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ACCIDENTAL DETONATION OF SEISMOCAPS BY ELECTROMAGNETIC RADIATION

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ABSTRACT

Simple calculations were made to determine the possible hazard when handling electric "caps" (used to initiate an explosion) in the field of a radar antenna. Then an assortment of 28 caps was checked for susceptibility by placing them in the beam of a radar transmitter. None of the caps detonated.

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ACCIDENTAL DETONATION OF SEISMOCAPS BY ELECTROMAGNETIC RADIATION

- W. G. Hoyle -

An investigation was made to find the minimum distance at which a hazard might exist from the handling of certain explosive items within the field of a radar set. Time was limited, and a specific answer, giving assurance in a particular case, was much wanted.

DESCRIPTION OF TEST PROCEDURE

The explosive items investigated consisted of two variations (with and without a metal shell) of two electric "caps", generally similar to those used for initiating a dynamite explosion. One is referred to as the "standard seismocap", the other is an experimental cap referred to as the "X128". (Both are manufactured by Canadian Industries Limited, Montreal, Que.)

Using t as milliseconds, i as milliamperes, the manufacturer quotes for the standard seismocap:

$$i^2 t = 2.4 + 0.10\,t, \text{ for the time of firing (50\%).}$$

Also, the (asymptotic) minimum or "steady" firing current $= \sqrt{0.10} \doteqdot 0.3$ amperes.

The bridge wire or actual heating element is made of Chromel A; the diameter is 1.5×10^{-3} inches, the resistance is 2.44 ohms.

For the X128 cap:

$$i^2 t = 560 + 16.8\,t,$$

and the minimum $i \doteqdot 4$ amperes.

The bridge wire is made of copper; the diameter is 3.5×10^{-3} inches, and the resistance is 0.04 ohms. All caps come fitted with a pair of leads, 8 feet long, No. 20 AWG, with modified pvc insulation held together by a web of insulation. In the trade these are referred to as "leg" wires.

The radar set used has a peak rating of 20 kilowatts, and the duty cycle is 0.0005. The frequency lies in the band 9320-9480 mc/s. The beamwidth is 1.2° horizontally, and 23° vertically; the antenna is a 6-foot paraboloid.

From Plates I, II, and III, a general picture of the test can be obtained. It was decided, and this decision is one of the most difficult in the test, that maximum receiving "antenna" gain could be obtained (accidentally) in practice as follows. The leg wires would be pulled apart, near the cap, in such a way as to form a rhombic antenna, of length ℓ, 10 wavelengths to a side. A longer ℓ would give greater lossless gain, but losses in practice might result in less gain, and, in addition, the beamwidth becomes extremely narrow, and also the likelihood of straight sides is much less at excessive lengths. The test receiving antennas are mounted at the same height as that of the transmitter and directly in line with it. The tests were done with no rotation, as being the worst (most dangerous) case. In operation, the antenna rotation is sometimes stopped.

It was assumed that a short stub of line existed between the rhombic antenna and the cap, of such a length as to give only 3 db loss. Since the impedance ratio is one to several hundred, the match is not likely to be good. It was also assumed (for calculation) that the excess supply wire acted as a line and formed a perfect terminating resistor for the rhombic antenna. Design [1] was thus based on a free-space rhombic antenna, zero vertical angle, and side-length to wavelength ratio equal to ten. The rhombic angle was computed to be $73\frac{1}{2}°$. The theoretical gain is 20.5 db. The near-field effect was ignored after reading the paper by Hansen and Bailin [2]. Note that Darling and Stevenson [3] assume power gains limited to 5 db at 10 Kmc/s, so that our 20 db-less-3 db-mismatch is very conservative. Reference 4 is also relevant.

CALCULATION OF HAZARD

There are two possible cases: first the probability of detonation by a single pulse, and second, detonation by average power.

If we use the basic formula

$$P_r = \frac{P_t G_t \times G_r \times \lambda^2}{16\,\pi^2\,D^2} = \frac{P_{te} \times G_r \times \lambda^2}{16\,\pi^2\,D^2},$$

where

P_r = received power

P_t = transmitted power 20 kw peak, pulses 0.5, μseconds, 1000/sec

G_t = antenna gain (transmitting) $1.2° \times 23° \longrightarrow 2.6 \times 10^3$

G_r = antenna gain (receiving)

