PHERMEX

PHERMEX, a Pulsed High-Energy Radiographic Machine Emitting X Rays, designed and built by members of the staff of the Los Alamos Scientific Laboratory, is a high-current standing-wave linear accelerator which generates intense bursts of x rays for flash radiographic studies of explosive-driven metal systems. A brief discussion is presented of the need for this device and of some of its design features, operational parameters, and radiation output. Several radiographs are shown which illustrate typical applications to studies of fluid flow. A detailed report ("A Pulsed High-Energy Machine Emitting X Rays" by T. J. Boyd, B. T. Rogers, F. R. Tesche, and D. Venable) is to be published elsewhere.

By Douglas Venable

Most particle accelerators have been built to perform certain predesignated tasks, sometimes to assist physicists in unfolding nuclear structure or to generate yet a new genus of particles. There is no exception to this convention relative to the special purpose accelerator at the Los Alamos Scientific Laboratory. PHERMEX was designed and built not by nuclear physicists but by a group whose inherent professional interests lie in fluid dynamics, chemical kinetics, and extreme states of matter. These interests have maintained the rigid objectives and provided the purpose and drive to complete this program successfully. PHERMEX is now operating, performing admirably the tasks for which it was designed. Therefore, perhaps it is time to say more about why this machine was built, how it was built, and what is being done with it today.

Under sufficiently high pressures, matter, which is usually found in the solid state, behaves as a compressible fluid, a concept not at all foreign to modern fluid dynamics. Such pressure conditions are commonly achieved in the laboratory by means of explosives systems. Indeed, pressures of several megabars have been attained at the Los Alamos Scientific Laboratory by means of reflected shock waves arising from colliding plates which were initially driven by explosive charges. The characteristics of fluid flow in such intense shock waves are a strong function of the equation of state of the particular material. This assumes, of course, that states of thermodynamic equilibrium are approached very closely and that identical dynamic and quasistatic compressions correspond to precisely the same pressure. Therefore, with adequate observation, equation-of-state data can be obtained for extreme conditions. As fluids, these materials also exhibit flow instabilities such as those associated with the names of Helmholtz and Taylor. Extremely high-velocity jets frequently develop which behave in spectacular ways. Detonations and detonation-wave interactions, as well as shock waves and shock interactions, fall in this category of relevant high-pressure events. These phenomena are but a few of the many which are of fundamental interest to the Los Alamos Scientific Laboratory. This interest provided the stimuli whose response resulted in PHERMEX.

However, all too often no satisfactory method exists by which these various phenomena may be observed directly. In order to capture a clear physical picture of the state of affairs, observations must be made under severe blast conditions and in very short times so that motion is virtually stopped. One instrument which is reasonably impervious to the violent abuses of high explosives is the x-ray quantum. When suitably detected, say with film, a sufficient number of penetrating

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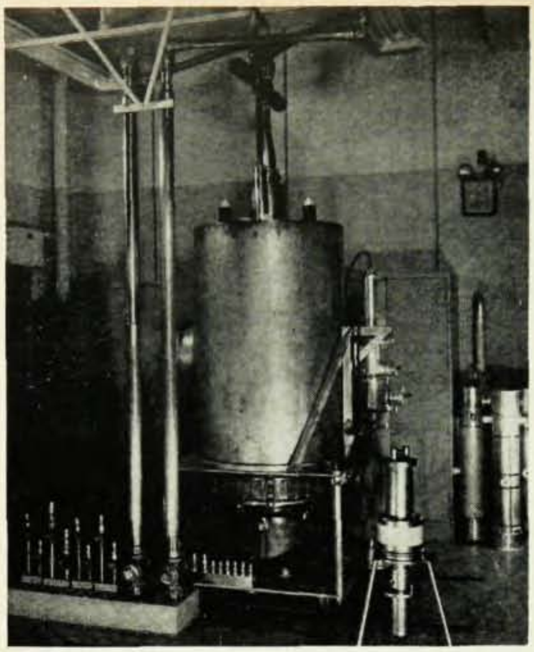


Fig. 1. A one-megawatt amplifier

quanta transmitted per unit area through an explosive experiment provides a means of determining mass distributions with statistical significance. High-explosive technology today has achieved such a remarkable state of advancement that explosive systems are reproducible to an almost fantastic degree. Hence, with repetitive experiments performed at different times or with repetitive gamma ray bursts during one experiment, a time sequence of mass distributions can be obtained. Such a set of radiographs when presented sequentially reveals mass flow much as a motion picture or film strip.

