One bomb could black out a nation

Electromagnetic pulse threat from nuclear blast

Nuclear devices exploded above the atmosphere may not hurt people or damage property on the ground in the conventional sense. But such explosions can produce an effect similar to a giant lightning strike and wipe out communications and power supply systems over huge areas, effectively crippling a nation's military forces.

by BRIAN DANCE

The two nuclear bombs used as weapons of war, and most of the nuclear test explosions, have been carried out in the atmosphere, at about ground level or underground. The biological effects on humans and animals, as well as the effect on military and civilian property, have been well studied as regards the damage caused by radiation, the heat flash, and subsequent fires. The air pressure waves have been investigated, and much is also known about the hazard of radioactive fallout in various weather conditions.

Much less is known about the effects of a nuclear explosion outside the atmosphere at a height where hazards to living things and buildings are quite small. It can be shown that such an exo-atmospheric explosion can produce short duration, but very intense, electric and magnetic fields which can destroy almost all semiconductor devices, which are not completely screened, over an area as large as a whole continent. This electromagnetic pulse (EMP) could render all radio transmitters and receivers useless and would also cause the telephone system to fail, since modern systems are largely dependent on electronic switching. Modern vehicle electronic ignition systems would be put out of action, as would many vital military computers.

At the same time, the power line systems would be tripped into the off state (possibly with permanent damage to the insulation) in much the same way as the lightning of electrical storms causes power lines to be tripped. However, EMP tripping would act over a far greater area.

(The effect would appear to be akin to that commonly experienced in the immediate vicinity of a lightning strike, where the electromagnetic field can induce destructive voltages in devices connected to antennas, telephone wires, and power lines, except that this is on a vast scale. Ed.)

EMP does not present a direct hazard to human life but it does pose a serious hazard to electrical and electronic equipment.

Thus, it can destroy the effectiveness of unprotected military equipment over a huge area, and hence the capacity of a

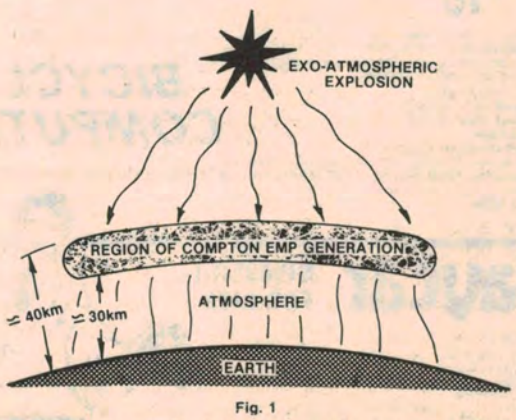

Fig. 1

A nuclear explosion above the atmosphere would create intense EMP effects on the Earth's surface.

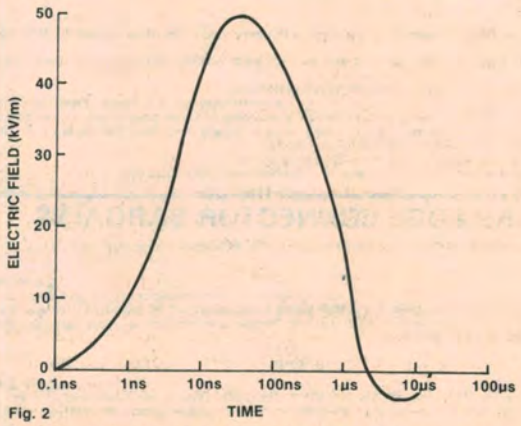

Fig. 2

A one megatonne explosion would generate fields of up to 50kV/metre, with a rise time of 10ns.

nation to respond to a nuclear attack.

The formation of the electromagnetic pulse is due to several mechanisms, but by far the greatest contribution is an extremely intense burst of gamma radiation at the instant of the explosion. Fission bombs, in which heavy elements such as uranium or plutonium split into lighter atoms, and fusion bombs (thermonuclear or hydrogen bombs) in which light atoms fuse together to produce heavier atoms, both produce EMP effects.

If the explosion occurs high in the atmosphere (Fig. 1), most of the high energy gamma rays will travel some distance through the rarefied air and will knock electrons out of molecules of the air in their flight (the Compton effect). The heavy positive ions move relatively slowly, but the light energetic electrons formed in this way form an electric charge which rapidly moves a distance of some hundreds of kilometres. This separation of electric charges in the upper atmosphere creates enormous voltages which give rise to the intense EMP effect at the surface of the earth.

All nuclear explosions generate at least a localised EMP effect. If the explosion occurs in the middle of the atmosphere, the resulting fields are relatively symmetrical and they therefore almost cancel at considerable distance from the explosion. However, where the explosion is above the atmosphere, the variation of atmospheric density with altitude provides the asymmetry required for maximum EMP effect.

Maximum EMP effect is believed to occur when the explosion is at an altitude of between 40 and 500km, but the size of the effect depends on the energy yield of the weapon. Most of the EMP currents occur at an altitude of about 30km.