$P_{te} = P_t G_t$

λ = wavelength, 0.03 meters

D = separation of transmitter and receiver

and the figures are given for the DECCA Radar 404, then G_t is computed from

$$G_t \doteqdot \frac{4 \pi ab}{\lambda^2} ,$$

where $a = 2$ meters, and $b = 0.1$ meter;

$$G_t \doteqdot 2.6 \times 10^3 .$$

We compute an effective power:

$$\text{PEAK} \quad P_{te} = P_t \times G_t = 20 \text{ kw} \times 2.6 \times 10^3 = 52{,}000 \text{ kw.}$$

$$\text{AVERAGE} \quad P_{te} = 52{,}000 \text{ kw} \times 0.5 \times 10^{-6} \times 1000 = 52 \times 0.5 \doteqdot 26 \text{ kw.}$$

For the two kinds of caps:

The standard type, firing 50% of the time at an average current of 0.30 amperes, power of 0.24 watt, or with an impulse energy of 0.005 watt-second.

The experimental X128 type, firing 50% of the time at an average current of 4 amperes, power of 1.5 watts, impulse energy of 0.50 watt-second.

We compute for two cases: single-pulse detonation and average-power detonation, for both the standard cap and the new cap.

For 50% firing with a single pulse, and the Standard Cap:

$$D^2 = \frac{P_{te} \times G_r \times \lambda^2}{16\ \pi^2 \times 0.005} \times 0.5 \times 10^{-6}$$

$$= \frac{52 \times 10^6 \times 100 \times \frac{1}{2} \times 3^2 \times 10^{-4} \times 0.5 \times 10^{-6}}{16\ \pi^2 \times 0.005} = 1.5$$

$$D \doteq 1.2 \text{ meters.}$$

For a safety factor of ten, we would say about 4 meters, but we have overlooked one factor.

A possible complication lies in the skin effect. We use the formula for skin depth*:

$$\Delta = \frac{6.62}{\sqrt{F}} \text{ cm.}$$

Then for our 0.004 cm bridge wire, full penetration just occurs at 6.5 mc/s. At 10,000 mc/s, only 1/20 of the wire need be heated. Of course, only the single-pulse case is affected. With a safety factor of ten, we have:

$$D = 17 \text{ meters, or about 60 feet.}$$

With the newly developed cap the calculated safe distance is smaller, and can be ignored.

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*See any standard radio handbook; e.g., Terman

Average power (Standard Cap)

$$D^2 = \frac{2.6 \times 10^4 \times 100 \times \frac{1}{2} \times 3^2 \times 10^{-4}}{16\,\pi^2 \times 0.24 \text{ watts}} \quad \text{(antenna at mid-beam)}$$

$$= 30$$

D = 5.4 meters, or say, 18 feet

= 17 meters for a power safety factor of ten times — say 60 feet.

With the new cap, taking 4 amperes instead of 0.3 and 0.04 ohms resistance instead of 2.44, the power required is three times greater.

$$D = \frac{5.4}{\sqrt{3}} = 3.1 \text{ meters, or 10 feet.}$$

For a safety factor of ten,

D = about 10 meters, or about say 30 feet.

With the antenna rotating, the average power is reduced to 1.2°/360 = 1/300 of that with the beam stopped. Distances become meaninglessly small.

There is a further question: that of near-field effects. These occur at distances from the antenna less than

$$D = \frac{2\,ab}{\lambda},$$

where ab is the antenna aperture and λ is the wavelength. As our antenna aperture is 2 meters by 0.1 meter

$$D = \frac{2 \times 2 \times 0.1}{3 \times 10} = 13 \text{ meters,}$$

so that there may be some near-field effects.

SIMPLIFYING ASSUMPTIONS

Concern about the near-field region was dropped after reading the paper by Hansen and Bailin [2]. They computed curves for the axial power density in the near-field region and found that the power density was decreased below the far-field formula value. Off the axis this is not true, an important fact for antenna people but of no importance here where only the high-power-density region on the axis of the beam is of concern. They considered several methods of feed and types of antennas.

The assumptions about the cap leads, however, are so implausible that I hesitate to give even these distances as possible. I have assumed that the cap leads form a rhombic antenna, ten wavelengths on a side, with a gain of 20 db. This figure is only 10 db less than that for the transmitting antenna gain, and to assume that a wire antenna at 10,000 mc/s works nearly as well as a horn and parabolic reflector is really ludicrous. Further than this, I have assumed almost perfect matching of the cap to the leads for power transfer, and again I see no way in which this could occur; I have, in addition, neglected losses in the wire altogether, though for such small wires the losses at 10,000 mc/s are high. Certainly, I can see no way in which a cap 60 feet or more from the transmitting antenna could receive enough power to detonate it.