The nature and breadth of experiments for which PHERMEX was designed dictated that an appropriate bremsstrahlung spectrum would be generated by 20-MeV electrons impinging on a tungsten target. This assures maximum radiation transmission through thick sections of materials of high atomic number, whereas quanta in the low-energy end of this same spectrum also would provide useful radiographic contrasts when penetrating low atomic number materials. An acceptable error associated with absorption statistics and space resolution then prescribed that a charge of 5 to 10 μC or higher, should be delivered to a 3-mm diameter target. Without belaboring the point a stored energy device, a triple cavity standing wave linear accelerator operating at 50 Mc, was selected since it alone had characteristics which assured success; there was no competition from other accelerators. Even during the past seven years of PHERMEX' construction, the capabilities of traveling-wave accelerators, Marx generators, as well as strip line pulsers have not advanced to the point where their demonstrated flash radiographic performances have become comparable to the standing-wave machine.

PHERMEX target currents of over 20 A now provide fluxes exceeding 9 roentgens per 0.2 μsec pulse measured on-axis at 1 meter from the target. Because of the nature of this accelerator a pulse of gamma rays consists of 10 sub-bursts each about 6 nsec long. The average dose rate is 45 R/μsec whereas the radiation rate during one sub-burst is about 150 R/μsec. Considering a bremsstrahlung production efficiency in the tungsten target of say 42 percent for 20-MeV electrons, gamma radiation is produced at a rate of about 170 MW

