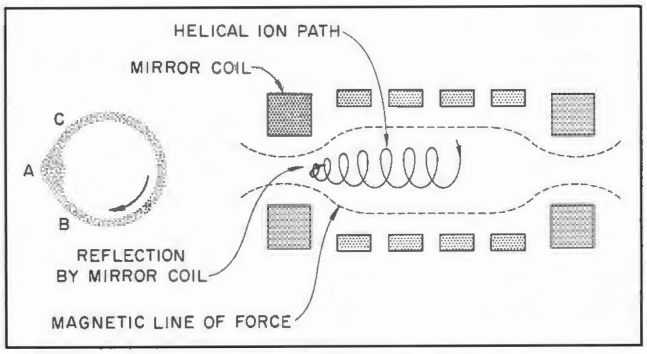


Figure 13. Generalized negative mass instability.

The second thermonuclear topic deals with the question: suppose we were able to control the plasma, could we then indeed build a fusion reactor, or would it be impractical or uneconomic for reasons of conventional engineering? This question has been around for a long time, but received no satisfying discussion until this year, when D. J. Rose, professor of nuclear engineering at MIT, spent most of a sabbatical year with our Thermonuclear Division. Rose's study finds a regime of relatively large deuterium-tritium fusion reactors, tending toward rather low magnetic fields and high relative plasma pressures, that look quite competitive so far as capital cost is concerned. For example, a 20,000-megawatt reactor (which may not be considered so large by the year 2000) with a plasma vessel, 5 meters in radius, using a magnetic field of 5 kilogauss, is estimated to cost about $7 per installed kilowatt. (This is for the reactor alone; it doesn't include the cost of pumps and generators.) The problem of how you fill such a volume with hot plasma is left to the next guy, but Rose does point out that in such sizes plasma loss by diffusion across the magnetic field may need to be only a few times slower than has already been achieved in some experiments.

Energy Sources – Fission Energy

Our country's movement toward nuclear power, though not as fast as it was last year, is still swift. Last year we had committed 46 × 10^6 kw to nuclear power plants; this commitment has now grown to 72 × 10^6 kw and represents an investment of around 10 billion dollars.

Some of the new reactors are encountering frustrating delays and increasing costs. For example, the very large pressure vessels at Oyster Creek and at Tarapur, India, have been cracked superficially by stress corrosion and are being reworked; other plants have been plagued with breaking-in pains, some rather serious. Yet two reactors in the 450-Mwe class, San Onofre and Connecticut Yankee, are now working well and the entire nuclear energy community is awaiting the commissioning of the first very large plants such as Browns Ferry.

The escalation – from \$110/kwe estimated four years ago for a 1000 Mwe plant to around \$150/kwe or more today – has disappointed us optimists. However, the prices of competitive energy sources have also risen, and power from light water reactors is still estimated to be cheaper than power from coal-fired plants if coal costs more than 23¢ per 10^6 Btu – that is, around \$4.50 per ton. As is characteristic of a very massive, slow moving technology such as nuclear energy, we shall have to be patient for yet another year, if not longer, before we can assess just how much power from light water reactors will cost.

As for our country's overall program to develop power reactors, the commitment to breeders is all but complete. This commitment was reinforced by President-elect Nixon who, in a position paper issued last October, stated, "I believe that we should step up the Atomic Energy Commission's breeder reactor project, which could provide virtually inexhaustible energy at an extremely low cost . . . its promise for mankind is as great as any other likely development."

The Commission, through its LMFBR program office, has formulated an elaborate plan to develop LMFBRs by mobilizing laboratories and industries throughout the United States. The entire program is scheduled to go on for 12 years, and to cost more than a billion dollars; our Laboratory expects to participate in this work much more heavily than it has in the past. To this end W. O. Harms of the Metals and Ceramics Division has been appointed coordinator of the LMFBR program at ORNL.

During the past year we have had, all told, about 150 technical people working on problems connected with LMFBR. The largest single job is the development of aqueous processing for recycle of stainless steel clad $(U,Pu)O_2$ fuels. Here the simplicity of the sol-gel process makes it readily adaptable to the handling of intensely α-active, plutonium-bearing fuel. And second, I mention the progress being made in the Metals and Ceramics Division in reducing the embrittlement and swelling of stainless steel caused by fast neutron bombardment. We now find that small amounts of dispersed titanium in the stainless steel will prevent embrittlement caused by (n, α) reactions. As for the newly discovered swelling phenomenon, specific metallurgical solutions are not yet in hand; we have found, however, that some alloys seem to be more resistant to swelling than are others, and this encourages us to believe that alloys will be found that resist fast neutron-induced swelling well enough to be used in commercial LMFBRs.

I turn now to the Molten Salt Breeder Project. As for the reactor itself, it completed a 188-day run last March. During this time the reactor was critical 98 percent of the time. Only the fuel sampler gave difficulty, and we now are operating with two sample capsules lost in the pump bowl.

The great technical event for MSRE was the chemical recycle of the fuel, and the replacement of ^{235}U by ^{233}U. In chemical recycle of fuel at MSRE, uranium is first treated with fluorine to produce the volatile UF_6; this is collected on NaF traps. The entire 219 kg of uranium was recovered and decontaminated in a matter of six days, and the new ^{233}U, which had been purified and made into UF_4 here at ORNL, was loaded into the reactor in September. The reactor was brought to power for the first time by AEC Chairman Seaborg on October 8 with R. W. Stoughton, co-discoverer of ^{233}U, looking on.

I cannot stress too strongly the importance of this demonstration of complete recycle of unburned fuel in a power reactor. Ever since the nuclear breeder was first suggested some 25 years ago, a rational and cheap way of recycling unburned fuel has been a prime technical goal. This indeed is the underlying motivation for liquid fuel in reactors. That now, after 25 years, we have demonstrated, on an actual

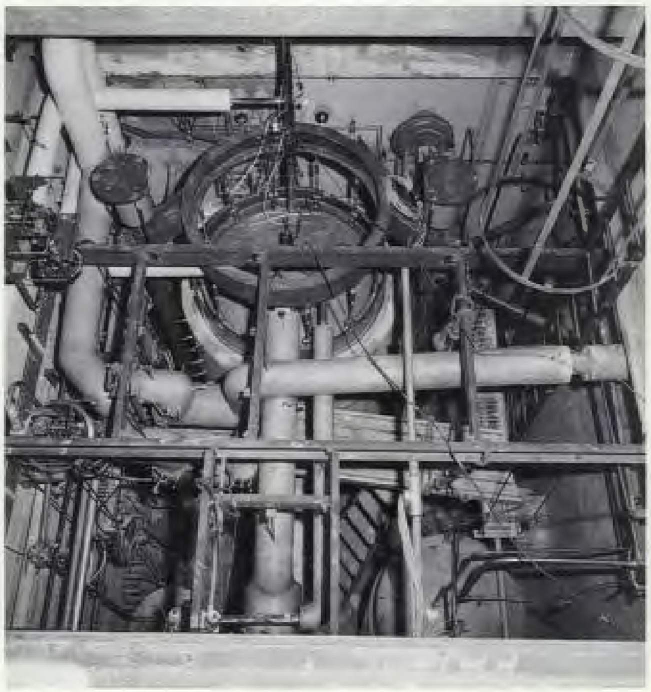


Figure 14. Chemical plant for MSRE.

reactor, a highly rational means of fuel recycling should be a very great source of satisfaction to all those who have been connected with the project.

The chemical recycle plant attached to MSRE, though very small, is actually large enough to handle a full-scale molten salt converter reactor of about 1000 Mwe, as shown in Figure 14. H. G. MacPherson presented the outline of such a reactor in a paper at the November meeting of ANS. MacPherson estimates the fuel cycle cost of such a reactor to be less than 0.7 mill/kwhe; what is more, such a converter could be built now without requiring any basic changes in the technology demonstrated by MSRE and the MSRE chemical plant.

During the year conceptual designs of a one-fluid, 1000-Mwe MSBR have crystallized. The core of the reactor is shown in Figure 15, and the overall layout in Figure 16. Although in this design we have substituted graphite balls for graphite bars in part of the core, our one-region breeder is really very much like an enlarged MSRE. We now estimate the capital cost of the MSBR to be about the same as the cost of large light water reactors; the fuel cycle should be about 1 mill/kwhe cheaper. The reactor would yield four percent new fuel each year, and its specific inventory would be 1.2 kg/Mwe. This performance is not quite as good as we expected from two-fluid reactors, but we believe, as we go into design details, that our estimates are becoming more realistic.

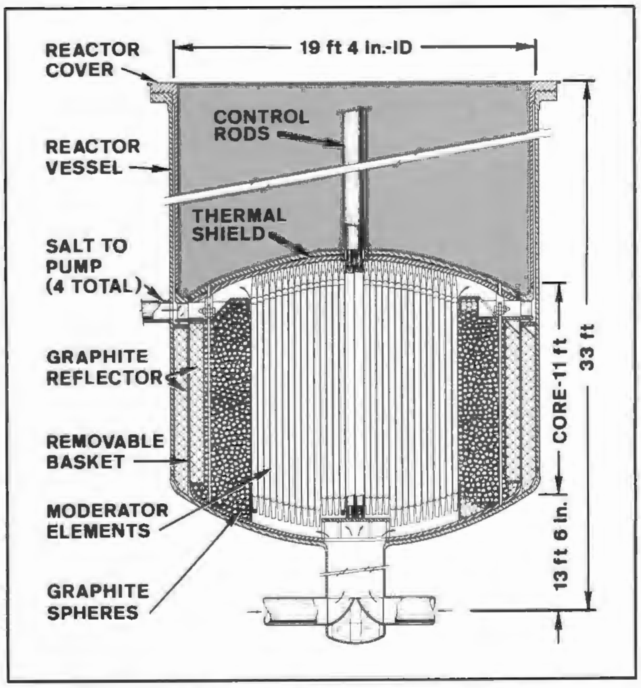


Figure 15. Molten Salt Breeder: Core design.

The key to ultimate success in the one-fluid molten salt breeder is a method for quickly removing ^{233}Pa and, on a slower schedule, the fission products. The former is unnecessary in a converter, and that is why we believe already demonstrated chemical processes will do for the converter. Our hopes for the rapid separation of ^{233}Pa depend on the bismuth reductive extraction scheme which I described last year. Progress has been steady during the past year: we now know that protactinium and thorium are sufficiently soluble in bismuth for thorium to be used as a reducing agent in the reaction, $\mathrm{Th}^{\circ} + \mathrm{Pa}^{IV} \rightarrow \mathrm{Pa}^{\circ} + \mathrm{Th}^{IV}$, the protactinium metal then being extracted into the bismuth phase. However, we have found the fission products to be less tractable than protactinium or uranium; and we may be obliged to return to some of the less attractive schemes, such as ion exchange, to remove them from the fuel stream.

The technical success of the MSR program has stimulated interest among several industrial and utility groups. No fewer than four separate consortia have expressed some interest in the molten salt reactor. Though it is premature to speculate too much now, I believe it to be quite likely that out of all this preliminary discussion will come a bona fide industrial-based project, probably aimed at a molten salt converter. In the meantime the Laboratory must pursue its course toward a molten salt breeder as rapidly as possible.

Applications of Nuclear Power, Particularly Agriculture

Increasingly we find ourselves concerned with the applications of nuclear reactors, as well as with their development. Nuclear desalination, which in many ways originated here at Oak Ridge, has now caught the world's imagination. This was evident at the IAEA's International Symposium on Nuclear Desalination held in Madrid this November. We learned at this conference that Spain plans two very large nuclear desalting plants, one near Barcelona, and other near Almeria, and that Saudi Arabia probably will expand its already large desalting capacity. And the returns are coming in on desalting projects in other parts of the world: India, Puerto Rico, the Middle East (to which I shall return), and Mexico. In every case the prospects continue to look sufficiently interesting to warrant further investigation.