(50kV/m peak intensity)

A large hydrogen bomb with a yield of one megatonne may produce a peak intensity field of some 50kV/m at the Earth's surface. As shown in Fig. 2, the peak pulse intensity is reached in about 10ns and its total duration is of the order of 1us. This is quite long enough to irrepairably damage semiconductor devices.

Power lines and telephone lines are very effective at picking up the extreme voltage gradients produced by EMP. It has been calculated that a large explosion could produce a short pulse of some ten million volts on power and telephone lines across the whole of a continent such as Australia, the USA, or Europe, while currents of the order of 10,000A may momentarily flow in power lines; possibly more than a hundred times the design capacity.

Pulses from power and telephone lines are readily picked up by other equipment in their vicinity which can thus be destroyed. In addition, the higher frequency components of the pulses can be picked up by quite short wires and can damage electronic equipment to which these wires are connected, no matter whether the equipment is operating or not. Radio aerials are obvious sources of EMP pickup, but far smaller wires will be able to pick-up enough voltage to produce semiconductor damage.

Component sensitivity

Semiconductor devices are inherently far more sensitive to EMP than the thermionic valves used in the past. Indeed, the fact that thermionic valves can be a million times more resistant is one of the reasons why the implications of EMP were not fully appreciated at an earlier date.

It is most interesting to note that when a Soviet defector flew a Russian MIG-25 fighter aircraft to Japan in 1976, this very advanced aircraft had a body shell arranged as a Faraday shield, with its onboard communications equipment employing sub-miniature thermionic valves rather than semiconductor devices.

The sensitivity of semiconductor devices varies widely, power transistors needing around ten times the energy to damage them than small signal transistors. Integrated circuits may be a thousand times more sensitive than small signal transistors.

The most resistant components are large iron-cored transformers, electric motors and other large components. However, the effects on specified items are difficult to predict owing to the many

Electromagnetic pulse threat to communications

ways in which the equipment can be arranged and the large number of methods by which damage can occur. The position is complicated by the lack of information on the precise EMP characteristics formed by weapons of a given type. (Nuclear powers are naturally unwilling to publish details of their weapons.)

EMP hardening

It is vital to national security that military equipment is made as resistant to EMP as possible. The process of building in or adding such resistance is known as "hardening". EMP hardening can be extremely expensive (and virtually impossible in the case of large structures such as power lines) and therefore it is only military rather than civilian equipment which is hardened.

Almost all items of military equipment currently produced are hardened against EMP effects, although there are obviously degrees of hardening and complete protection may be impossible. The computers in missiles and military aircraft are usually especially well hardened against EMP, but the problems presented are very different from the hardening of, say, 100,000 army radio receivers.

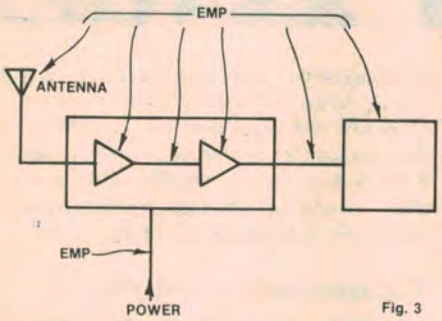

Fig. 3

Pulses would affect all stages of electronic equipment. Fig. 4 shows the effectiveness of various shielding materials.

EMP may affect a simple piece of equipment at many points as indicated in Fig. 3. Some manufacturers such as the M.O. Valve Co of London and Siemens of Munich manufacture gas filled surge protectors which can operate at extremely high speeds (under 1ns). If connected between sensitive points (usually all signal and power inputs and outputs) and ground, they will short circuit the EMP so that it is unlikely to damage the equipment.

Really thorough screening and double screening helps to provide at least some protection against EMP. Siemens produce rooms shielded like a Faraday cage, but use welded iron shields and copper screens to meet various requirements. This company considers wire mesh screening inadequate. As indicated in Fig. 4, a 6mm network of 0.5mm diameter wire in the form of a double screen is not adequate in upper radio frequency regions.

For their most sensitive computers, the Swiss have decided that it is more economical to place them some 600m under the Alps than to thoroughly screen them on the surface. In the case of power and telephone lines, it is probably not economically feasible to bury them over long distances at an adequate depth, so surge arrestors are more practical for this type of problem.

The use of fibre optics for long distance communications, and even for short distances between units which are EMP hardened, is basically very attractive because fibre optics do not pick up EMP and can carry high data rates. However, fibre optics are somewhat susceptible to moderate doses of nuclear radiation which reduces their transparency, at least for a time. Much work is being carried out to try to develop fibre optics which minimise this problem.

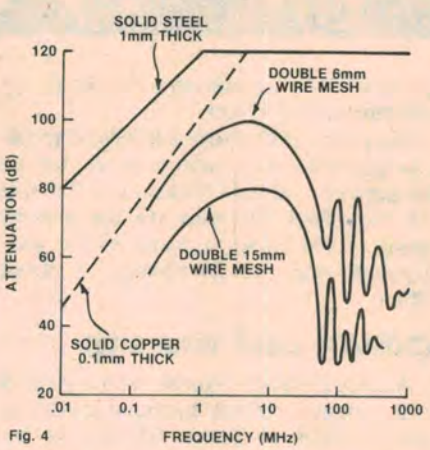

Fig. 4

Although the electronic systems handling the signal before it is converted into light pulses need careful EMP hardening, this may be carried out by using a shielded enclosure for the whole system with the power input protected and only the optical fibre emerging from the unit. Current military trends are very strongly towards using screened rooms for central transmission through optical fibre cables.

