

# Cyberwar Before there was Cyber

## Hacking WWII Electronic Bomb Fuses

Peter Gutmann

University of Auckland

## Bombs

### Thinking process

- We want to cause disruption
- Blowing s\*\*t up does this
  - And it's fun!

## Bombing: Step 1



## Bombing: Step 2



## Bombing: Step 3

Profit!



## Bombs (ctd)

Revised thinking process

- We want to cause disruption
- UXBs can cause more long-term disruption than explode-immediately bombs
- Just one UXB that fell on the NPL at Teddington took 9,800 man-hours of work to recover



## Bombs (ctd)

UXB additional considerations



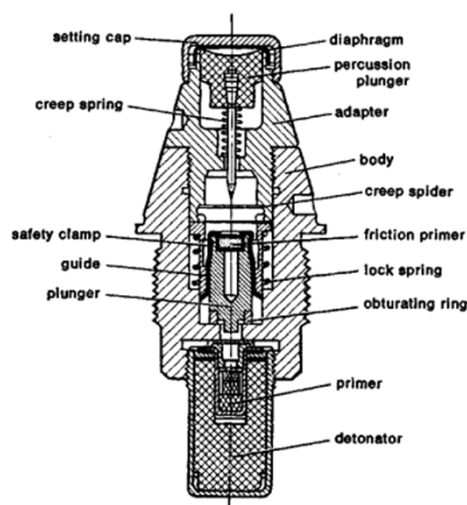
- Defenders can disarm the bomb at their leisure

Two approaches to combat this

- Make the bomb hard to disarm
- Rig things to kill the defenders

## Bomb Fuses

Traditionally chemical and/or mechanical



## Bomb Fuses (ctd)

Germany carried out electronic fuse trials in 1931 and 1932

- Work had started in 1926 at Rheinmetall-Borsig
- Treaty of Versailles forbade development of war weapons
- Testing was done in secret in Russia
  - That's "in Russia", not "on Russia"
  - Based on normalised relations after Treaty of Rapallo, 1922

Tested 250 mechanical and 250 electronic fuses

- Electronic fuses were found to be far superior

Adopted for general use in 1937

- First combat use was in the Spanish civil war

## Bomb Fuses (ctd)

Function of a fuse

- Secondary purpose: Make sure it detonates when intended
- Primary purpose: Make sure it doesn't detonate when not intended

In WWII, the Japanese had the lowest percentage of duds

- Safety mechanisms? What are they?

## Electronic Bomb Fuses

### Traditional bomb fuse

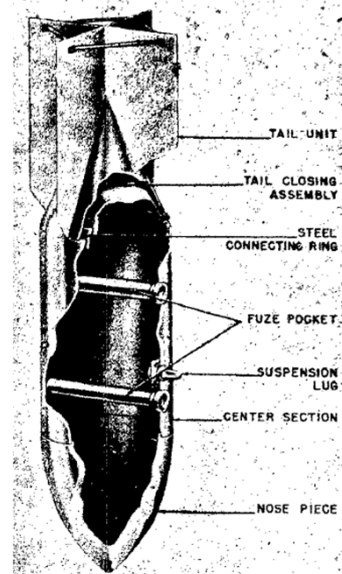
- In the nose of the bomb

### Electronic fuse

- In fuse pocket in the side of the bomb

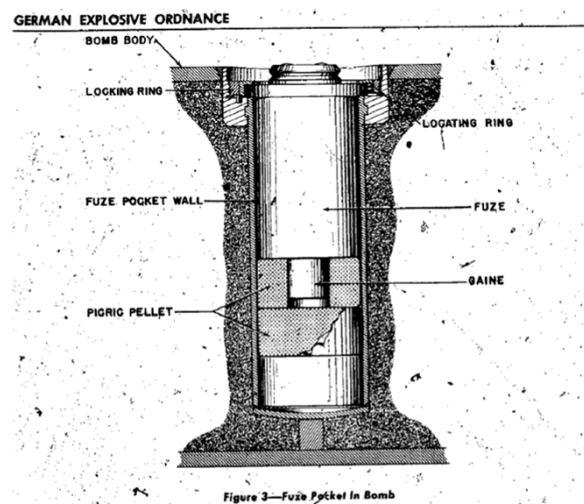
Bomb can contain more than one fuse pocket