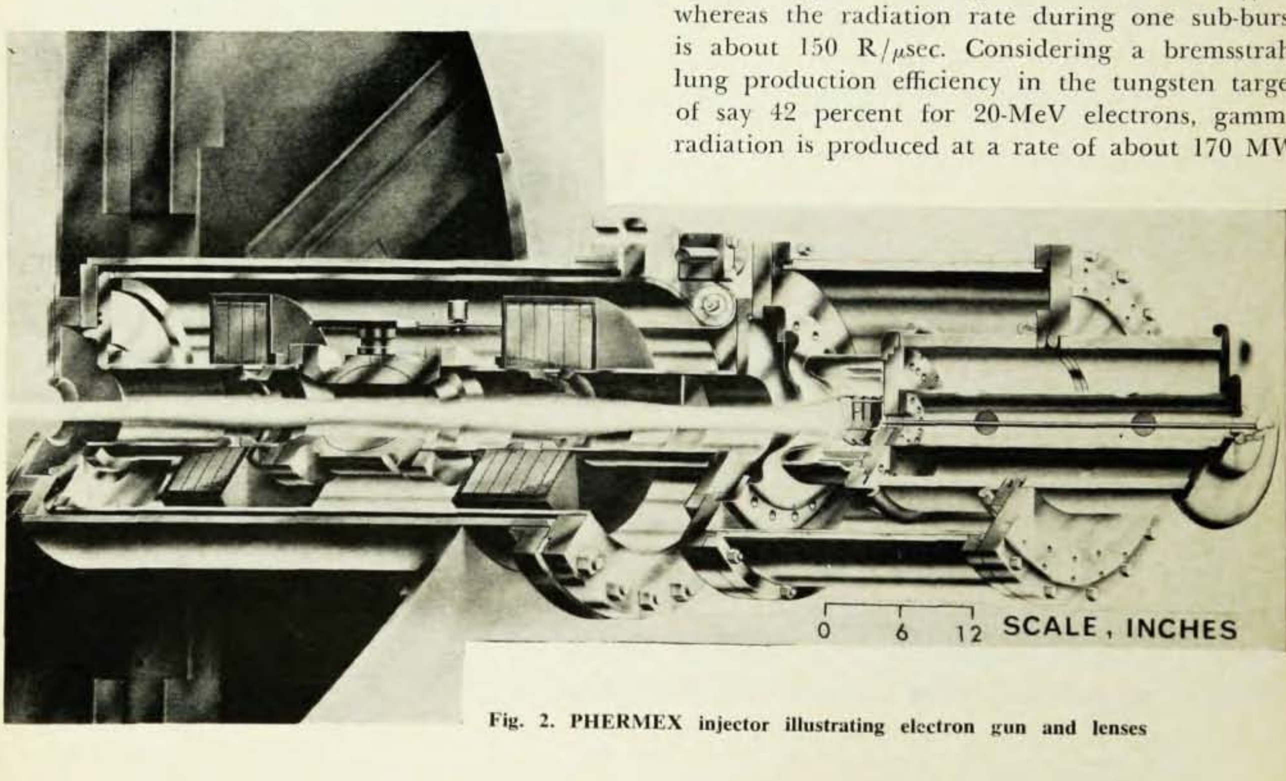


Fig. 2. PHERMEX injector illustrating electron gun and lenses

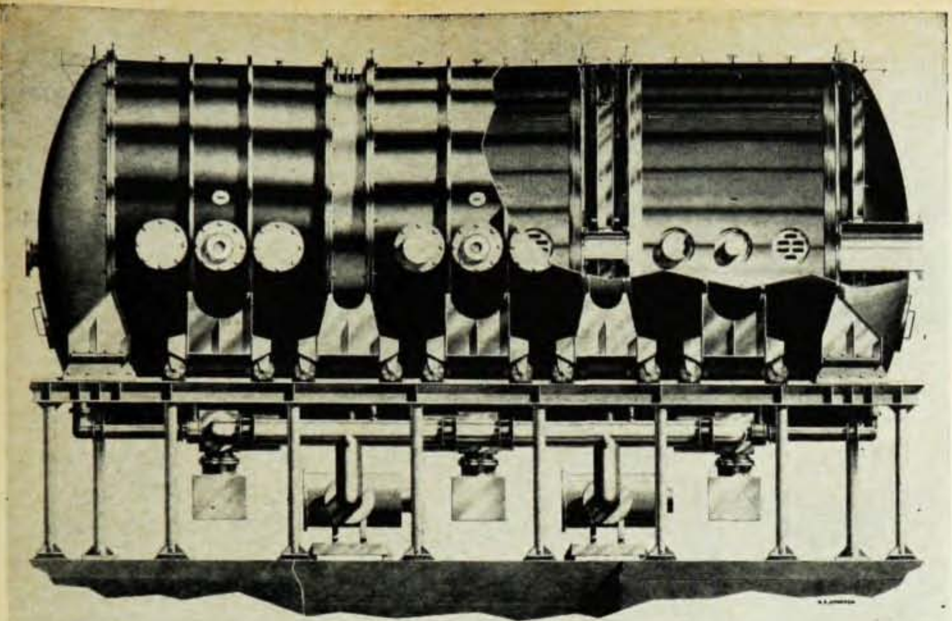
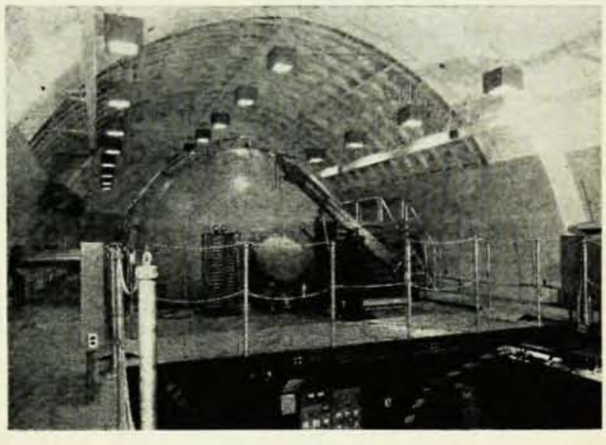