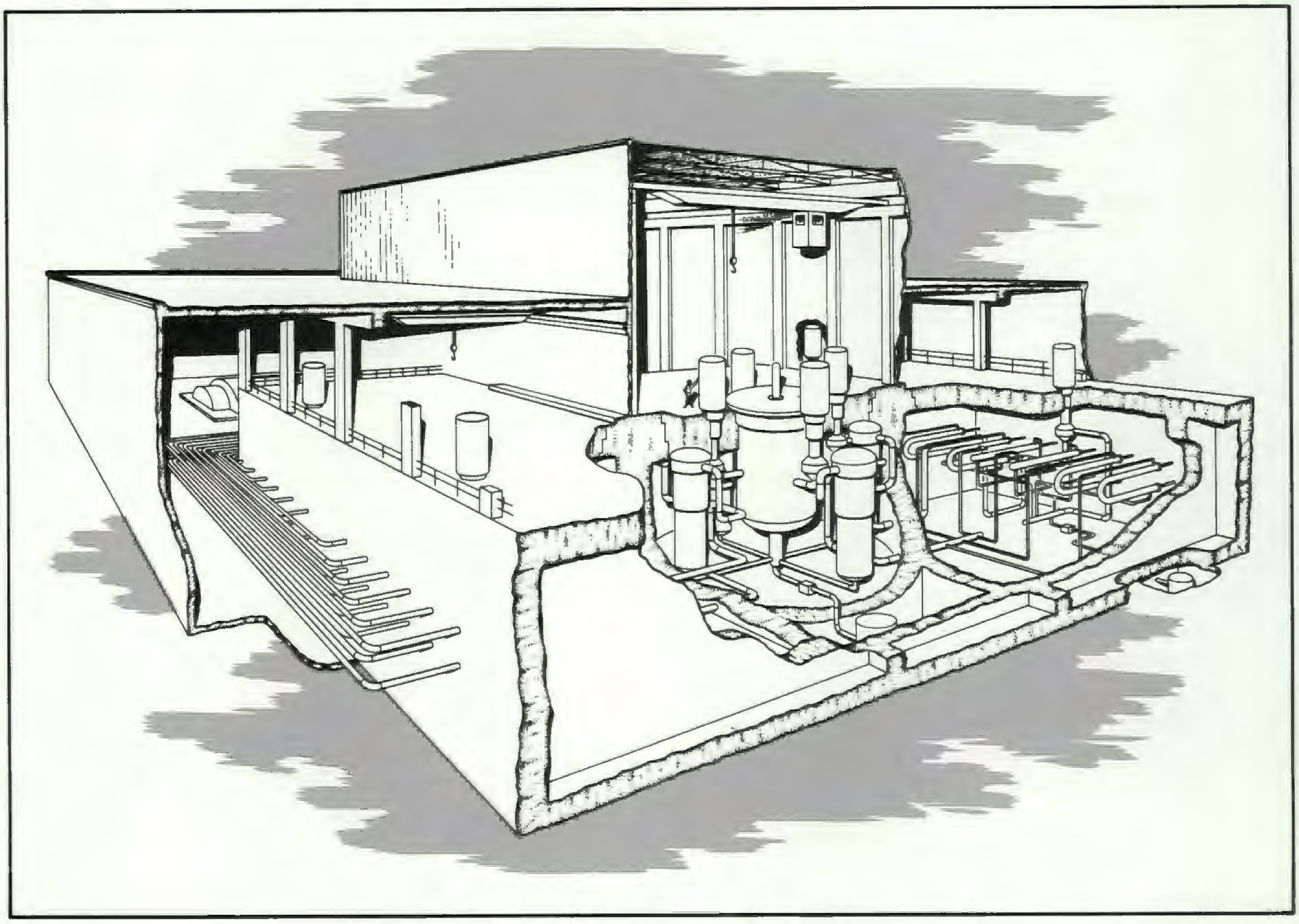


Figure 16. Molten Salt Breeder: Overall layout.

It is therefore most disappointing that the Los Angeles Metropolitan Water District (MWD) project (150 million gallons per day, 1600 Mwe) has been cancelled, I hope temporarily. The project now is estimated to cost $\$750 \times 10^6$, not the $\$450 \times 10^6$ originally estimated; this was probably the main reason for the cancellation, though organizational difficulties played a role. One gets little satisfaction from the comparable escalation in cost of the Feather River Water Conveyance project: desalting will suffer from the postponement of the MWD, for it is urgently necessary to build some very large evaporators simply to get experience. One is struck by the analogy with Shippingport where we paid $1000/kw to acquire experience, realizing at the time that the plant would be uneconomical.

Turning now to other industrial applications of nuclear power, I mention the Conference on Abundant Nuclear Energy held in Gatlinburg in August. Participants representing industry, universities, and government heard discussions of all the chemical and metallurgical miracles that would come to pass provided power is cheap enough.

Perhaps even more exciting is the growing belief that intensive agriculture could under some conditions be conducted economically with distilled water on desert sands. This idea was examined by a panel of distinguished agronomists convened by the Rockefeller Foundation early this year: the panel concluded that the idea probably was sound, and that the next step was a pilot scale "farm" operating in an arid region with distilled water. Should such a pilot farm be established, it is possible that ORNL will be asked to participate in the project.

Our original study on nuclear-powered agro-industrial complexes has been completed, and several reports summarizing our findings have been issued. The agro-industrial idea is now being studied intensively in specific locations – two agro-industrial complexes in India, one in Gujarat based on desalted water, another in the Ganges Plain based on well water; an industrial complex in Puerto Rico; and an agricultural complex in Mexico and the Southwestern United States.

The Laboratory plays a supporting role in these studies. We are, however, charged with primary responsibility for studying agro-industrial complexes in the Middle East. A group of about a dozen agronomists, economists, chemical engineers, political scientists, and reactor experts has been mobilized under J. A. Lane and C. C. Burwell to study the applicability of the agro-industrial idea to the troubled Middle East. The study is being conducted with the cooperation of the IAEA; participating in it are experts from various Middle East countries as well as from other government agencies in the United States. A most likely site for development seems to be along the Mediterranean Coast near Borg el Arab. The land there is fertile, and the climate is superb; in fact, during Roman times, this area was cultivated intensively. The group has also begun studies of complexes in the region around El Arish near the Gaza Strip and a location in Israel proper.

It is too early to say just what will come of these studies. That they may have wide-reaching effect is suggested by the inclusion in the political platforms of both national parties of recommendations for nuclear desalting plants in the Middle East. From the strictly economic and technical standpoints, the studies we have made so far seem to me to be convincing. Yet I suppose all of us would feel more comfortable if the 1000-Mwe light water reactors under construction, or the very large evaporators, were now operating. Solving today's social and economic problems with tomorrow's technology is risky. This merely points again to the high priority that ought to be given by our government to demonstrating the technologies on which the Nuplex depends: big reactors, preferably breeders; big evaporators; and intensive agriculture based on a sparing but reliable supply of distilled water.

Work for Other Agencies: Civil Defense, Urban Research, Environment

Our small civil defense project has rather naturally become involved in other problems of the city. We now have small contracts from Housing and Urban Development to study nuclear energy centers for cities, handling of solid wastes, and tunneling. Each of these tasks flows easily from other interests at ORNL: to make underground shelters one needs tunnels, which however could also be used as transportation and communication arteries. To provide a clean source of energy for a city – incorporating possibly schemes for recycling waste waters – requires nuclear technology coupled with knowledge of how to clean up contaminated waters. As for solid wastes, we have acquired much expertise over the years in handling radioactive solid wastes, and this experience may be applicable to the handling of the city's wastes.

How far we go in directing our civil defense project toward broader concerns of the city is difficult to say. We have had contacts with officials of HUD, and they have expressed interest in what more ORNL might be able to do about the city, beyond the specific tasks we have already undertaken. It has also become apparent that civil defense in our cities can hardly be separated from other aspects of the city, and our civil defense advisory committee has urged us to broaden our base to include matters more properly of concern to HUD. In particular, realizing our weakness in the social sciences, we have begun conversations with the University of Tennessee regarding collaboration between ORNL and social scientists at UT who are interested in the city.

The other major new contact with outside federal agencies, in connection with environmental pollution, has not fared so well. A proposal drafted by our ecologists and by others concerned with the environment at ORNL to study eutrophication of streams and its relation to land management and agricultural practices has for the time being been turned down by the FWPCA. On the other hand, our ecologists have been asked to participate strongly in the International Biological Program; they would coordinate the many related projects at universities and government stations concerned with the Eastern United States biome. This project would be sponsored jointly by NSF and AEC.

Education

Of our many educational activities I can mention but a few. The UT-Oak Ridge Graduate School of Biomedical Sciences now has 15 students. The Oak Ridge Engineering Practice School, a counterpart of the MIT Practice School, has begun to operate. And as a result of recommendations by our committee reviewing educational activities at ORNL, Ralph Livingston has been appointed liaison officer between ORNL and the University.

We have become a sister laboratory to the Pakistan Institute for Nuclear Science and Technology in Islamabad. M. K. Wilkinson and H. W. Schmitt spent two weeks in Pakistan during October as our first emissaries. If plans proceed as we expect, many other ORNL scientists will spend various periods in Pakistan helping this country in its scientific efforts. Pakistan is the second Asian country that we serve as a sister; the other is Thailand.

ORNL – A "National" Laboratory

Though we have had to tighten our belts, and may yet have to tighten another notch or two, all of us at ORNL should derive satisfaction from the way most things have gone this year. The general principle that the large nuclear energy laboratories ought to broaden their missions and become true "national" laboratories has acquired respectability throughout our government and indeed throughout the world. We see Harwell as well as other European nuclear laboratories redeploying in a manner not unlike our own. The Subcommittee on Science, Research and Development of the House, chaired by Congressman E. Q. Daddario, held hearings this year on redeployment of federal laboratories and recommended "... greater interagency use of federal laboratories as a viable alternative to creating new institutions ..."

We have been redeploying for about five years, and by now some 14 percent of our support comes from other agencies. I will not pretend that all has gone smoothly; some agencies understand us better than do others, and perhaps we understand some agencies better than we do others. But despite the difficulties, I am convinced that what we are doing is proper, and is in the best interest of ORNL and our country.

The main reason for this belief has to do with the peculiar fragmentation and rigidity that bureaucracy imposes on socio-technical problems. Take desalting the sea. Because of the accidents of government organization, desalting technology per se was the responsibility of the Office of Saline Water; nuclear energy was the responsibility of AEC. But the key to a successful attack on desalting was to combine desalting and nuclear energy. This was difficult to do at the Washington level. But at the working level, in the interdisciplinary environment of a laboratory like ORNL, combining these two elements was perfectly natural and has led to important advances. This is not an isolated instance. Our experience in the MAN Program, in civil defense and the city, in the Middle East study group – all these suggest that places like ORNL are capable of reintegrating at the working level the segmented approaches to national problems that result from the fragmentation of our government's bureaucracies. I believe this reintegrative function of the big laboratories will eventually be recognized as one of their most important strengths, and that therefore they will be called upon by many branches of government to deal with problems that transcend the responsibilities of a single agency.

Our Laboratory will then have to undertake heavy responsibilities that will extend our capabilities, and possibly try our patience. I think all of us must look forward to such a future with exhilaration, rather than with apprehension. We shall be grateful for the opportunity to create some order – scientific, technological and social – in this complicated and demanding world.

Joanne Levey is engaged in information retrieval research for the ORNL Civil Defense Project, which she joined in December 1965. Under the Project's contract with the national Office of Civil Defense and the AEC, much of her work entails collecting and processing civil defense research information in such a way as to provide a capability for computer searches of the collected material. The overall goal is a national information center on civil defense research. Having had a longtime interest in the soviet Union and its literature as a hobby, she was asked by Eugene P. Wigner, the Civil Defense Project's founding father, to write an article for *Survive*, a journal of civil defense, on the subject of civil defense in the Soviet Union, of which the accompanying article is a shortened version. Prof. Wigner, former director of the Laboratory, is currently on the staff of Palmer Physical Laboratory of Princeton University. The illustrations are taken from the U.S.S.R. official documents in which Mrs. Levey conducted her research.

Civil Defense in the Soviet Union

By Joanne Levey

OPPONENTS of a solid civil defense system for the United States frequently use the argument that such a program would not only be ineffective, but that it would tend to provoke attack by its implications of preparedness for nuclear warfare. If this argument is valid, it is instructive to ask ourselves why the Soviet Union has such a program.

For the Soviet Union does not rely wholly on its ballistic missiles to deter enemy attack or to defend against such attack should it occur. It has two additional arms of defense: an antimissile system and a civil defense program.

How effective is the Soviet civil defense organization? And why is it important for us to know this? To answer the second question first, if Russian military strategists could protect their urban population from the effects of nuclear weapons either through substantial urban blast shelters or preattack evacuation, they would have a decided strategic advantage over an enemy that could not do likewise. Even if the Soviets were mistaken in believing that their civil defense system is adequate, they could still take political advantage of an opponent who had a less effective means of protecting its population by holding that population hostage.

While this is the most important strategic advantage of an effective civil defense program, the Soviets, for obvious reasons, do not emphasize it in their unclassified literature. But they do indeed make other claims for the strategic importance of civil defense: Civil defense makes it possible to mobilize the armed forces during the initial period of war, to support troops with equipment and weapons as the war runs its course, and to protect and repair industrial, transport, and communication facilities.

Since these strategic advantages would arise from the effectiveness of any civil defense program, as well as the more obvious humanitarian benefits, it can profit us to try to get a realistic picture of the Soviet civil defense capability.

Unclassified Soviet military literature abounds in articles on all areas of civil defense; selected reading of these provides an overall picture of the Russian program: its scope, its quality, and its emphasis. Needless to say, such a reading does not reveal the exact number of Soviet shelters, or the extent of their effectiveness. Inferences, however, can be drawn. For example, some idea of the abundance and the convenient location of the shelters can be gained from articles that repeatedly instruct the citizenry to go to the nearest shelter at the sound of the Air Alert, and that indicate further that such shelters exist everywhere that people live and work, to enable them to take cover quickly.

The following comments on the Soviet civil defense program are based on a study of about 50 articles from the unclassified Soviet military literature, appearing, for the most part, during 1967 and 1968. They offer one reader's impression of the highlights of the Russian approach to civil defense.

An Overall View

Civil defense in the Soviet Union is a broad-based, well integrated program. It encompasses, at least in some degree, all aspects of protecting the population from the consequences of enemy attack and involves every citizen, from top government and party officials to the man in the street. The program is endorsed by both the central committee of the Communist party and the Ministry of Defense, and is implemented through an enormous organization which reaches down into every region, city, village, collective farm, and industrial establishment. While this represents a massive effort, it is not a crash program: its strength is cumulative, lying in a steady attempt to expand and upgrade every facet since its inception around 1950. It is quietly impressive rather than dramatic or flamboyant.