- Mix and match fuse types/ functionality



## Electronic Bomb Fuses (ctd)

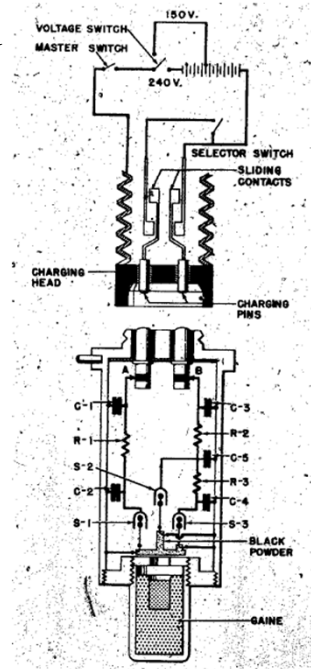
### General physical form of German bomb fuse



## Electronic Bomb Fuses (ctd)

### Functional diagram of electronic bomb fuse

- Upper section in aircraft/bomb rack
  - Selector switch
  - Arming contacts
- Lower section in bomb
  - Storage capacitors hold initial charge
  - Leaks through to firing capacitors
  - Firing capacitors fire the igniter on trembler contact



## Electronic Bomb Fuses (ctd)

Time for charge to leak from storage to firing capacitor is the bomb arming time

Depending on fuse settings, igniters will activate bomb immediately or start black-powder delay trains for delayed ignition

- Allows greater penetration of the bomb before detonation

Electronics control arming delay

- Pyrotechnics control detonation delay

Most of the circuitry is to prevent inadvertent detonation, not ensure detonation

## Electronic Bomb Fuses (ctd)

Fuses were regarded as sufficiently safe that bombs could be transported in the fused state



- SC250 in fused ('fertig' = finished/ready) state
- Bombs could be stored in this state for up to six months

## Electronic Bomb Fuses (ctd)

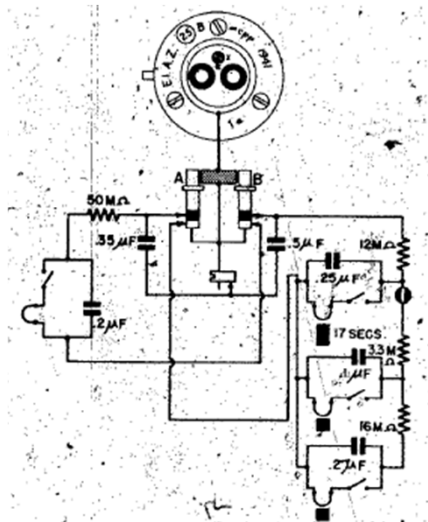
Type 25B electronic fuse

- Most common type of fuse
- Selector switch in fuse head enables/disables short-delay circuits

Detonation delay options

- Instantaneous
- Short < 1s
- Long 17s

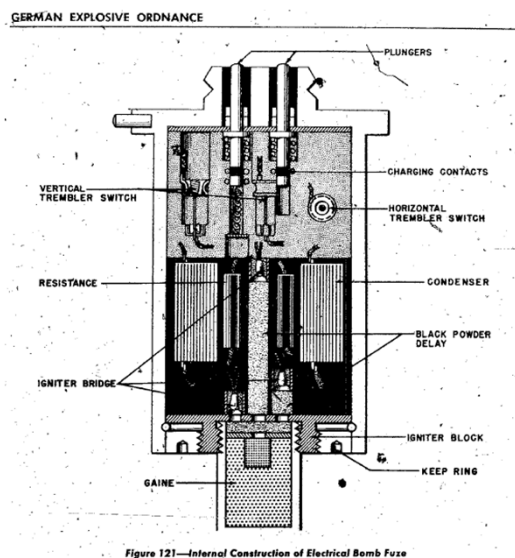
Handled different types of bombing, e.g. low-alt.