Fig. 3. Cutaway illustration of three-cavity system

Fig. 4. View of PHERMEX showing electron-gun pulser and injector encapsulated in a plastic bag filled with SF_6



for 0.2 μsec whereas the on-axis intensity at one meter is several megawatts per square centimeter.

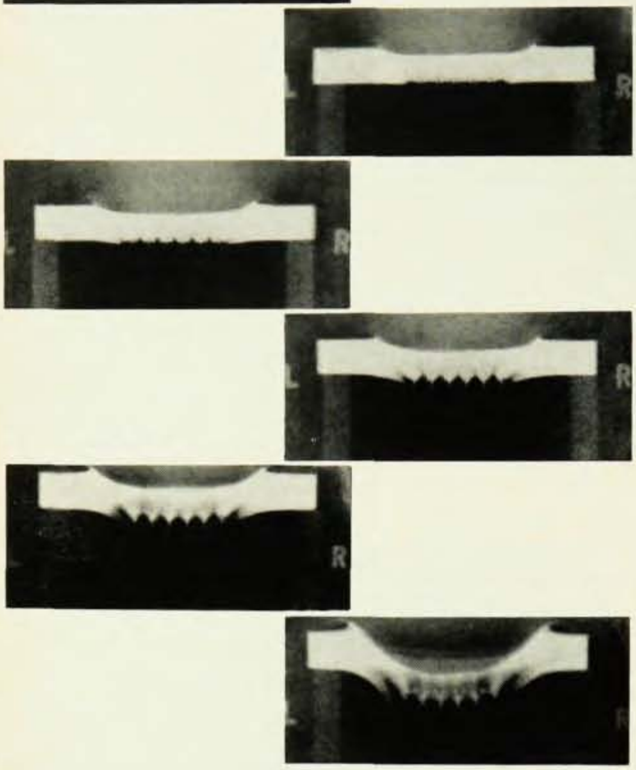
Figure 1 illustrates a nominal one-megawatt radio-frequency power amplifier now in service. The fourteen-inch coaxial transmission line leading to a cavity is not shown in this photograph. The electron beam injector that is presently used is shown in Fig. 2. Here the profile of a typical 250-A beam was obtained from measurements of beam diameter at various axial positions. This beam is then injected continuously for 0.2 μsec into the entrance aperture of the first cavity shown on the right of Fig. 3.

The physical layout of the PHERMEX complex was dictated primarily by its concrete housing which provides adequate protection from blast and shrapnel. Indeed this is one reason why the beam is piped about ten meters to the protected target which is located outside the blast-proof bunker. Figure 4 is a photograph of the injection end of the machine. Although today the trend in electronics seems to be toward micromodules, the hydraulic hoist shown here is needed to handle the one-ton electron gun assembly.

An attempt has been made to describe briefly the needs for, and the characteristics of, the device known as PHERMEX. This machine, as a high current electron accelerator, is very interesting in its own right. There are obviously many stimulating experimental tasks in other fields that could be performed by such a device. For example, the output electron beam might well be used to generate exceedingly powerful bursts of Cerenkov radiation in the millimeter wavelength range. It might serve equally well for studying the effects of high-intensity electron or gamma radiation upon the properties of matter, including biological tissue. If adequate instrumentation were available, nuclear spectroscopy might look attractive. Indeed, some modest electron-beam and gamma-ray work is planned.

However, PHERMEX was built to implement studies in modern fluid dynamics through the techniques of flash radiography, potentially a very rewarding field of endeavor. This is its primary function today. Exploratory experiments have encompassed observations of Mach stems arising from the interaction of detonation waves in high explosives. Measurement of the distribution of mass behind the detonation and shock waves associated with Mach reflections will lead to a better understanding of these phenomena. As mentioned earlier, statistically significant observations of matter in extreme states will be very fruitful indeed.