EXPERIMENTAL TESTS

To verify these calculations, some seismocaps with 8-foot leg wire were arranged in the form of the rhombic antenna postulated. At the cap or receiving end of the rhombic, a short length of wire was left as a matching device to the cap. Seven such antennas were constructed for each of the four kinds of caps, and the lengths of the matching stub for each were as follows: 0.1 in., 0.2 in., $1/4\ \lambda$, 0.4 in., 0.5 in., $\frac{1}{2}\lambda$, and 0.6 in.

These 28 rhombic antennas, with their caps and matching stub were mounted on $\frac{1}{2}$-inch polystyrene boards for rigidity and placed, one after the other, centrally in the transmitter beam, at a distance of 10 feet from the antenna. None of the caps detonated.

CONCLUSION

In summary, the only possible practical case of hazard is that with the antenna stopped and pointed directly at the receiving antenna (cap leads). With the new-type cap, and with almost impossible assumptions, it might be possible to fire such a cap (50% point) at 10 feet from the transmitter. Since the power drops as the square of the distance, we could have a safety factor of ten by keeping 30 feet away from the antenna. For the regular seismocap, these distances become 17 and 60 feet.

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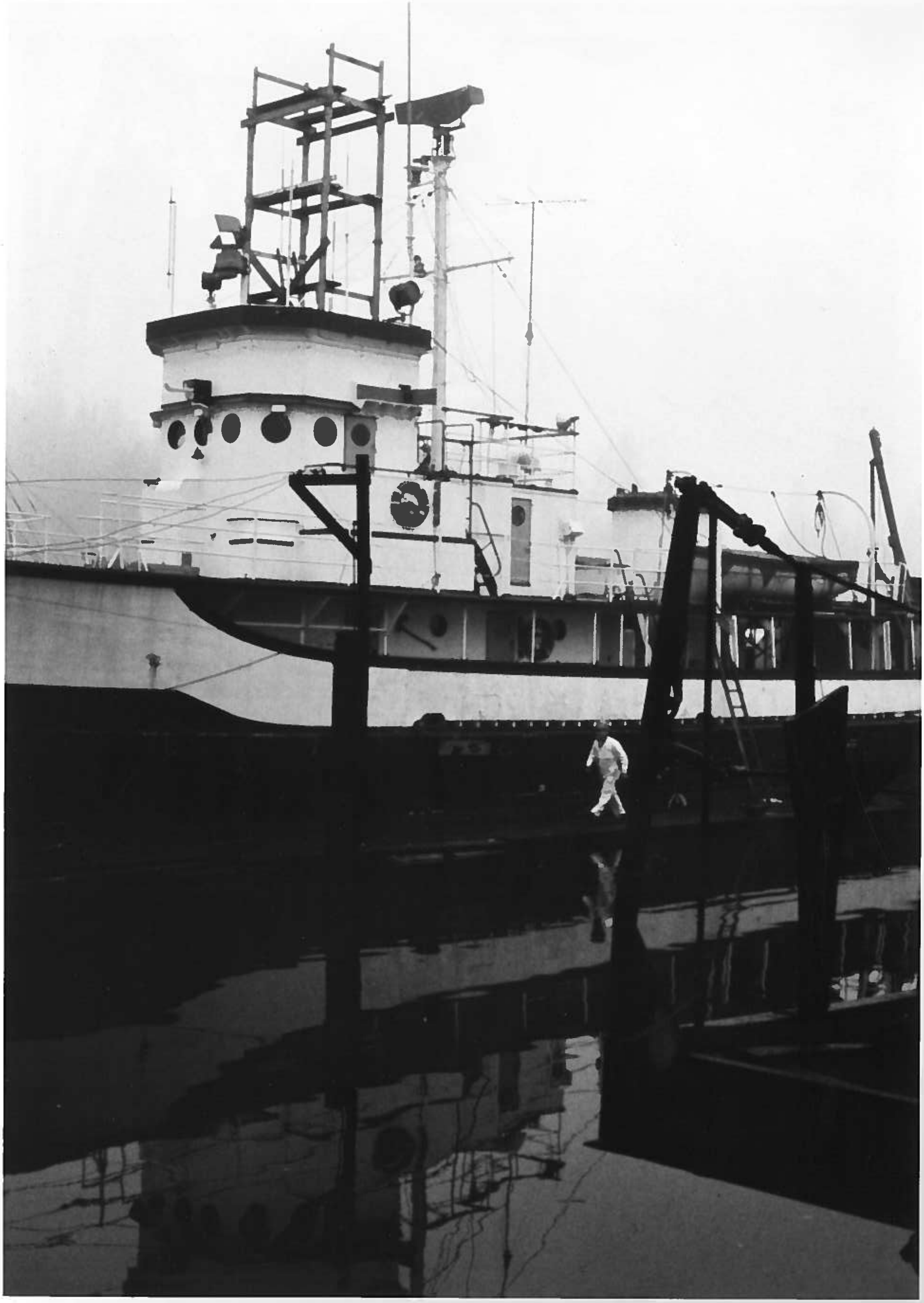