## Electronic Bomb Fuses (ctd)

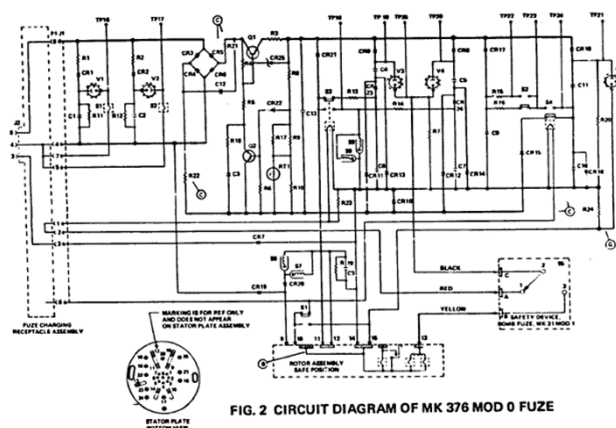
### Physical layout

- Trembler switches trigger firing bridges
- Gaine contains PETN ('nitropenta') primary explosive charge
- Triggers picric acid ('pikrinsäure') booster
- Electronics are potted in bitumen



## Electronic Bomb Fuses (ctd)

Half a century later...



Mk.376 electronic bomb fuse

## An Aside: How to Mail a Bomb Fuse

CUSTOMS DECLARATION DÉCLARATION EN DOUANE		CN 22	
Great Britain/Grande-Bretagne		May be opened officially Peut être ouvert d'office	
Important! See instructions on the back			
<input checked="" type="checkbox"/> Gift/Cadeau	<input type="checkbox"/> Commercial sample/Echantillon commercial		
<input type="checkbox"/> Documents	<input type="checkbox"/> Other/Autre	Tick one or more boxes	
Quantity and detailed description of contents (1) Quantité et description détaillée du contenu	Weight (in kg)(2) Poids	Value (3) Valeur	
ANITRIVE CAPACITIVE LOAD - ELECTRICAL COMPONENT	0.4	£30	
For commercial items only If known, HS tariff number (4) and country of origin of goods (5) N° tarifaire du SH et pays d'origine des marchandises (si connus)	Total Weight Poids total (in kg)(6)	Total Value (7) Valeur totale	
I, the undersigned, whose name and address are given on the item, certify that the particulars given in this declaration are correct and that this item does not contain any dangerous article or articles prohibited by legislation or by post.			
Date and sender's signature (8)			

## Bomb Fuse Hack #1

Arming contacts also act as disarming contacts



- Screw on Crabbtree discharger
- Depresses plungers 3mm to make electrical contact
- Wait for charge to leak back from firing capacitors to storage capacitors and through discharger

## Bomb Fuse Hack #1 (ctd)

### Removing the fuse

- Pull it out remotely using a lanyard

### What if it's jammed?

- Bomb has impacted with enormous force
- Casing deforms, fuse jams

### Attack it with a cold chisel and hammer

- ... trembler switches ...

## Bomb Fuse Counterhack #1

### Only worked on the early Type 15 fuse

- Publish feel-good stories of how effectively bombs could be defused in order to help civilian morale
- Germans redesigned the internal circuitry to prevent discharge via the plungers
- See also Type 50 fuse

## Bomb Fuse Hack #2

### Brass liquid discharger

- Brass container screwed over top of fuse
- Filled with salt-saturated meths
- Forced into the fuse under pressure (bicycle pump)

Conductive salt solution shorted out the capacitors and discharged them

- Required 30 minute wait

Should any man suggest that he took his first bomb without being frightened, I'd say either he was unwise to have done it under the influence of a stimulant or else he's a liar