As with any such program, its basic objectives are the safeguarding of the population, industry and agriculture, including a system of rescue and reclamation after attack. Of interest are the weapons from which protection is offered: nuclear, chemical and bacteriological. Methods of protection are many: warning systems, shelters, provision of protective clothing, mass evacuation, rescue and repair operations, and medical aid are some of them. Of paramount importance is the maintenance of full communication between the State and the populace at all times. This is effected not only during attack, to provide instructions and bulletins and to prevent panic, but also in longterm preparation, through elaborate training programs that begin in childhood.

Individual protection against fallout: gas mask, gloves, cloak, etc.

No Matter of Controversy

There is little question about the importance of civil defense in the Soviet Union. "Defense of the Socialist Motherland" includes both active and passive defense and is regarded as everybody's business—party and government, armed forces and civilians. It is not a matter for debate, partly because the Soviet system discourages controversy, but also because many Russians living today have had firsthand experience with enemy attack on the homeland during World War II. People who have pulled incendiary bombs out by the fins and seen Red Square on fire and the Kremlin ablaze "have been there before." They need no convincing about the importance of civil defense.

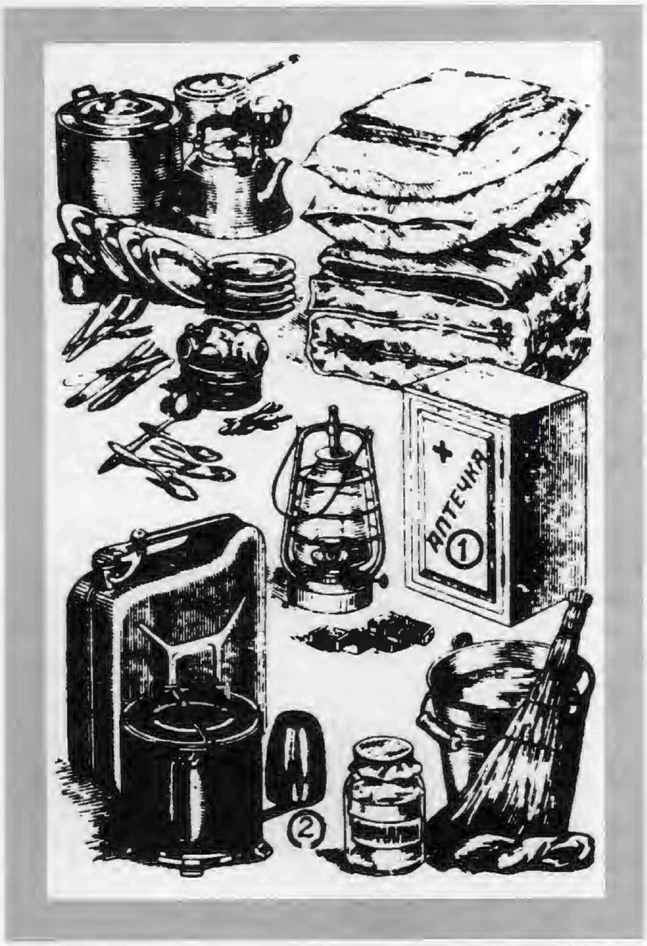
A Trained Population

Civil defense training in the Soviet Union is compulsory and universal. Everyone is exposed to it—school children in grades five through nine, both in classrooms and in summer camps, pre-draft-age boys in military-sport camps and in educational institutions, industrial workers at their places of employment, and members of collective farms. There is multiple exposure: civil defense is publicized at movies, on radio and television, and in magazines, newspapers, and plant publications. Civil defense courses are tailored to the needs and ability of the trainees. Grade school children are taught how to use individual means of protection, to take cover in shelters, and how to conduct themselves when they get there. Older children (in grades seven through nine) are taught rescue work and first aid along with methods of protection. Farm children are taught how to protect cattle, forage, food and water supplies as well as themselves. Factory employees learn rescue and reclamation operations and ways of reducing the vulnerability of their shops. All Russians are trained to identify and make the appropriate response to the seven warning signals (Air Alert, All Clear from Air Alert, Threat of Radioactive Contamination, Radioactive Contamination, Chemical Attack, Bacteriological Contamination, and Threat of Flooding). They are also instructed on how to respond to surprise attack and to the preattack government order to evacuate their cities. Instructions are specific and concrete. For example, if at home when the "Air Alert" is given, citizens are told to get together individual protective equipment (gas mask or dust mask, raincoat, and rubber boots), close the windows, turn off heating devices, gas, stoves, and lights, take the previously prepared supply of food, water, and personal documents, and head quickly for the nearest shelter, warning their neighbors (who may not have heard the signal) on their way out.

Postattack reconnaissance workers with dosimeters.

Realistic Exercises

Soviet civil defense training for male youth and adults puts emphasis on going into stricken areas almost immediately after attack to perform rescue and reclamation operations. They are taught to use cranes, bulldozers, and other heavy equipment to dig people out of caved-in shelters, to build emergency passageways in buried shelters, to extinguish fires, to administer first aid, and to evacuate the injured. The training exercises for these complicated operations are realistic with actual protective clothing and heavy equipment being used. Realism extends in other program areas to the simulation of chemical warfare agents from inexpensive materials available in any drugstore and to the practice evacuation of the newly delivered mothers and babies of a maternity home to a kindergarten 37 kilometers away.



Supplies for shelter living.
(Box, "FIRST AID;" jar, "FORMALDEHYDE.")

Detailed Plans

Besides being realistic, civil defense plans are, at least in some important instances, extremely thoroughgoing. The Soviet military literature describes, for example, plans to protect the employees of one large industrial enterprise having 57 buildings. The plant director has arranged personally with the help of his civil defense staff to settle all plant personnel in the country if international crisis should develop. Plans have been made to billet these workers and their families in homes in the surrounding villages, to increase the food supply of the stores at which they would get groceries, to provide water for the additional members of the communities (in one village an artesian well was dug on the spot when it was apparent that water was in short supply), to arrange for the post office to deliver, on short notice, mail and pensions to the evacuated population at their new addresses, and to stock shelters in the villages to accommodate the additional shelterees.

The Practical Approach

Practicality is the byword of the Soviet program. Since optimum first aid materials would probably be scarce, the use of belts is recommended for tourniquets, doors or sheets for stretchers, and dilute eau de cologne or vodka for the treatment of burns. While informed health physicists recognize the advantages of reference tables and slide rules over graphs in determining the permissible radiation dose, graphs are nonetheless recommended because they are more readily available. In drills at children's camps when rubber boots are absent for practice crossings over "contaminated" territory, heavy paper is used to bind the feet; and when the ground is too frozen to dig earth to pile around a potato bin for use as shelter, farmers are told to add support to the roof and use the potatoes for shielding against radiation.

Evacuation

Preattack evacuation of large segments of the urban population to rural areas under certain conditions of crisis escalation is an important plank in the Soviet civil defense platform. Industrial workers in cities are to remain on the job and take refuge in shelters at or near their place of work, but nonessential workers, school and preschool children, and retired people are to be transported to the country. Upon arrival, the evacuees are to assist their rural hosts in constructing hasty fallout shelters on sites that have already been surveyed for this purpose. Plans for evacuation are detailed, including, for example, time schedules for departure to collecting points, the presence of a doctor on each evacuation train (or with every convoy of trucks); instructions on what each family should bring (depending on climate and season), and special evacuation passes with a stub and a detachable slip for each person. In addition to having plans for evacuation, the Soviets also have the experience, the capability, and the organization. Their experience dates from World War II, when they successfully transferred over ten million people and over 1,300 basic industries from vulnerable areas to the interior. Further, Soviet transport capability has moved rapidly forward since World War II days. The system of railroads alone—the backbone of the USSR transport system—adds about 1,000 kilometers of new line per year and converts 2,500 kilometers of existing line to electric motive power. Motor transport and maritime transport have also made great strides, and the Moscow subway system, initiated in 1932, has grown in the past 35 years to 122 kilometers with more than 80 stations erected. Subways now also exist in Leningrad, Kiev, Tbilisi, and Baku. The daily number of subway passengers in Moscow alone is over 4,000,000. The combination of Soviet transport networks within cities and between cities and rural regions suggests substantial capability for evacuating urban dwellers to areas outside the city. In addition to having the experience and capability for evacuation, the Soviets are acquiring the organization. There is a civil defense transport service, operated by a specialized staff, and there are also dispersal leaders, still another specialized category of civil defense personnel assigned to evacuation.

Rural Civil Defense

The other side of the evacuation of urban dwellers from the cities is the reception and protection of these evacuees in the country. The Soviet rural civil defense program addresses itself to this matter and has three other important aims as well: (1) furnishing manpower for rescue and emergency restoration work in the city, (2) assuring the output of agriculture in wartime, and (3) protecting people, livestock, food, fodder, and water supplies against radiological, chemical, and bacteriological weapons. Emphasis is on protection against fallout in the country. Thus, there are explicit manuals with detailed instructions, both on erecting hasty shelters out of materials at hand and on converting vegetable bins to fallout shelters. There are also instructions for providing fallout protection for livestock both by adapting farm buildings as shelters and by driving the cattle into forests and other sheltered areas away from the probable direction of the advancing radioactive cloud. Builders of individual houses are encouraged to construct simple "cover" in basements with bricks allotted to them for this purpose.

While Soviet authorities acknowledge that the rural civil defense program has lagged behind its urban counterpart, nevertheless, it has been considerably upgraded in the last two years. The recent introduction of the fifteen-hour program into grades five, six and seven of their elementary schools and the strengthening of the training program in grade nine have reduced the discrepancy between the instruction offered to rural and urban school children. Further, the press, radio, and television are playing an increasingly important role in preparing the rural population in methods of protection.

Shelters

Soviet authorities emphasize the importance of shelters as the most effective means of defense against nuclear weapons. There are numerous kinds of shelters, such as subways, which are equipped with heavy blast doors; substantial, isolated, single-purpose shelters (largely for key government and party personnel); and basement shelters in apartment houses and public buildings. Certain mines, also, have evidently been designated for use as shelters.

Large public shelters are equipped with heating systems and with filter-ventilation units that keep out radioactive dust and chemical and bateriological agents. In addition to water, food, toilets, medical chests, and bunks, they contain crowbars, picks, and shovels for breaking holes in the walls, if necessary, and for dismantling obstructions. There is also a box of clay for sealing cracks, and there are burlap, rags, and binding wire for wrapping patches on damaged air ducts. Standard equipment includes a supply of radiation measurement instruments and protective clothing to enable selected personnel to make radiation reconnaissance missions and to conduct the urgent operations outside the shelter. Portable radios are on hand to establish communications with local civil defense headquarters and with rescue units.

Detailed articles with tables and diagrams appear in the Soviet literature on adapting building basements as "cover." Since "cover," unlike shelter, does not protect against chemical and bacteriological weapons, individual protective means must be used when seeking refuge. Householders are also expected to bring along their own food, water, and first aid kits when taking cover in apartment house shelters. It is noteworthy that in the majority of cases, the ceilings in building basements support only their useful loads and can therefore withstand only the load from weak shock waves with a maximum pressure of $1\frac{1}{2}$ to 3 psi. Thus, in setting up cover in existing basements, it is necessary to reinforce ceilings to withstand loads from shock waves and the possible cave-in of the building.

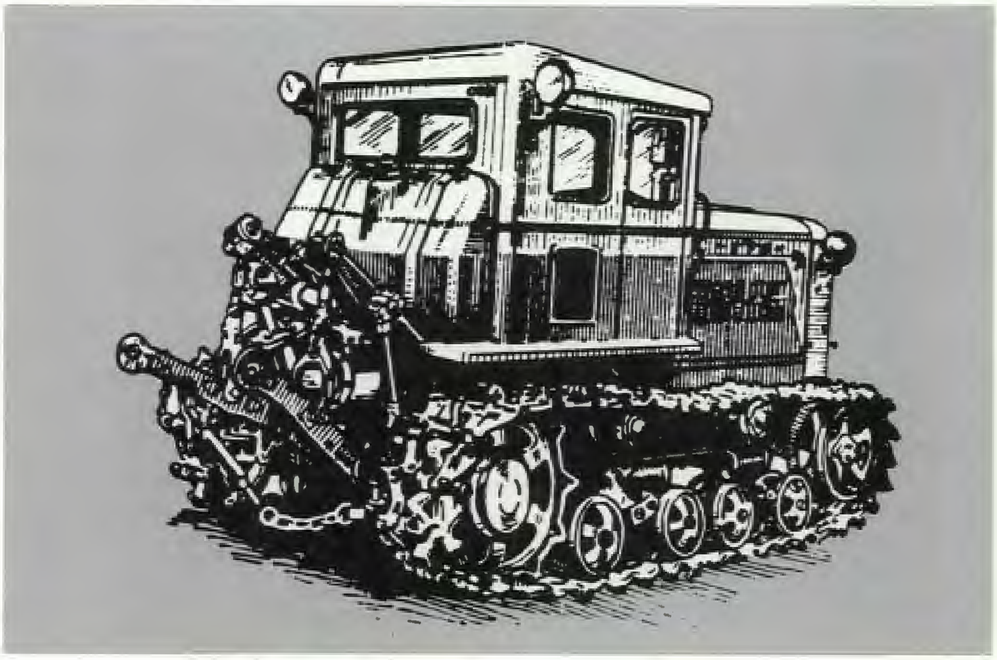
Soviet shelters are provided with emergency exits for getting out of the shelters in the event that the main entrance is buried by building fragments. The emergency exit consists of a covered underground passage, the egress of which is protected against debris of falling buildings. The overhang is located at a distance of at least half the height of the building and is three meters away from each of the surrounding buildings.