Plate I — Scaffolding for supporting test antenna in front of radar antenna

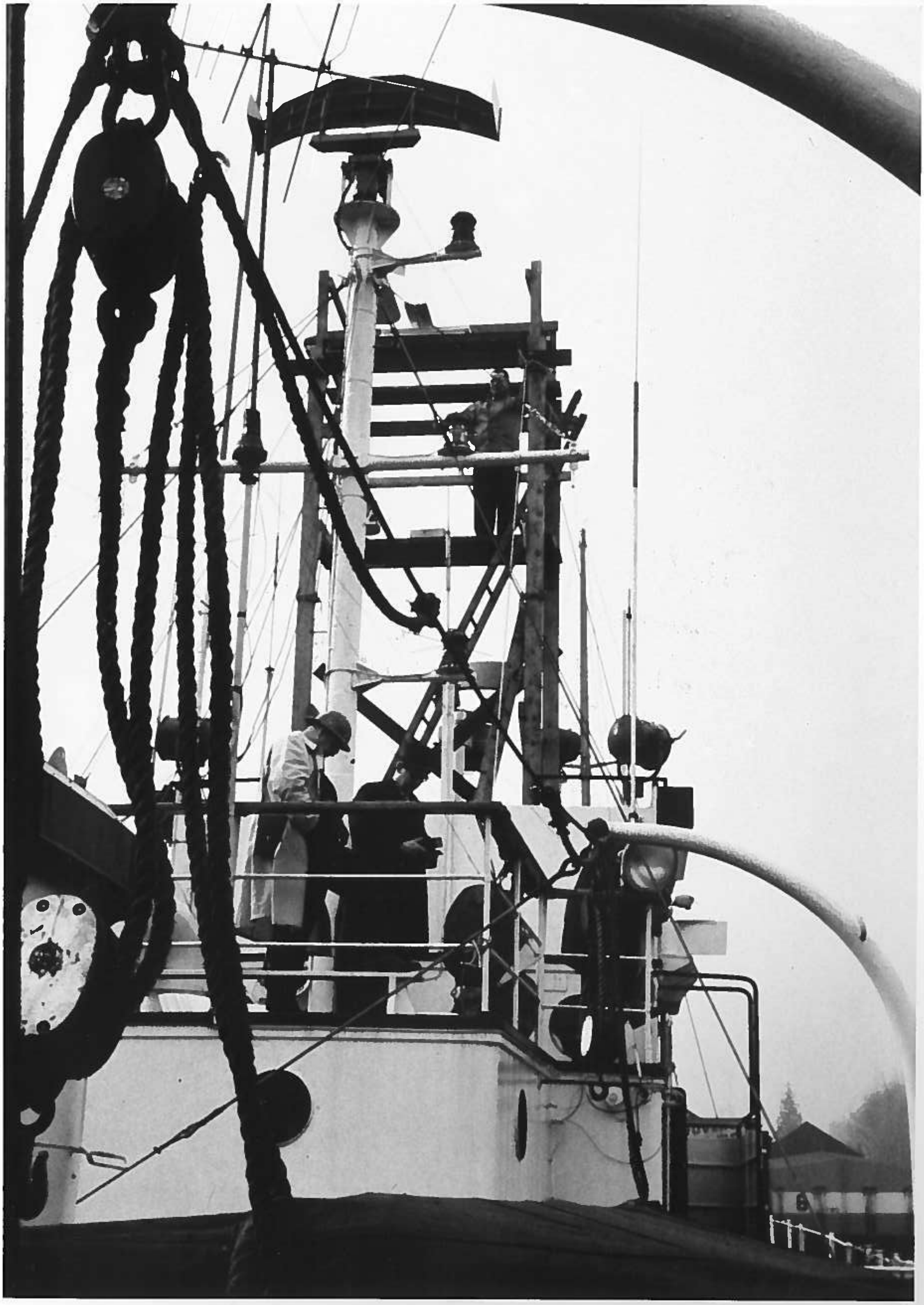

Plate II — Test antenna in place on scaffolding. Actual rhombic antenna and cap are concealed by the supporting member.

Plate III — Radar antenna details