Testing

When one has finished a job in almost any field of electronics, the final stage is to test the equipment. Unfortunately it is most difficult to test the performance of the hardening systems used against EMP and, the larger the equipment, the more difficult testing becomes.

The last observed effect of EMP produced by an exo-atmospheric explosion occurred in 1962 when a 1.4 megatonne thermonuclear weapon was detonated about 400km above Johnson Island in the Pacific Ocean. It extinguished street lights in Hawaii some 1300km away and caused other unexpected results, yet the effects on local radio and radar were not very prominent, for reasons not fully understood. Doubtless the sparse population of the area and the wide use of thermionic valve equipment played an important part in reducing the effects.

Following this, a theory of EMP generation was evolved in detail, but before the US could test this theory, it had signed an agreement not to perform atmospheric tests, although some initial tests were carried out using underground nuclear explosions which can generate a limited amount of EMP.

Most current EMP testing is carried out using EMP simulators which generate an electro-magnetic field which resembles a nuclear EMP as closely as possible. Initially, simulators were able to test individual components only, but in 1980 the US Air Force Weapons Laboratory in New Mexico brought into operation an EMP simulator which can hold a B-52 bomber. It operates by discharging two 5MV pulses into transmission lines surrounding the aircraft. The United Kingdom has three EMP simulators at its Atomic Weapons Research Establishment, Aldermaston.

All simulators are inevitably compromises between economy, the size of the equipment they can accept, and the problems caused by the intense electromagnetic fields which are generated in the vicinity. Pulses are often generated by discharging capacitors through a gas gap, but must have a very rapid rise time.

Although huge sums are spent on simulators, it is clearly impossible to construct one large enough to test a telephone or power line network. Work on screened cables has indicated that great improvements may be obtained against EMP – possibly up to 120dB/m or more. However, much of the work on large systems remains theoretical.

The cost of satellite communications is falling so rapidly that military and civilian long-distance links are using this technique far more frequently. To some extent satellites can be hardened against EMP before launching and, unlike other long-distance communications networks, can be laboratory tested for the effectiveness of this hardening.

Strategic implications

In the event of a nuclear war, the availability of first class communications

Electromagnetic pulse threat

and reliable electricity supplies would be absolutely vital to the population surviving the first onslaught. These factors, together with ample computing power and vehicle reliability, would be essential to any nation requiring to make a nuclear response to the initial attack.

Nuclear EMP effects threaten to disturb the very sensitive balance of power which seems to have kept the world free from any major war since the end of World War II in 1945. Some people believe that no matter how much hardening is put into equipment, only a "use it or lose it" war philosophy can work. This can only lead to a "trigger happy" situation where ideas of "controlled" nuclear war give way to the older idea of Mutally Assured Destruction (MAD).

To make the situation even more delicate, there is the risk that a country may not even get the warning of a rocket carrying an EMP weapon entering its atmospheric space. Many satellites orbit the earth, and a suitable satellite with a nuclear charge could be exploded at will, reducing any warning time to milliseconds. Such a danger is thought by some people to make the idea of a "flexible nuclear weapon-for-weapon" response untenable, an all-out nuclear war being the only possibility. Who can forecast the position unless and until the effects of hardening systems have been thoroughly tested using exo-atmospheric nuclear explosions?

Although there remains much to be learned about the effects of EMP, the nuclear powers certainly have weapons which have been specifically designed for the purpose of paralysing the communications and mains power supplies of a country.

Except for the EMP effect, such weapons would not affect people or buildings and would not necessarily be regarded as a nuclear attack, so a conventional war could follow with one or both sides having lost much of their communications and power systems. The limited number of hardened military systems which survived would be overburdened by the demand for communications and even emergency fire and ambulance requirements would have to give way to military communictions needs.

As the rise time of an EMP is in the nanosecond region, the whole communications system of a nation could be lost almost instantaneously. If the nation detected the rocket carrying the EMP weapon, it could have a warning period of perhaps a few minutes – if that long – before the EMP wiped out control over its armed forces. Many experts therefore fear that this could result in a philosophy of ordering a full scale nuclear response in the very early stages of a suspected attack.

It is horrific to think about the implications of such a situation which could result in a full nuclear war, perhaps in error, because one nation sends a rocket carrying an unknown, and possibly innocent, payload above the air space of another nation. Much depends on the amount of confidence the "attacked" nation has in its hardened communications systems, but no one really knows the exact performance of such systems because of the atmospheric nuclear test ban agreement.

It is significant that Edward Teller (known as the "father" of the US hydrogen bomb) is reported to have said that he would like to roll back the test ban so that more can be learned about EMP and its implications for the balance of power. The US is ready to carry out exo-atmospheric nuclear tests for EMP investigations and to check effectiveness of EMP hardening if ever the partial test ban treaty should be lifted.