Shelter control units, composed of five to seven men, are organized with a unit commander in charge of all operations. The personnel of the unit is selected from among the workers in every industrial establishment and institution and from the technical and service staff of the housing operations office for apartment buildings. This shelter crew must have intimate knowledge of the layout of the shelter, the emergency exit, and the location of water, sewer, telephone, and power lines. The unit commander, in particular, must be thoroughly familiar with the emergency power system and the filter ventilation system. For he will be the one to make such possibly crucial decisions as when to turn on the ventilation system. Should he delay too long, the temperature and humidity in the shelter could rise to dangerous heights, whereas were he to act too soon, the filters could become clogged up with dust from the surrounding destroyed buildings. He must also decide when it is the best time to send out a reconnaissance crew and when it is safe for everybody to vacate the shelter.

Civil defense units or crews are organized by the special services in each "rayon" (or region). Thus, fire fighting units are established by the fire department, first aid detachments by the Red Cross and Red Crescent, mobile kitchens by the trade and catering service, and units for protecting public order by the militia.

Protection Against Chemical and Bacteriological Agents

If attacked, the Soviets expect nuclear, chemical, and bacteriological weapons to be used. For this reason equal billing is given to protection against all three types of weapons, and Soviet citizens are instructed to use such individual means of protection as gas masks, rubber boots, raincoats, and rubberized gloves. There are also explanations of the procedures in an area which is put under quarantine because of bacteriological attack. The civil defense medical service, for example, introduces prophylactic measures for the entire territory, giving injections to all residents. Clothing, household articles, and residential premises are disinfected; anyone showing symptoms of illness is immediately isolated; and those caring for the sick are taught to exercise precautions both on entering and leaving the sick room. Door knobs, stair railings, and toilets are frequently disinfected.



A tractor for removing rubble.

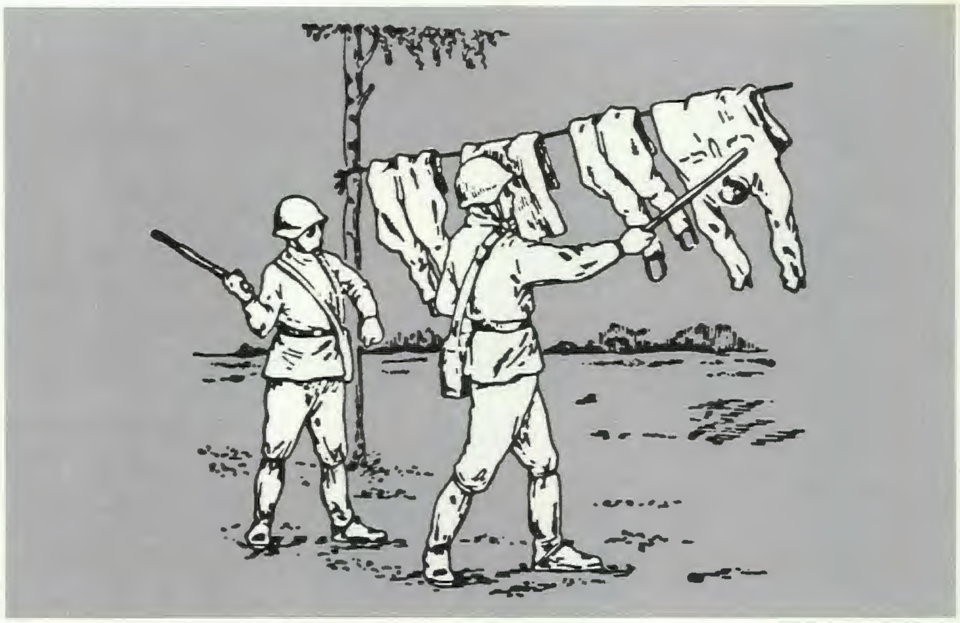
Protection of Industrial Operations

Soviet planners are aware of the importance of continuing industrial operations during wartime. To secure the survivability of industrial installations, they urge dispersion of industry, duplication of production, missile defense, and the removal, in some cases, of the most essential industrial plants to the interior at the beginning of war or when war threatens. Still another approach is to reduce industrial vulnerability by strengthening the plant buildings and their contents against possible damage from nuclear weapons. Thus, we come across the recommendations in Soviet literature that civil defense chiefs at various installations should organize qualified groups of people to determine the vulnerability of basic units, assemblies, and equipment on the basis of prognosticated damage assessment and to consider ways to reduce it. One way would be to slant new construction and reconstruction towards this end.

It is the director or head of each industrial establishment who is in charge of the civil defense plans and the procedures to safeguard the personnel, buildings, and equipment in the event of nuclear attack. He usually has a civil defense chief at his plant to assist him, but the ultimate responsibility falls on his shoulders. Among the most readable articles in the unclassified Soviet military literature are those describing how individual directors of large enterprises secure their establishments. An example is the account of Grigory Petrovich Garmash, assistant director of a large Kharkov tractor plant and a reserve officer. Men like Comrade Garmash must indeed be dear to the hearts of the Soviet civil defense heads. Comrade Garmash knows that "the important thing is to prevent panic." "Experience suggests," he remarks, "better to see once than to hear about ten times." With this practical guidepost in mind, Comrade Garmash organized civil defense teams in each shop and section—four decontamination teams from the test experiment shops, six medical detachments from the fuel equipment shop, and a team for technical emergency work from the repair machine shop. In all, ten civil defense services were established at the tractor plant—the three mentioned above and seven others, including services for fire protection, preservation of public order, blackout and power supplies, and shelter and cover. Elaborate plant exercises were organized in which 800 people participated. That Comrade Garmash means business is shown by the following story. Several times Comrade Garmash told the chief of the ZhKO (Housing and Communal Service Section): "'Put the shelters in order.' The latter promised. But he did not act. Then he was punished by the director. Now the shelters are in order." (You had better believe it!) While it is not possible to know just how many plant directors rise to their responsibilities as wholeheartedly as Comrade Garmash, there is reason to believe that there are at least a fair number that do. There are many stories in the literature similar to the one told about Comrade Garmash.

Prevention of Panic

A fundamental and publicly underscored goal of the Soviet civil defense program is the prevention of panic. Soviet strategists like Sokolovsky recognize that the explosion of nuclear weapons could easily cause an outbreak of panic. Should this occur, uncontrolled streams of refugees could disrupt the deployment and mobilization of the armed forces, and, further, the effectiveness of rendering aid to the civilian population itself would be seriously hampered. Therefore, Soviet defense planners have taken two lines to counter the possibility of a collapse of morale: (1) they have created a service within the militia with the explicit purpose of preserving order and morale and (2) they continue to instill patriotism into the population and also the readiness to bear hardships. The most recent effort to promote love of country and loyalty among the young has been the passage of the Law of Universal Military Obligation in October, 1967, by the Twenty-Third Session of the USSR Supreme Soviet. This law seeks to "achieve a profound understanding of personal responsibility for the Soviet state by the future servicemen" (the young people in the new compulsory pre-service training program) by "patriotic indoctrination" and to "strengthen ideological conviction and unflagging loyalty to the motherland in the youth studying in the clubs . . ." The law is also designed to bring about "a further improvement in the work on military-patriotic education of the Soviet people, and the formation among them of the necessary moral and psychological qualities which permit withstanding, if necessary, the severe tests of war . . ." Leaders like Tolstikov believe that "civil defense will be much stronger if the morale and political unity of the citizen is strong and the citizens are rallied around the true ideas which can inspire people to heroic deeds and sacrifices."



Partial decontamination of clothes by beating.

Compulsory Training of Students

As a result of the new Law of General Military Obligation, the Soviet civil defense effort has taken a marked thrust forward during the past year (1967–1968). In compliance with the new law, primary military training of youth has been introduced in the high schools and the trade schools, as well as at enterprises, institutions, and collective farms. The program for the youths in these schools and farms includes not only combat training but also knowledge of the properties of weapons of mass destruction and methods of protection against them.

Nor is it only the pre-draft age boys that come in for a greater share of civil defense training under the new law. To reach as many students as possible in 1967–1968, compulsory civil defense education was introduced into the fifth, sixth, and seventh grade classes of the secondary and eight-year schools of general education under the fifteen-hour program. School children in these grades throughout the Soviet Union are taught the principles of protection against nuclear, chemical, and bacteriological weapons, the civil defense signals and the proper responses to them, the location of the nearest shelters and the rules of conduct after entering them, the use also of individual means of protection, and first-aid care of the injured. Seventh graders of city schools are taught, in addition to methods of self-protection and first aid, the procedures for performing rescue work in centers of destruction. The goal of the new system of instruction is to give pupils sufficient civil defense training in their secondary school years so that when they go to work in industry, the time spent in civil defense instruction under the industrial program can be reduced.

To make the civil defense courses as interesting and worthwhile to the students as possible, specialized people, such as medical workers, are brought in to hold classes on self-help and first aid. Also, a wide assortment of teaching aids were introduced last year to the classroom for civil defense training purposes—view graphs, slide projectors, posters, special movies.

Inducements for Learning

In an article about civil defense training of school children, a Leningrad school was mentioned where instruction included training in the use of small arms, motorcycles, and even parachutes. Other inducements for learning about civil defense include visits to national monuments and shrines and sessions with war heroes and with civilians who participated in the heroic defense of Moscow in World War II. Instructors are told outright to link bravery and heroism not only to the field of battle but also to defending the peaceful population behind the lines—in the rear. It is an interesting sidelight to Soviet pedagogy that while teachers are instructed to capitalize on their young charges' propensity for patriotism and idealism and to enlist their interest with such glamorous equipment as motorcycles, they are nevertheless cautioned: "It should not be forgotten that a lesson or studies with all their entertainment are work and not fun. Like any labor they require willful physical and mental strain."

In summer camps, where emphasis is on putting into practice what the children learned in the classroom, pennants, citations, and buttons are awarded for excellence in drills and exercises. The best detachments are singled out for gifts, and there is occasional television coverage of the exercises so that the children can have the treat of seeing themselves on the TV screen.

At industrial plants, competitions are held among the various civil defense squadrons with awards for the winners. Distinguished performances in all areas of civil defense are cited in the literature. Directors of large industrial establishments, shop heads, instructors, and ordinary factory workers have an equal chance to be named, for example, in *Military Knowledge.* Conversely, those who flagrantly shirk their civil defense responsibilities may also get to read about themselves in a journal. Comrade Blinov, instructor in a highway technical school, is a case in point. The unfortunate comrade was cited in *Military Knowledge* for his lackadaisical attitude toward his civil defense duties. He declined to make use of the special classroom set aside by the directors of the technical school for a special civil defense office; he failed to acquire sufficient training equipment and visual aids, and those he did get were kept in a state of disorder. And worst of all, the lessons conducted by Comrade Blinov both "in content and in method are beneath criticism." Poor Comrade Blinov!

Soviet Willingness to Acknowledge Inadequacies

The Soviet literature is curiously lacking in bravado when it comes to discussing the civil defense program. While there are many examples of successful programs, there is also a significant sprinkling of criticism throughout: excellent civil defense training materials are available, but the best use is not made of them; there is a paucity of actual dispersal exercises for workers; certain civil defense plans look good on paper, but there is a discrepancy between how they look and how they are; training in rural civil defense camps for children is still "thoroughly bad" in many instances; there are not enough gas masks at seventy-five percent of the camps in a certain region. The willingness to cite inadequacies along with accomplishments shows the earnestness in the Soviets' desire to improve the program.

Summary

On the whole, the Soviet civil defense program is comprehensive, well integrated, and substantial. This is not to say that it is above criticism. The Soviets themselves admit the discrepancy between the civil defense blueprint and the current edifice—the plans are well conceived but their implementation, imperfect; there are pockets of apathy as well as inefficiency and, in some cases, poor quality of performance.

And yet, the Soviet civil defense effort is impressive. There is no question that the Russians have made considerable strides in their attempts to upgrade the program. In the last year alone, civil defense planners have introduced (1) compulsory civil defense instruction for school children, youth, and factory workers; (2) better training for those who teach them; (3) more detailed and concrete evacuation plans; (4) greater realism and practicality in the scenarios; (5) an improved communication system; and (6) extended radio, television, and newspaper coverage.

How effectively the Soviets could protect their urban population from nuclear weapons either through urban shelters or preattack evacuation to rural areas is not easy to determine. But, should war occur, there is at least one important goal that they might well approach: the maintenance of morale and prevention of panic. A disciplined population, having high morale and well trained in how to make the best use of the warning time at its disposal—be it two minutes, two hours, or two days—is not likely to give way to panic or to give up in resignation. It is indeed difficult to estimate how many lives would be saved and how many lost, but the state of discipline and morale of those saved would be an extremely important factor in enabling them to withstand the severe hardships of war and to work toward victory and recovery.