A typical example is represented by the accompanying sequence of radiographs, Figs. 5



Figs. 5–10. Top figure (5) shows shock wave incident upon grooves in aluminum plate. Time: 1.8 μsec. (6) Initial formation of jets. Time: 4.1 μsec. (7) Jets continuing to grow. Time: 4.6 μsec. (8) Flow pattern behind jets revealed. Time: 6.1 μsec. (9) Plate breakup becomes significant. Time: 8.6 μsec. (10) Laminae developed in plate. Time: 16.6 μsec.

through 10, which depict the time evolution of metallic jets. These have been formed by virtue of an explosive-induced shock wave interacting with grooves in a one-inch thick aluminum plate four inches wide by eight inches long. A study of the time history of these jets indicates that they are rather slow for jets, only about 6000 meters/sec, roughly half the earth's escape velocity. Zero time here is taken to be the instant the detonation wave strikes the aluminum.

As when a sufficiently high-velocity wind blows over water, a wave develops and grows in the surface of the aluminum and is propagated laterally by virtue of momentum imparted to it by high-velocity gaseous detonation products. Not only the motion of various parts of the aluminum plate can be seen in the original radiographs but so can the lateral flow of gases and the shock wave reflected back into the reaction products. In the terminal phase of this sequence of radiographs the aluminum plate appears to have developed numerous laminae. Several additional shots were radiographed; each demonstrated a high degree of reproducibility of this same effect. Recovered fragments also confirmed the laminated condition which probably occurs when the plate realizes it has lost its fluid properties. The gross qualitative features of the flow patterns as well as laminations shown in aluminum have been also observed in dimensionally similar plates of copper, iron, and lead, although iron demonstrates significant differences in details of fragmentation. Figure 11 is a radiograph of a set of aluminum jets in collision, a dramatic event.

Many people have contributed heavily to the success of PHERMEX, too many to enumerate here. However, there are several who should be mentioned in relation to their specific areas of responsibility. T. J. Boyd treated all of the electrical controls and radio-frequency power problems from microwatts to megawatts with eminent success. Ivan J. Cherry provided very able assistance in guiding the development of electronic computer codes which describe the characteristics of this machine and the properties of particle orbits. D. H. Janney, after rather extensive study, generated the various methods of reliable data collection such as appropriately tested high-speed film-screen combinations with blast-proof cassettes as well as electronic radiation detectors and an electronic competitor to film to be used for certain experiments. B. T. Rogers supervised the overall mechanical engineering of both the firing site and the accelerator proper and, with H. G. Worstell, developed the vacuum system and the technology which consistently achieve vacua like 10^{-8} torr throughout PHERMEX. The task force leader for this activity was F. R. Tesche.

Now that PHERMEX is completed and operating, it is hoped that the people who have been intimately associated with this project can find time to report in detail those fruits of their respective responsibilities which have made this machine a success.

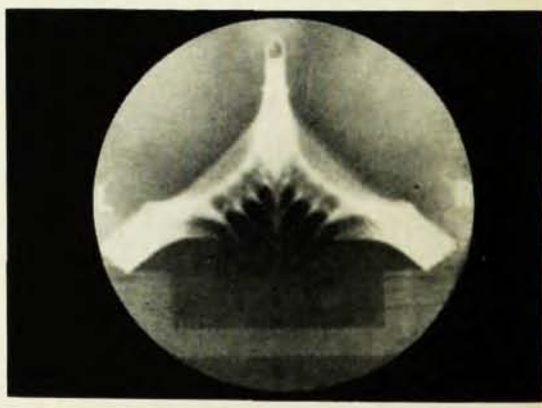


Fig. 11. Aluminum jets in 90° collision. Time: 16.6 μsec.