Hamilton	10/15/58	16:00:00.2	36°48′08″N 115°55′56″W	50	Tower		1.17			
Logan	10/16/58	06:00:00.1	37°11′03″N 116°12′04″W	−830	Underground	5.0		0.4	0.7	
Dona Ana	10/16/58	14:20:00.1	37°05′12″N 116°01′25″W	500	Balloon		37			14:20:00.5
Vesta	10/18/58	23:00:00.2	37°07′21″N 116°02′05″W		Surface		24			
Rio Arriba	10/18/58	14:25:00.1	37°02′28″N 116°01′33″W	70	Tower		90			14:25:00.1
Socorro	10/22/58	13:30:00.2	37°05′12″N 116°01′25″W	1,500	Balloon	6		0.02	1.0	13:30:01.0
Wrangell	10/22/58	16:50:00.1	36°47′53″N 115°55′44″W	1,500	Balloon		115			16:50:01.2
Rushmore	10/22/58	23:40:00.1	37°08′05″N 116°02′27″W	500	Balloon		188			23:40:00.3
Catron	10/24/58	15:00:00.2	37°02′35″N 162°01′37″W	72.5	Tower		21			
Juno	10/24/58	16:01:00.2	37°07′24″N 116°02′16″W		Surface		1.7			
Ceres	10/26/58	04:00:00.2	37°10′53″N 116°04′07″W	25	Tower		0.67			
Sanford	10/26/58	10:20:00.1	36°47′53″N 115°55′44″W	1,500	Balloon	4.9		0.07	0.8	10:20:00.8
De Baca	10/26/58	16:00:00.1	37°05′12″N 116°01′25″W	1,500	Balloon	2.2		Trace		16:00:01.3
Chavez	10/20/58	14:30:00.2	37°02′41″N 116°01′47″W	52.5	Tower					
Evans	10/29/58	00:00:00.2	37°11′41″N 116°12′17″W	−848	Underground		55	No motion		
Humboldt	10/29/58	14:45:00.1	37°02′52″N 116°01′29″W	25	Tower		7.8	No motion		
Santa Fe	10/30/58	03:00:00.1	37°05′12″N 116°01′25″W	1,500	Balloon	1.25				03:00:01.5
Blanca	10/30/58	15:00:00.2	37°11′09″N 116°12′07″W	−835	Underground	19.2		0.7	0.7	
Titania	10/30/58	20:34:00.2	37°10′38″N 116°04′09″W	25	Tower	0.15				

* *P* wave amplitudes and periods at Pasadena from Benioff short-period vertical.
† Rayleigh wave amplitudes for period of 20 seconds from Benioff long-period vertical and Press-Ewing long-period vertical.

TABLE 2. Energy Coupled to Seismic Waves and Rough Equivalent *P* Wave Magnitude for a 20-kt Nuclear Explosion under Various Conditions

	E_s^*/E_0	Magnitude
10 km air burst	1×10^{-5}	3
1 km air burst	3×10^{-5}	3½
Surface	1×10^{-4}	4
300 m underground	1×10^{-3}	5
30 m underwater	5×10^{-3}	5½
100 m underwater	2×10^{-2}	6
500 m underwater	4×10^{-2}	6½

* Ratio of seismic energy to total energy (yield).

deep 25-kt underwater explosion is equivalent to a 10-Mt surface explosion. Thus, for seismic research, it appears that deep underwater explosions are most desirable, with underground explosions a poor second. If the underwater tests have a scale depth of 500 meters for 1 kt (5 km for 1 Mt), there will be very little surface disturbances, since the gas bubble will reach the surface only after about 8 pulsations, by which time it will have been reduced to negligible size.

The largest nuclear explosion which could be safely contained in the ocean is about 10 Mt. This would produce distant *P* wave amplitudes corresponding to those of the largest earthquake man has ever recorded, and may be larger than is needed. Such a large explosion would best be set off in one of the deepest of the ocean trenches. These trenches are all seismically active, so one would lose the advantage of producing a seismic source in an aseismic area.

A clean 1-Mt explosion could safely be conducted almost anywhere in the deep ocean. Very little, if any, radioactivity would be brought to the surface if the explosion were at a depth of 5 km. The radioactivity would be mixed with an enormous volume of water and would be diluted so quickly that no contamination hazard to commercial seafood could occur. The total activity would be comparable to that in the Wigwam test, and it would be diluted very much more before it rose to the shallow depth of commercial fishing. No contamination of fish was found at Wigwam. The total fission product radioactivity would be comparable to that produced in 1 day by a Hanford reactor. There would be no damage to shipping outside the immediate area of the explosion, although the explosion would be felt at great distances.

A deep underwater 1-Mt explosion would give *P* wave amplitudes corresponding to a magnitude-8 earthquake. Earthquakes of this size occur only about once every 3 years, always in the small regions of high seismicity. Since one-quarter of the earth's surface is covered by oceans more than 5 km deep, 1-Mt shots could be conducted in a wide variety of regions where large earthquakes have never occurred.

One-Mt explosions would be completely contained on land, if detonated at a depth of 1.5 km (5000 ft). It is difficult to compare a megaton explosion underground with a corresponding underwater burst because we lack experimental data or appropriate theory. However, such explosions would be recorded world wide.

It is perhaps worthy of mention that several sources, appropriately disposed, may be detonated in a time sequence to produce directional effects, to favor the propagation of a particular wave mode, or, possibly, to excite the fundamental modes of oscillation of the earth as a whole.

Since we are considering explosions in general, we should consider equally the possibilities of chemical explosions. Whenever a chemical explosive will do the job as well and the cost is not excessive, it is clearly preferable to a nuclear explosive. Chemical explosives have not been exploited enough in terms of large explosions planned and detonated for seismic purposes. Soviet scientists have shown how much detailed information on crustal structure can be obtained with chemical explosives.

The cheapest of chemical explosives costs about ten cents a pound. Figure 2 shows the ratio of cost of chemical explosives at this figure to the cost of nuclear explosives released by the AEC [*Vortmann*, 1958, p. 70]. Since the cost of a nuclear explosive does not vary rapidly with yield, the ratio of costs is nearly linear. This suggests that all explosions up to a few kilotons should be chemical, unless the cost of emplacing them is large compared with the cost of the explosive.

Whereas it is highly desirable that nuclear explosions on land be completely contained, to prevent dissemination of the radioactivity, chemical explosions do not need to be contained.