Atom Talk

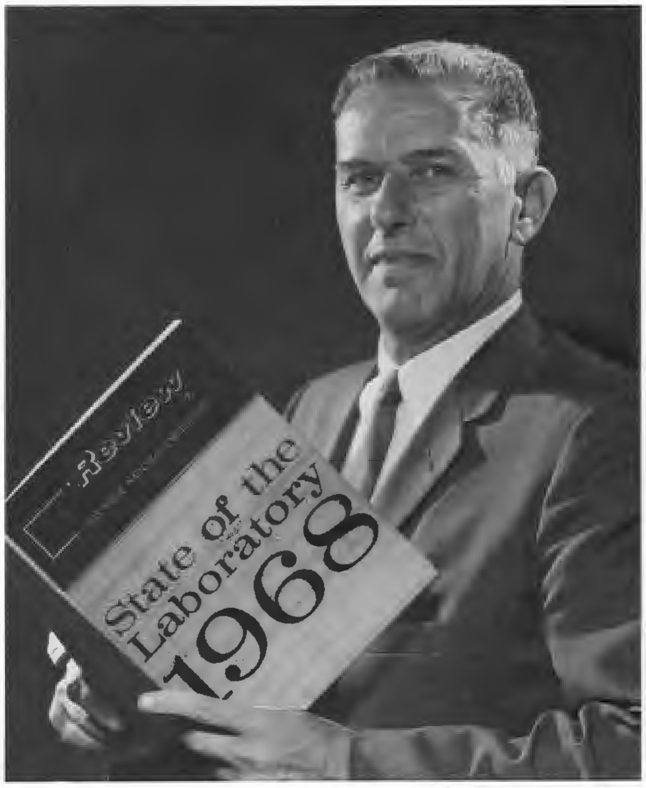
By François Kertesz

"AT THAT point I killed the dead man."

I looked at the verbatim transcript of a technical session devoted to reactor operations safety. I read the words, understood every one of them, and still failed to get the message. Only after careful consideration did I realize that the speaker was referring to the so-called "dead man's button," a safety device installed in subway trains and electric locomotives. The engineer must keep this button depressed, or the train will stop. This protects the passengers against any sudden disability of the engineer, such as a heart attack. In this particular case, it was necessary to eliminate temporarily this safety device by means of a bypass circuit; thus the speaker could state quite naturally that he "killed the dead man."

Modern life has become very complicated and our language reflects this. In an isolated, homogeneous community everybody speaks the same language, but 20th Century man lives in a society which pro-

Occasionally the services of a public information staffer are called upon to decipher the cryptic sign that indicates the road to the Laboratory's 7000 area. Such shorthand designations form part of the subject matter for the accompanying article, a longer version of which may be found in the Laboratory Documents collection (ORNL–TM–2367). Its author, François Kertesz (right) is coordinator of the Laboratory's information centers, and has long had an interest in verbal communication. Hungarian-born and educated in Germany and France, he commands eight languages, a fact that has made him of inestimable value to the ORNL translation services program. Herewith are some results of his research into one of the more esoteric languages to give color to contemporary speech.



duces and uses tools of ever-increasing complexity; therefore, new terms must be invented or new meanings must be given to old words, in order to identify a specialized concept.

I would like to examine one of these highly specialized languages, that of the nuclear engineer and scientist. This relatively new field needed many new words to convey a specialized meaning or to designate new machines and facilities. Some of the terms were taken from the basic sciences involved in nuclear research; many entries in nuclear glossaries and terminology books are simple engineering and scientific terms as used in nuclear applications.

The purely scientific terms represent an important source of the nuclear language. The concepts must be carefully defined to ensure that the reader will understand exactly what the author means. They usually are issued by national and international committees and are made available in the form of official glossaries.

Although the reader of a technical paper is not a layman, he must be advised what is meant by expressions such as decontamination factor, migration area, multiplication factor, et al. Modern science deals with exact quantities, and any reference to concentration, weight or volume must be clear and unequivocal.

As the nuclear field continued to grow and assume and increasing importance in the economy and political life throughout the world, more ambitious cyclopedias and lexicons were published in various languages. These have been useful to a variety of people—the interested citizens and the newspapermen as well as the specialists.

When we examine the origins of "nuclear language," we must keep in mind that the field grew up in secrecy; it was born under conditions of wartime urgency, followed by a period of mutual suspicion which divided the scientific countries of the world into opposite camps. When the first truly worldwide meeting was held in Geneva in August 1966, many nations discovered that their language did not have the terms suitable to express the new concepts. Because of its rich nuclear literature, English became the predominant language and ever since has exerted a great influence on the terminology throughout the world. One of the first acts of the organizers of the 1955 Geneva Conference on the Peaceful Uses of Atomic Energy was to commission the compilation of a nuclear dictionary covering the official languages of the United Nations.

A new improved edition was published in time for the Second Geneva Conference. Within a short time, a number of bilingual and multilingual nuclear dictionaries appeared on the market.

In this short review I propose to leave the serious examination of technical terms to the learned committees, and will examine primarily the more colorful expressions of the nuclear language, which enrich the field and give it a special flavor.

There are many expressions, such as the first sentence of this article, which are used primarily orally and are seldom written down. I heard a nuclear incident described as a *felt-hat incident.* This concept postulates that a worker near a swimming-pool reactor will sometimes wear a felt hat which will drop into the pool and will be sucked to the fuel elements where it will prevent the flow of cooling water, resulting in a meltdown of the element. Such accidents have indeed occurred, although with shoe covers, loose pieces of metal, etc. instead of felt hats. They are usually referred to as "felt-hat accidents" although not in formal reports.

Such expressions were coined because they satisfy a communication need and also, perhaps, to keep the subject matter from the uninitiated. This often resulted in a compromise, as if technical discussions were a guessing game, in which the subject is disguised but some helpful hints are given.

I intend to concentrate my attention on individual terms and code names used by nuclear specialists, trying to decipher how and why they were chosen.

It is important to keep in mind that words not only have intellectual meanings, but may also carry an emotional impact. And because public acceptance of the Nuclear Age is still affected by the legacy of its first application, the imagery evoked by the new science's teminology is of utmost significance. Many factors affect the language of a new technology: the requirements of secrecy, ego boosting as expressed by belonging to a select group, and euphemistic tendencies in general. Let us see how these factors have shaped the language of nuclear science.

Early Secrecy

At the beginning of the Manhattan Project, steps were taken to avoid mentioning the element uranium. In all the reports it was referred to as Tuballoy (long u) and designated by the symbol T. The enriched material was called Oralloy, and ^{235}U was called "element 25," from the last digits of its atomic number 92 and atomic weight 235; by the same token plutonium, with its atomic number 94 and atomic weight 239, became 49.

At a meeting in Chicago in the spring of 1942, the problem of code names for the newly discovered transuranic elements was discussed. One of the possibilities considered was to call Element 93 *neptunium* and Element 94 *plutonium.* It was agreed, however, that these designations might eventually be the actual names for these elements and therefore should not be used as code names. Up to that time the terms *copper* and *silver* were used to refer to the new elements. This caused considerable confusion with the real copper and silver, especially if they were involved in the same processes. It was often necessary, in fact, to use the term *honest to God silver* to distinguish Ag from Pu.

The afore-mentioned coding system based on the last digits in the atomic number and atomic weight was probably responsible for the naming of *K-25,* now the Oak Ridge Gaseous Diffusion Plant.

Research on transuranium elements continued. Since our solar system revealed no more planets to supply names for the new elements, the next two were tentatively called *pandemonium* and *delirium* by the workers. These names did not reach the public. The story of naming the following heavy elements is told by Seaborg in his book, "Man Made Transuranium Elements" (Prentice-Hall, 1963). Element 97 was called *berkelium* after the city of Berkeley, California, and Element 98 was named *californium* after the university and state where the work was done. However, this latter name does not reflect the observed chemical analogy of Element 98 to Element 66, dysprosium, as the names of americium, curium and berkelium signified that these elements are chemical analogs of europium, gadolinium and terbium, named after a continent, a scientist and a city, respectively. In announcing their discovery in the *Physical Review,* the authors commented, "the best we can do is to point out, in recognition of the fact that dysprosium is named on the basis of a Greek word meaning 'difficult to get at,' that the searchers for another element a century ago found it 'difficult to get to California.'"

The *Manhattan District* of the U. S. Army Engineers camouflaged well the giant wartime operation. The name of the town of *Oak Ridge* itself is a cover name. After the location was found which satisfied the requirements, a name was sought which would not arouse suspicion. One of the ridges in this hilly area was called Blackoak Ridge, and therefore the name Oak Ridge was chosen as being sufficiently bucolic and general to be used as a cover name for the residential area. The plant operations were called *Clinton Engineer Works,* after the nearby town of Clinton.

The *Metallurgical Laboratory* of the University of Chicago was another innocuous cover name; of course, its scope greatly exceeded the field of metallurgy. It was the precursor of the present Argonne National Laboratory. It is of interest to recall how this institution acquired its name after the war. As the Laboratory outgrew its campus facilities, additional space was provided in a wooded area belonging to the Cook County Forest Preserve District. These preserves being named after famous World War I battlegrounds, the site in question was called Argonne Forest. Although the newly created national laboratory was established at a new site after the war, some distance from its Argonne Forest, for sentimental reasons it has retained the wartime name. The District's activities at Columbia University carried the name *SAM*, an acronym for Substitute Alloy Materials.

Browsing through the lists of index headings, abbreviations, nicknames and acronyms, one learns that *Mighty Mouse* represents a proposal for a heterogeneous enriched-uranium heavy-water-cooled and moderated research reactor, related to the Argonne Advanced Research Reactor, or A^2R^2, and that *Juggernaut* is the Argonne Low Power Research Reactor. Much work went into creating acronyms with special meaning, as witness the early high-speed computer at ORNL, the *ORACLE* (Oak Ridge Automatic Computer Logical Engine).

Attempts were made to systematize code designations. For example, the underground nuclear tests at Los Alamos were designated first by names of burrowing animals such as *Bandicoot, Bobac, Aardvark,* etc., a seemingly appropriate category. Eventually, however, the list was exhausted, and subsequent test series were named after fish, birds, colors and even alcoholic drinks.

During the war, code names were needed for the actual sites of the large projects. Oak Ridge, Hanford and Los Alamos were designated *Sites X, W* and *Y.* At Berkeley, the Oak Ridge Y-12 plant was known as *Shangri-La.* The DuPont group in charge of the X-10 site where ORNL is now was part of the Explosives Department of that company, and was called the TNX Division, although this had nothing to do with the explosive trinitroxylene.

Whimsy

Sometimes, new terms have been introduced into the language because somebody deliberately tried to be funny. Thus, an Oak Ridge waste tank concentration plant carried a sign for a while after the war, *Lower Slobovian Distillery,* after the "country" popularized by the cartoonist Al Capp; this was too much, however, and a superintendent who was not amused removed it.

At Los Alamos, at the Kappa site there were installations called *Eeny, Meeny, Miney* and *Lower Slobovia,* the latter apparently for its isolation.

Reactors are the most impressive and exciting devices of the nuclear age. Let us examine reactor name compilations to see how they were acquired.

Many of the names given to reactors during the last two decades have been quite prosaic; they are simply initials of rather unimaginative identifying terms. The first one was the historic *CP-1* (Chicago Pile #1); eleven months later the first true reactor, with a sizable power level was in operation. This was the *X-10* reactor, now a registered national historic landmark. Going through the series as listed in various compilations, we encounter names that do not stir the blood of the reader: *MTR* (Materials

Testing Reactor), *BWR* (Boiling Water Reactor), *PWR* (Pressurized Water Reactor), or, to use local examples, *ORR* (ORNL Research Reactor), *TSR* (Tower Shielding Reactor), *HFIR* (High Flux Isotope Reactor), *LITR* (Low Intensity Testing Reactor) and so forth. These groups of letters are easily forgotton by all except people who use them constantly.

More imagination was used in the early days. Let us take the plutonium-fueled reactor, which was under construction in one of the canyons at Los Alamos. One of the scientists who was transferred kept wondering about the progress of the project but for reasons of security could not ask about it openly. The location of the project and the material they worked with (49) suddenly recalled to him the old prospector's song:

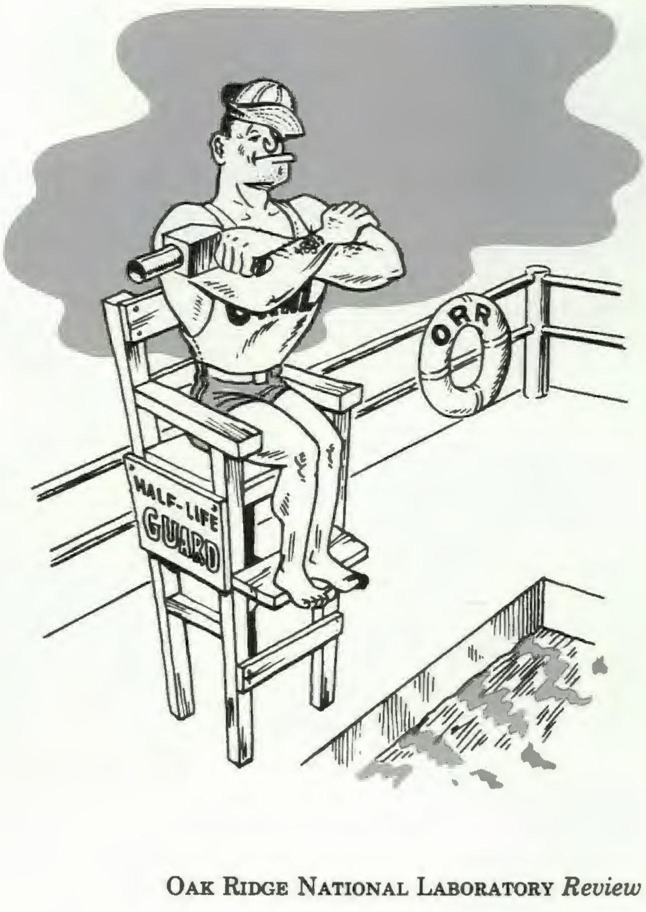
"In a cavern, in a canyon, excavating for a mine,
Lived a miner, forty-niner, and his daughter Clementine."

He sent a telegram: "How is my darling Clementine?" The message was understood and the reactor became known as *Clementine.*

There are other colorful examples of Los Alamos names: *Jemima* consisted of stacked flat plates which evoked the well-known brand of pancake flour; *Jezebel* was "mean and hard to handle;" and *Topsy,* like the character in "Uncle Tom's Cabin,"—she just grew. One of the best known among the Los Alamos reactors is the one, built without reflectors, which operated with fast neutrons: the bare and fast *Godiva.* More recently, a highly descriptive name was employed to designate a reactor prototype of the nuclear rocket project, used for so-called "captive firing" tests. The *Kiwi,* a reactor designed to propel a rocket but held on the ground, was very aptly named after the flightless New Zealand bird.

The acronym of the South African Fundamental Atomic Reactor Installation, although obviously contrived, gives the flavor of the mysterious continent. Although European acronyms for their reactors are sometimes forced, the resulting words often have meaning. The British have *Dido* (named because it was heavy-water moderated, DDO or D_2O) and *Zephyr* (Zero Energy Fast Reactor); the French Reactor, *Mélusine,* on the other hand, was named after a fairy. One needed some knowledge of mythology to recognize that the plutonium-fueled reactor experiment *Proserpine* was named for the wife of Pluto. The first French zero power reactor was called *ZOE* after zero (power), oxide (of uranium) and eau lourde (heavy water). The French sodium-cooled, fast reactor is called *Rapsodie,* from the first syllables of the official descriptive terms "rapide" and "sodium;" the breeder reactor mockup at the Cadaráche Nuclear Center (France) is known as *Masurca,* a compression of its formal name Maquette Surregeneratrice Cadaráche, which recalls the Polish dance. The international collaboration in Europe was emphasized by the name of the Cadaráche fast reactor, *Harmonie.*

The name *Aquarium* was an obvious one for the Los Alamos critical facility, immersed in water; it also designated the design, construction and operation of a swimming-pool type reactor for the First Geneva Conference in 1955 (cf. *Review,* Winter 1968). The term *swimming pool reactor* was used at ORNL for its own reactor prior to this conference; it was a logical expression to designate reactors placed in a water-filled rectangular hole which looked like a swimming pool. It was feared that this less-than-serious term might be misconstrued by the public, and so the reactor was officially named the *Bulk Shielding Reactor.* Although the term *swimming pool* was removed from the official papers submitted



to the Geneva Conference, newsmen got hold of it and no censorship could prevent references in various languages to the swimming pool reactor: *réacteur piscine, Schwimmbadreaktor,* etc. Today, *pool-type reactor* is a generic term.

Argonne National Laboratory's family of reactors are called *Argonaut* for Argonne Naught Power Reactor. It is of interest to note that the modern Argonauts also crossed the sea and established a colony of such reactors in Europe: there are *Jason* reactors in England and Holland.

Most of the Soviet reactors carry alphabetic designations, but there are examples of more colorful names. The organic-cooled *Arbus* has a name close to the Russian word for melon (arbuz). The *Romashka* reactor of the Kurchatov Institute in Moscow is named for the Russian word for daisy; indeed, the design of its fuel elements resembles flower petals.

Colorful terms are still being invented. The Tennessee Valley Authority announced recently that containment structures of its new Sequoyah Nuclear Power Plant near Chattanooga will be lined with five million pounds of ice cubes. It was unavoidable that the press would call it *Reactor on the Rocks.*

The thermonuclear researchers seem to lean toward humor and mythology when naming their facilities. We must admit, however, that the name of ORNL's *DCX* machines, standing for Direct Current Experiment, is not as colorful as that of the Los Alamos toroidal pinch experiment *Perhapsatron* or the magnetic mirror experiment, *Scylla.* Fusion research is fraught with obstacles as were Ulysses' voyages; we can expect sooner or later the appearance of a machine called *Charybdis.* And as thermonuclear fusion tries to imitate what's happening on the sun and other stars, it is natural that the technology has devices named *Stellarator* or *Astron.*

There are several (apocryphal) stories about the origin of the code name for the thermonuclear fusion program. According to one version, a scientist said to another: "It would be good to make the fusion energy of the sun available to mankind." The other replied,"It sure would." Thereupon the undertaking was dubbed *Project Sherwood.*

The cyclotron at Saclay, France, is encircled by a large ring; it was therefore logical to call it *Saturne.* The name of *Nimrod* at Harwell, England, indicates that it is used for hunting or searching. Familiarity with American television is revealed by the names of a German accelerator and a Swedish one, *Desy* and *Lusy;* they stand for Deutsches Elektron Synchrotron and Lund Synchrotron, respectively. Other acronyms of these interesting devices include our own *ORIC* (Oak Ridge Isochronous Cyclotron), and *ORELA* (Oak Ridge Electron Linear Accelerator); *LAMPF* (Los Alamos Meson-Proton Facility) and *TRIUMF* (Tri-University Meson-Meson Facility) in Vancouver. A fourth university has joined the original sponsors, but it is unlikely that the acronym will be changed. The names of *Bevatron* at Berkeley and *Cosmotron* at Brookhaven National Laboratory emphasize the tremendous size of these machines.

The energy level, of course, is a very important feature of accelerators; nowadays it is given in terms of billion electron volts, or BeV. However, "billion" is a false friend which confuses the trusting reader: it means thousand million in the United States and million million in most of the rest of the world. Therefore the prefix "giga-", abbreviated to G, was adopted for the factor of 10^9, and BeV became GeV. In this connection, it has been reported that Professor Victor Weisskopf of MIT, a former director of the European high-energy research center CERN, in Geneva, Switzerland, started to say in a speech, "GeV – oh, I'm sorry; over here I have to remember to use Brookhaven electron volts." He thus gave an excellent mnemonic rule: Geneva electron volts and Brookhaven electron volts, for use in Europe and the U.S., respectively, to indicate 10^9 electron volts.

Wartime Code Names

In addition to the previously mentioned Tuballoy and Oralloy, there was also, by analogy, *Myrnalloy,* for thorium, based on the name of the motion picture actress. *Hex* was uranium hexafluoride (usually enriched), while *D-38* indicated uranium depleted in the 235 isotope. The term *derby* indicated an ingot of depleted uranium received from the metal reduction plant. Fissionable materials were shipped in containers held in a *birdcage* to prevent their stacking and creating a critical mass. This highly descriptive term is still used.

Codes in use at the Gaseous Diffusion Plant included *L-28* for liquid nitrogen and *H-24* for helium (based again on the atomic number and weight). The production of the plant was reported in units of *kegs of eggs* standing for kilograms of X (or ^{235}U). The center of the K-33 cell floor was called *5th Avenue and 42nd Street,* while the K-29 spread was referred to as the *Ponderosa.* Many of these terms outlived their usefulness, but the expressions *green salt* and *orange oxide* are still used for uranium tetrafluoride and trioxide, respectively.

At the Electromagnetic Separation Plant (Y-12), the letter *F* designated calutron ion beam; *calutron* itself was a contraction of the words California University and cyclotron. In that plant, the ^{238}U isotope was indicated by the letter *Q,* and ^{235}U by *R; M* designated the calutron source and *E* the calutron receiver, while *Z* was the system's magnetic field. The *track* was the complete magnetic system containing many calutrons, and *cubicle* referred to the power supply and control center of an individual calutron. *Alpha* separation referred to a first pass in the process on the 48-inch radius machine, and *beta* separation to the second pass on a 24-inch device.

A *dee,* because of its shape like the letter D, indicated the alpha 1 calutron source, receiver and linear assembly; the term *bin* referred to the calutron's vacuum chamber and the *Mae West* was its electron drain system component. In that plant the liquid nitrogen (atomic number 7, atomic weight 14) was designated by *714.* Cooling was very important; there was a special code *(753)* for the condensation trap using carbon dioxide and a solvent. The *sump* was a calutron receiver for decelerating and collecting the ion beam and *slug* (also used to designate the short, aluminum-clad uranium rods of the X-10 reactor) indicated a one-unit mass separation in the electromagnetic process.

Crud (supposedly originally standing for Chalk River Unidentified Deposit) was a secret word at the Y-12 Plant.

New Terms for a New Science

New concepts in the field of nuclear physics made it necessary for the scientists to invent new terms. In cross section measurements the expression *barn* was introduced. This small surface, 10^{-24}cm^2, is "as big as a barn" for nuclear processes. The well-known neutron cross section compilation, BNL-325, has the picture of a barn on its cover and is popularly known as *The Barn Book.*

The first studies of chain reaction were made with uranium and graphite blocks that were stacked, or piled, whence the term *pile,* recalling the voltaic pile, the original primary battery, which consisted of a series of alternating copper and zinc disks, with disks of cloth moistened with an electrolyte between them. Later it was decided to use the more euphonius term *reactor.*

Another term, this one still widely used, became part of the technical language at the birth of the atomic age. During the experiment that culminated on December 2, 1942, in the accomplishment of the first controlled nuclear chain reaction, a safety rod was held by a rope running through the pile and weighted on the opposite end. The young physicist in charge was told to watch the indicator; if it ex-

ceeded a certain value, he was to cut the rope and scram. Since then the term *scram* is used to designate the emergency shutdown of a reactor. Today the urgency is lost and the word scram indicates simply a fast-shutdown operation.

The term *cross section* was mentioned above. In its new meaning, it is "a measure of probability of a specified interaction between an incident radiation and a target particle;" it has the dimensions of area. The words *dollar* and *cent* have nothing to do with money; they represent a unit of reactivity equal to the difference between the prompt critical and delayed critical conditions of the reactor. The term *rabbit* designates a device to move radioactive samples from the reactor to the laboratory or to send specimens for short periods of time through the reactor core; the opening through which it entered was naturally called the *rabbit hole.* After having been for years the exclusive property of nuclear engineers, the new meaning of this word has been listed by dictionary editors, but one must be careful when translating it into other languages.

Milking refers to the continued removal of a daughter radioactive decay product from the parent. *Breeding* indicates conversion when the conversion ratio is greater than unity. When the reactor man speaks of *sandwich* and states the thickness of the *meat,* he is referring to the uranium-aluminum alloy fuel, covered with a sheet of aluminum; the meat is the central, fissionable material. *Decladding* is the removal of the protective coating from the fuel element, usually by chemical means. If the operation is carried out mechanically, it is called *dejacketing.*

Chemical processing also developed its special expressions. A *direct strike* referred to the addition of a phosphate anion to form bismuth phosphate which carried the plutonium; in the *reverse strike* the phosphate was added to a uranium solution containing plutonium, after which the bismuth carrier was added. The plutonium concentration was designated *x-level* and *w-level* depending on the plant or site, while the difficulty arising from handling plutonium was called the *alpha problem.*

There were a number of extractive separation processes with names ending in "-ex," e.g., *Thorex, Elex, Purex,* etc.; otherwise, the chemists and chemical engineers used mostly the terms of their own field. Handling radioactive materials brought into the language the term *hot,* and as with "honest-to-God silver" occasionally care had to be taken to specify that the solution was *thermally* hot. Today "hot" means "highly radioactive," but *hot atom* indicates "an atom in an excited state or having kinetic energy above the thermal level of the surroundings, usually as a result of nuclear processes."

Let us look at the nuclear language from another viewpoint. The emotional impact of certain words is well known. It is surprising how many such "loaded" words are used in the nuclear field. People were afraid of anything atomic to start with because of the awesome origin of the field; the terminology developed by the practitioners did not alleviate this feeling. The public's suspicion and confusion is understandable when one reads about *mean life, dead time, excited state, burnup, burnout,* even though these terms are used to designate "innocent" technical concepts. Further unpleasant imagery is conjured up by expressions such as *neutron capture* and *master-slave manipulators.*

William E. Shoupp, a former president of the American Nuclear Society, feels that the nuclear industry bears a great portion of the responsibility for the fact that the public misunderstands its true nature, its promise of a brighter future; he squarely attributes this to the unfortunate choice of terms used by practitioners of nuclear engineering and science. In his widely acclaimed speech as outgoing president, he eloquently described the misinformation, ignorance and confusion of the public. He cited a public-opinion survey of teenagers who, even though they had not been born when the atomic bomb was dropped, associated atomic energy with war and not peace. In spite of the excellent safety record at the national laboratories and major research centers, people are afraid of reactors, as shown by citizens' protests whenever new projects are planned. This reaction is reinforced by words conveying an unpleasant connotation. He decried the use of terms such as *maximum credible accident* and asked why reactor engineers must talk about a *hazards report* instead of a *safeguards report.* He pointed out, as have others before him, that the nuclear jargon is filled with gloomy, funereal terms: fuel elements are transported in *coffins* and reactors are *poisoned* to control them. It is indeed unfortunate that we use expressions like a reactor *going critical* and carrying out *critical experiments* in a *critical facility.* To the layman the word "critical" means that the patient is very sick, but for some reason, it is associated with the healthy functioning of reactors. Contaminated items are disposed of by taking them to *cemeteries* or *burial grounds.* The previously mentioned "scram" does not help either, as it implies "run like hell!"

Although many of us still remember the birth of the atomic age, it is fast becoming history. We should not lose the opportunity to examine carefully the linguistic residue of a giant national and international effort while many persons who can shed light on certain facets of the scene are still alive. Such an effort could usefully complement the work of the Historical Advisory Committee of the Atomic Energy Commission.

I cannot claim to have done justice to the language of nuclear science; it is impossible to cover all facets and ramifications of the trade jargon of this highly specialized field. I have tried to point out the impact of the vocabulary on our feelings: the same words that arouse fear and suspicion among the public stir feelings of pride and nostalgia among the practitioners.

A new "language" has been developed in the relatively short time of a quarter of a century. Although the field is not the youngest any more, it still dominates international politics and people who plan the future of mankind count on its resources. What the politicians, the planners, and, especially the scientists and engineers have to say must be clearly understood by everybody.

In his book, "The Intelligent Man's Guide to Science," (Basic Books, Inc., New York 1960) Isaac Asimov underlines the obligation of scientists to society and to their colleagues to make themselves understood. They must make sure that they will not lose touch with non-scientists, that science will not appear as "incomprehensible magic."

I would like to close by citing the now famous telephone conversation between Arthur Compton in Chicago, after the first self-sustaining chain reaction was achieved, and James B. Conant at Harvard. It heralded the beginning of a new age for mankind, and it was instantly understood although the code was not prearranged.

"The Italian navigator has landed in the new world," said Compton.

"How were the natives?" asked Conant.

"Very friendly."

For several years, beginning in 1956, Landry was a member of a group of ORNL researchers engaged in nuclear explosion studies at the Nevada Test Site. They conducted experiments on sampling and isotope recovery in connection with test shots performed in Nevada in 1957 and 1958, and a Plowshare shot in New Mexico in 1961. In 1960, Landry completed a course in "Nuclear Explosives for Excavation and Construction" at the University of California (Berkeley). Under the auspices of the Chemical Technology Division and the ORNL Traveling Lecture Program, and additionally on invitation, he has delivered more than a hundred talks on the subject of peaceful uses for nuclear explosives. The result of these experiences has been a growing personal conviction with regard to the potential for good in the Plowshare Program. The following article traces his thinking along this line.—Editor's note.

The Case for Plowshare

By John Landry

An engineer cites some of the reasons for his conviction that civilian use of nuclear explosives holds promise for many world benefits.

SINCE 1943, the exigencies of hostile competition have caused much of the development effort on energy to be appropriated on swords. As worldly creatures, and more, we are obliged to attend both to self-preservation and to the good of our neighbor. It is poetic, therefore, that the sword forged from the new knowledge can now be seen as a vast instrument for more good in the world than most of us ever imagined possible.

The United States and Russia have stockpiled an amount of nuclear weapons equivalent to ten tons of TNT for every man, woman, and child in the world. During weapons development, however, many observed effects suggested a variety of peaceful uses for nuclear explosives.

After the world's first thermonuclear detonation was conducted on Elugelabium Island at Eniwetok Atoll in 1952, some of the debris was processed at Berkeley to yield the discovery of einsteinium and fermium, elements 99 and 100. Some of the early nuclear explosives that were tested at Bikini and Eniwetok excavated large craters.

John Landry came to Oak Ridge in 1944, shortly after receiving his degree in Chemical Engineering from the University of Wisconsin. He is at present on loan to Y-12 from the ORNL Chemical Technology Division. His interest in Plowshare dates from 1956 when he went to the Nevada Test Site as ORNL representative to prepare for research, which he later conducted, on the first underground nuclear test, the Rainier shot, detonated in September of 1957. He is shown here in conversation with Edward Teller, right, of Lawrence Radiation Laboratory at Livermore, Cal. Teller, known as the father of the hydrogen bomb, has long been a proponent of Plowshare.

Since then many constructive uses of these powerful sources of energy have been suggested: excavations for canals, dams, storage reservoirs; recovery of natural gas and oil; production of industrial chemicals. The list expands with the study. Not to be ignored is the value to researchers of the intense neutron flux that results from a nuclear detonation. The most obvious use, however, and probably the one that will be accomplished with the largest economic gains, is earth moving. Indeed, geographic engineering is one of the most exciting debutants of the Plowshare Age.

During the Suez crisis of 1956, the possible use of nuclear explosives for excavating an alternate canal was considered at the Lawrence Radiation Laboratory (LRL) at Livermore, Cal. The Rainier weapon development experiment in Nevada, detonated September 19, 1957, was the first underground, contained, nuclear explosion. The experiment laid the groundwork for measurement, prediction, and understanding of underground nuclear explosion phenomena. The resulting chimney of rubble was later investigated by drilling and tunnel reentry and the feasibility of the block-caving method of nuclear mining was demonstrated.

Plowshare is the American research and development program for realizing these industrial and scientific applications of peaceful nuclear explosives. It is organized to foster national and international participation. The U.S. AEC formed, in 1961, its Division of Peaceful Nuclear Explosives (DPNE). This new division assigned the technical direction of its Plowshare Program to the University of California's LRL.

At the request of AEC and LRL, in 1956, Oak Ridge scientists in the Chemical Technology and Engineering and Maintenance Divisions designed, built, and installed remote sampling and handling equipment for studying products of the Rainier test shot. Members of these divisions and of Instrumentation and Controls Division performed similar roles in isotopes-producing experiments in the Tamalpais shot in Nevada in 1957 and in the Plowshare Project Gnome experiment near Carlsbad, N.M., in 1961. Although Rainier and Tamalpais were not Plowshare shots the technology that ORNL scientists helped develop for recovering products of nuclear explosions was of value in the Plowshare program. They designed, built, and installed prompt samplers on the ends of long, straight, evacuated pipes aimed

Sedan crater hours after 100-kiloton detonation of second Plowshare shot, July 1961. Photo courtesy U. of Cal. Lawrence Rad. Lab. Nev. and USAEC.

in the detonation chamber to receive the neutron-irradiated target material. A sequence of samples from the pipe were valved in 50-microsecond intervals into collection tanks. The valves were explosive-operated and were produced in a joint task of ORNL and Frankford Arsenal. For the proposed follow-on experiment, Project Coach, the Chemical Technology Division developed a radiochemical process flowsheet for recovering isotopes to be produced by a nuclear detonation in a salt formation. At present the Chemical Technology Division is pursuing chemical and engineering research directed toward the use of nuclear devices in the recovery of copper from ore deposits and in the recovery of oil from shales. The ORNL Health Physics staff is helping in bio-environmental and radiological-safety feasibility studies for Gasbuggy, an experiment now in progress to investigate the possible recovery of natural gas from underground formations, and also for the Atlantic-Pacific interoceanic canal. The ORNL Analytical Chemistry Division is setting up equipment to analyze for tritium and other components in the products from nuclear-stimulated gas wells.

Many branches of our government and industry participate in the program. A few examples, besides ORNL, are Los Alamos Scientific Laboratory, the U.S. Bureau of Mines, El Paso Natural Gas Company, and Kennecott Copper Company. CER Geonuclear (owned by Edgerton, Germeschausen and Grier, and Continental Oil Co.) and Gulf General Atomic, Inc., are examples of companies providing nuclear blasting service to industry. The Plowshare program is largely unclassified, except the information pertaining to the explosive device. Observers from other nations have attended some of the experiments, and the AEC cooperates with nations inviting its consultation regarding Plowshare applications to their needs. The average annual operating budget is about $16 million, or about two-thirds of one percent of the total AEC budget. To put this in another way, of each 365 days of government-financed atomic effort, a total of 1.5 days is appropriated to the Plowshare program, including a ten-minute ORNL contribution.

As membership in the so-called "H-Club" grows, Plowshare becomes more and more of worldwide interest. Russia is leading in the peaceful applications of conventional explosives and is believed to be interested in constructive uses of nuclear explosives. There may be misgivings that Plowshare could be used for weapons development, but when these are allayed, many parts of the world stand to gain by Plowshare applications. The program is sure to figure in the important non-proliferation treaty just ahead. As nations negotiate a treaty that is predominantly negative, Plowshare provides an item that is positive: it might well be the focus of agreement.

The Instrument and Its Cost

Consider the great potency of these power packages that come in a wide range of energy yields. A nuclear explosive is measured in terms of the amount of TNT its energy release simulates. Thus, a megaton device releases as much explosive energy as a million tons of TNT. Plowshare nuclear explosives come in energy yields that range from around 10 kilotons up to a possible 10 megatons.

Radioactivity is a gradually diminishing drawback to the use of peaceful nuclear explosives. In excavation applications such as canal building, the explosion vents to the atmosphere. Because introduction of fission products into the atmosphere is to be avoided, Plowshare explosives are being developed that employ the fusion reaction instead of the fission reaction. This minimizes the problem from fission products but does not solve it completely because the thermonuclear device requires a fission "trigger" to ignite it. Hence, some fission products will be present after detonation of the explosive. Although the thermonuclear explosion itself produces no fission products, it does produce tritium and it also produces radionuclides when the neutrons released in the process react with some elements in the surrounding environment. The fission component in these thermonuclear explosives is being made very small and the devices can be shielded by borated compounds to reduce the neutron activation. In other Plowshare applications, like mining for instance, the explosion is contained underground. In some of these cases fission products might be more tolerable than tritium and an all-fission device might be used. Ways are being found to reduce the amounts of radioactivity released to the biosphere enabling planning for more extensive use of Plowshare explosives in construction projects. The technology is now well enough understood that if we are careful where we shoot and how we shoot we can begin enjoying benefits of constructive nuclear explosives today. Refined nuclear excavation technology is available, but the possible effects of radioactivity, ground shock and aerial blast must be determined for the particular site of an excava-

If a megaton of energy is defined as the quantity (10^{15} cal) yielded by a 1-megaton detonation, some comparisons can be made. As mechanical energy it could raise the weight of Norris Dam 150 miles. By an additional 9 megatons of energy, this million-ton mass then could be accelerated to 17,000 mph, or orbited. As heat, one megaton of energy will boil into steam an amount of water that would float a fleet, a volume of water equal to the displacement of 21 Queen Elizabeths (83,676 tons). A megaton fusion explosion would produce about 10^{27} neutrons. This 1-megaton nuclear detonation produces this many neutrons in less than a millionth of a second. In 1964, a 30-kiloton experimental Plowshare isotope-making device ejected into each square centimeter of its target the same number of neutrons that it would take the ORNL High Flux Isotope Reactor over thirty years of continuous operation to deliver to each square centimeter of its targets. In fairness to the HFIR, it can be mentioned that the target-recovery problem is different.

tion project. A thorough investigation of a proposed site therefore is mandatory and the public safety must be ensured before plans for a project at that site may proceed. If safety is not ensured, either a new site must be selected, or the project postponed or abandoned.

The larger nuclear explosives are very economical. Thermonuclear, or fusion, explosives are generally preferred to fission explosives for their economy as well as the more obvious reasons. The AEC has released projected charges for thermonuclear explosives. These projected charges are $350,000 for a nuclear explosive with 10-kiloton yield and $600,000 for a nuclear explosive with 2-megaton yield. The charges cover the nuclear materials, fabrication and assembly, and arming and firing service. They do not include safety studies, site preparation, transportation and emplacement of the explosive, and support. For the requisite public-safety survey conducted by the Government there would be a related service charge. These figures, issued for estimating purposes only, are based on a projection to a time when explosives will be produced in quantity for routine commercial utilization and are based on an explosive design suitable for excavation-type applications. By comparison, 10 kilotons of conventional explosive (TNT, nitromethane, ammonium-nitrate) costs about $1 million, and two megatons about $200 million.

Excavation with small nuclear explosives at present is not economically compelling. The cost of excavating rock and dirt by a single 10-kiloton nuclear explosive is calculated to be around $2/cu. yd., as compared with large-scale excavation by conventional methods at 25¢/cu. yd.

Excavation with large nuclear explosives, however, costs only a few percent of conventional excavation cost. A 2-megaton nuclear explosive buried about 1,330 ft. in hard rock would excavate about 72 million cu. yd. and yield a crater about 2,600 ft. in diameter and 750 ft. deep, large enough to create a harbor. The project cost for this shot would be around $2–3 million, bringing the cost of nuclear excavation down to around 3¢/cu. yd.

Nuclear explosives do not compete with conventional explosives and conventional excavation; they take over when these leave off. In excavating with conventional explosives the explosives usually are used only to break the rock; the broken rock is loaded and hauled away. Nuclear explosives at

Dr. Teller has mentioned the following example of the imaginative scientific experiments that may be made possible by the instruments to whose creation he has contributed so much. A thermonuclear device would be rocketed on a course that would carry it to the back of the sun as seen from the earth. It would be detonated as it crossed the sun's horizon. A comparison of the detonation pulse parameters, i.e., wave lengths of radiation, times of arrival, and the sun's gravity and electron fields, might provide new insight into subjects currently in controversy.

once break up the rock and remove it by ejecting it over the lip of the crater.

Nuclear explosions, when detonated deep enough in the ground to be fully contained, can economically break up rock. A Russian engineer at Expo 67 mentioned to me that a nuclear explosion in his country produced aggregate used in constructing a dam. If the 2-megaton device is buried a mile or deeper, it will not produce an excavated crater. Instead, it produces a large cavity which then collapses, leaving a broken zone. Depending on the rock type, the zone is about four to five cavity-radii high and contains in the order of a hundred million tons of broken rock. This tall, cylindrical zone of broken rock is called a "chimney." In granitic rock, for instance, the chimney is extremely permeable and has been observed to have about 25% void space with 75% of the fragments smaller than 12″ diameter.

Under favorable circumstances, depending on geology and petrology, over 90% of the radioactivity in nuclear chimneys is fixed in an insoluble glassy melt buried at the bottom of the chimney. Furthermore, the broken rock of the chimney often contains zeolitic minerals with exchangeable calcium and sodium; fission products prefer residency in these rocks to any ground water that may be present, by an average factor of 100 to 300. The fission products move slowly and don't go far. Creation of the initial cavity often crushes and compacts the rock surrounding the chimney, leaving this rock impermeable to water, and to a degree isolating the chimney from ambient ground water. These are a few of the many variables controlling the course of the radioactivity which must be investigated for the individual site of a proposed project.

Subsidence cratering minimizes the risk of radioactivity release. Our explosive can be buried at intermediate depth so that the broken zone, or chimney, extends to ground level and, if the rock is a type that does not bulk appreciably on breaking, a subsidence crater may result. Providing the rock has the requisite qualities, a linked row of these craters has been suggested as a possible means of forming a canal. The earth is compressed and displaced around the base of the chimney, the chimney rubble consists of collapsed and slumped material, and the radioactivity is fixed in an insoluble glass on the floor of the chimney or absorbed in the rubble.

Nuclear Canals

The Panama Canal locks, which have overall dimensions of 1,000 ft. by 110 ft. by 41 ft. depth of water, deny transit of the canal to over 300 commercial vessels and 24 United States Navy aircraft carriers. The 14,000-manpower requirement to operate the canal at present amounts to an annual payroll of $43 million. It is estimated that before the year 2000 the increase in canal traffic will exceed the capacity of dams and associated water supply facilities to supply enough water to operate the locks, and additional water will have to be pumped from the sea. Economic, strategic, and political considerations indicate that a sea-level canal across the isthmus would be much more satisfactory than the present lock canal. Its advantages are that ships can transit in about half the time, there are no size restrictions on vessels, the estimated manpower re-

"Economic, strategic, and political considerations indicate that a sea-level canal across the isthmus would be much more satisfactory than the present lock canal."

quirement is about 700, and it is almost invulnerable to destruction by sabotage and attack. The costs of converting the present canal to a sea-level canal and of building a sea-level canal 100 miles to the east with conventional construction methods were estimated in 1964 to be $2.2 billion and $5.1 billion respectively. The costs were then estimated for the nuclear explosive approach.

The route used in the comparison study is 48 miles long and runs from San Miguel Bay on the Pacific Ocean to Sassardi Point on the Caribbean Sea. It crosses the Continental Divide where the elevation is 1,080 ft. According to LRL's isthmian canal studies of 1964, an estimated 302 nuclear devices varying in yield from 100 kilotons to 10 megatons would be required to excavate the canal.

The estimated cost of this nuclear canal includes several items. First there are site surveys to be paid for. Then there must be studies to determine not only the topography, but also the meteorology, ecology and hydrology of this little-known region because these affect the final disposition of the involved radioactivity. The ecology must be known as well for evaluating the effects of opening a ditch between tropical seas. Engineering surveys are needed. About 35,000 or more natives must be relocated to new villages, an estimated 245 miles of roads must be built, and the work force of 650 persons requires a town to be constructed. Harbors and breakwaters are also included in the cost estimate, but no treaty or defense costs are included. The estimated total cost of the nuclear-dug canal, constructed in one-fifth the time, is $747 million, or about a sixth that of a new canal by conventional means.

The Atlantic-Pacific Interoceanic Canal Study Commission, appointed by the President under Public Law 88-609, is currently engaged in evaluating the case for a sea-level canal.

Natural Gas Production and Storage

Natural gas companies are enthusiastic about their Plowshare prospects. The San Juan Basin of Colorado and New Mexico is underlain by a rock formation that contains an estimated 33 million cubic feet of gas under each surface acre. The El Paso Natural Gas Company (EPNG) among others recovers about 10% of the contained gas over a 20-year period by sinking wells into the formation. Recovery is low and slow because the producing formation is tight, which is to say that it contains fine pores that are partially clogged by clay and other cementing materials. EPNG is of the opinion that its gas wells might be stimulated with nuclear explosives, increasing recovery to 66% and meeting peak-flow requirements. The anticipated additional gas production returns about 50 times the energy from the expended nuclear devices. These explosions convert 100 yards or more in the length of each well into a broken zone, or chimney. They thereby may accomplish three things: They may expand the effective well bores, through which gas permeates into the wells, from several inches to several hundred times as much; they may improve the gas permeability of this surrounding formation by producing cracks and microcracks for hundreds of yards beyond the chimneys; and, because there are voids between the chunks of broken rock in the chimneys, they may provide gas storage reservoirs to meet peak demands.

The amount of contaminated gas involved in this scheme does not appear to be prohibitive. The gas originally present in the chimneys will be contaminated and must be sacrificed. However, only a few percent of the production would be lost because, it is estimated, about 97% of the gas production would come from the rock formation surrounding these chimneys and not the chimneys themselves. Only the shock waves and little, if any, of the radioactive products of the nuclear detonations would be expected to act on the formation outside the chimneys.

America's first industry-government cooperative experiment with industrial nuclear explosives was Project Gasbuggy. EPNG, the AEC's Nevada Operations Office, and the Department of the Interior, with LRL as scientific advisors, detonated a 26-kiloton nuclear explosive 4,240 feet deep in the EPNG gas field, 55 miles from Farmington, N.M., on December 10, 1967. The $4.5 million maiden experiment produced a chimney about 155 feet in diameter and about 335 feet high containing about 2 million cubic feet of voids. The chimney is producing a steady half million cubic feet of gas per day while holding pressure of 870 psi.

Gas storage reservoirs are another Plowshare possibility attracting the natural-gas companies. America's increasing concern with the environmental pollution problem is shifting the country's fuel consumption from coal to natural gas, which contains less sulfur. Fifty to 75% of all U.S. gas delivery is from storage. U.S. gas storage capacity currently is 4.3 trillion standard cubic feet (scf) and may need to be 14 trillion scf by 1975. Gas storage facilities are needed near the consumer, i.e., near the population centers. However, most of the present storage is in underground reservoirs in depleted gas fields in the West. New England and the Southeast have no underground gas storage

Nuclear dredging of harbors, such as the one recently approved for study in Australia, is illustrated in this schematic plan for a hypothetical waterfront excavation (U. of Cal. LRL-AEC drawing).

reservoirs. A 50-kiloton nuclear chimney as a gas storage reservoir would cost about $1.40 per 1,000 scf capacity; this is half or less than half of the present cost of gas storage in the East.

On August 28, 1967, Columbia Gas Systems Service Corporation proposed Project Ketch. Ketch would involve a 24-kiloton shot 3,300 feet deep in a shale formation. A proposed site was near a gas line in the middle of Pennsylvania 20 miles north of the Penn State campus. Other sites in Pennsylvania and West Virginia are being considered, too. The proposal calls for an 8-month safety study; as soon as public safety could be ensured, there would follow a 5-month construction period leading to the shot. The proposed overall project time was 45 months. The cost of this experiment, estimated at $6 million, again would be shared by industry and the government. The estimated results would be 2.75 million cubic feet of voids in the chimney of broken rock, yielding a storage capacity of 465 million scf at 2,100 psi and a daily peak deliverability of 90 million scf.

Gas companies are not the only ones interested in making inexpensive storage reservoirs. Nuclear chimneys as water reservoirs have caught Arizona's interest. Also, the nuclear department of the University of Virginia School of Engineering is studying the feasibility of nuclear chimneys with respect to chemical industry waste disposal. Oilfield operators are considering them for their brine wastes.

Oil Recovery

Peaceful nuclear explosives can be used in several other ways to recover oil. Regarding mineral wealth, Uncle Sam's greatest treasure trove is the Green River Oil Shale reserve in Colorado, Wyoming, and Utah. Its two trillion barrels of oil represents about three times the proved crude-oil reserve of the rest of the world today. Oil companies mine the shale and burn it in pilot-plant retorts to recover an average of 25 gallons of oil per ton. At the going price of $2.50 per barrel, the reserve's one and a half trillion barrels of recoverable oil represents a substantial natural resource.

CER Geonuclear Corporation and about a dozen petroleum companies have proposed Project Bronco to the AEC. The Bronco experiment would be a 50-kiloton nuclear detonation at the bottom of a 3,350-ft. well in the oil shale formation 25 miles west of Meeker, Colo. The shot would produce a chimney estimated to be 420 ft. high by 230 ft. in diameter. Air, and possibly some natural gas, would be forced down wells into the top of the chimney, where the shale would be ignited. The hot combustion gas from the fire, as it moved down through the chimney, would pyrolyze the shale ahead of the fire, producing natural gas and oil as mist and vapor. The product would be withdrawn from the bottom of the chimney. The fascination of this nuclear in-place, combustion-gas-retort scheme is the elimination of the present mining and waste problems.

Copper Mining

A method of mining low-grade copper ore is seriously needed. U.S. copper consumption has increased from 1.3 million tons in 1960 to 2.3 million tons in 1966, a 74% increase in six years. Of more concern is the rate of increase, which was 8% in 1961 and 17% in 1966. Our high-grade reserves are depleted. The world has richer reserves that can be developed, but world demand is increasing twice as fast as our domestic demand. Copper has become a strategic commodity; with our strategic-defense stockpile having dwindled from 775,000 tons down to 260,000, the U.S. now sets aside part of domestic production as a strategic reserve. One hundred million dollars per year is invested by the copper companies for exploration but only for reserves that offer reasonable promise of profitable extraction. Just how much copper the U.S. has in its low-grade-ore reserve (less than .5% copper) will be determined only when a new mining technology is tried and proved, giving industry an impetus to explore the extent of this resource.

Nuclear mining may be the answer. Kennecott Copper Company, and others, are leaching old stopes that had been filled with waste rock containing small amounts of copper. Finding this chemical recovery system successful, Kennecott believes nuclear "dynamite" is the means of economically breaking up low-grade copper ore right where it occurs in the ground so that the leachant may be percolated through it and pumped to a precipitation plant to recover the copper. Kennecott has proposed an experiment, Project Sloop, to test the safety, soundness, and feasibility. In Sloop, as in Bronco, the mining and waste disposal problems of conventional mining are minimized. Because of the radioactivity involved, safety hydrology and product marketability are major concerns of the experiment.

Gasbuggy cannister is lowered into emplacement well preparatory to first cooperative government-industry Plowshare experiment (New Mexico, 1966—LRL-AEC photo).

Scientific Applications

Nuclear detonations offer an attractive alternative and complement to reactor synthesis of transuranics and other isotopes. The intense flux and short time of the Plowshare route results in multiple-neutron capture before the chain of synthesis can be broken by a specie with short half-life. Also, the detonation method produces isotopes that lie more on the neutron-rich side of the line of maximum stability. One interesting possibility is the teaming of reactor and Plowshare. The reactor, at present limited to producing isotopes of about mass 259, would relay the target material to its mate in reaching for a goal not attainable by either alone. An exciting possibility is that the postulated region of stability at the higher masses may be attainable by the joint route.

These fastest-of-all pulsed reactors are an excellent source for neutron experiments. Consider the advantages that nuclear explosives have afforded to neutron experimenters who depend on time of flight for separating the supplied neutrons according to their energies: The neutrons are produced in a pulse that is extremely short and well known. Its width at half-maximum is in the range of a few hundredths of a microsecond, and there is a one-to-one correspondence between it and the gamma pulse. Moreover, the flux is sufficient for the flight path to be a quarter-mile or longer, thereby providing good resolution between neutrons of differing energies and between neutrons and background, yet providing a flux that can be measured as a current rather than in counts.

Nuclear explosions have already made a significant contribution to the field of seismology. Offering as they do a controlled shock in which the time and space coordinates, as well as the amount of energy expended, are known in advance, they have provided valuable data to world seismologists. Seismic waves from pre-specified Plowshare shots have been recorded by the seismograph operated at ORNL by W. C. McClain of Health Physics.

Plowshare technology is included in courses taught in the nuclear schools of many American universities. Plowshare is available in elective courses in the curricula of Teller Tech at the University of California (Davis), of Stanford University, and of Georgia Institute of Technology.

The national laboratories have an invitation to participate in Plowshare according to their areas of competence. The AEC wishes to broaden the base of participation in order to gain maximum benefit from these expensive experiments. Representatives of the Commission and LRL, in a special seminar here on April 9, 1957, invited Oak Ridge scientists and engineers to apply their trades, talents, and imaginations toward experiments and applications for peaceful nuclear explosives.

In the years since then, nuclear engineering has found a place among the world's technologies. One of the measures of man's material progress is the amount of energy at his disposal. With research and development at the national laboratories solving the problems of reactor technology, the nuclear reactor has made the energy of the atom available for generating electricity and is being looked to for providing water from the seas. At Lawrence Radiation Laboratory, and elsewhere, r & d proceeds apace to cope with the technical snags of constructive nuclear explosives. In Plowshare lies the hope of applying the abundance of atomic energy directly to some of the world's greatly needed engineering projects too huge to be afforded by today's conventional methods. Let us hope that as the technical problems are solved the international political problems will also be solved. The world may then move toward the benefits promised by Plowshare.


GASBUGGY

THE LABORATORY STATE OF
STATE OF THE LABORATORY
LABORATORY STATE OF THE
OF THE LABORATORY STATE
THE LABORATORY STATE OF
STATE OF THE LABORATORY
LABORATORY STATE OF THE
OF THE LABORATORY STATE
THE LABORATORY STATE OF
STATE OF THE LABORATORY
LABORATORY STATE OF THE
OF THE LABORATORY STATE
THE LABORATORY STATE OF
STATE OF THE LABORATORY