— Anonymous Bomb Disposal officer quoted in  
“Unexploded Bomb”

## Mechanical Bomb Fuses

### Type 17 clockwork fuse

- Standard electronic impact fuse in upper portion
- Arms clockwork lower portion on impact rather than firing igniter
- Time delay of 2 — 80 hours after arming

Often used as a secondary fuse alongside other fuses

- The canonical ticking bomb

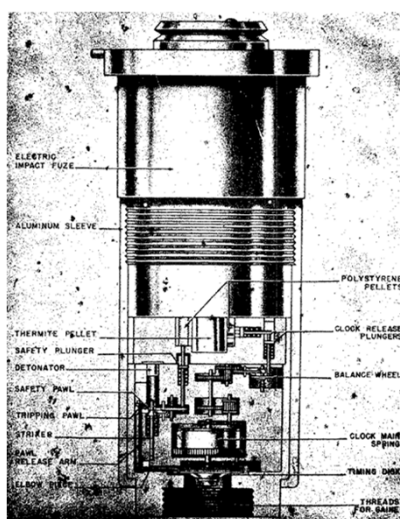


Figure 153A—4171A Electrical Clockwork Time Fuse

## Mechanical Bomb Fuses (ctd)

Can't tell what delay has been set

- Wait 96 hours before messing with a bomb

Particularly nasty failure modes

- Stop on impact, restart on disturbance
- Count down nearly to zero and stop, then restart and detonate on disturbance

Some Type 17-fused bombs detonated a year or more after impact when the fuse restarted for some reason

## Bomb Fuse Hack #3

Type 17 fuse contains metal components

- Bronze and steel

Use magnetic collar to lock the steel components in place

- Excavate a space around the bomb
- Clamp on the collar
- Hope the ticking stops



### Bomb Fuse Hack #3 (ctd)

“Clock-stopper” or Q-coil was about the size of a horse collar and weighed 90kg

- Fed from 140VDC source
- Came with an electronic stethoscope to check that the ticking had stopped

Once the clock-stopper was applied, the bomb could be moved to a safe location for further work

- Later deployed in improved form, the K.I.M.

Later approach (long after the original Blitz) injected urea-formaldehyde resin into the fuse

- Solidified and jammed the mechanism

### Bomb Fuse Counterhack #1

In August 1940, bomb penetrated under an oil storage tank in a burning oil refinery in Swansea

Bomb was extracted with some difficulty

- Other UXBs detonated while it was being recovered

Case had split open

- Fuse pocket was removed to reveal a Type 17 with a new type of fuse, the ZUS 40, underneath

## Bomb Fuse Counterhack #1 (ctd)

Withdrawing the main fuse caused the ZUS 40 to fire

- Fuses like the Type 17 could be stopped, but not disabled unless they were withdrawn
- ZUS 40 prevented main fuse from being withdrawn

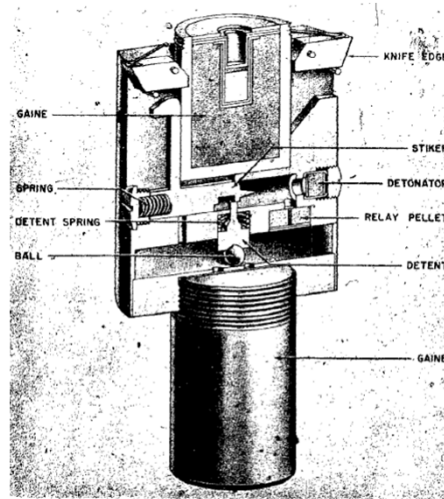


Figure 181—ZUS 40 (Type I) Mechanical Antiwithdrawal

## Bomb Fuse Counterhack #1 (ctd)

All Type 17s (and other fuses) could potentially have a ZUS 40 fitted

Germans had gone to strategy #2, “Rig things to kill the defenders”

## Bomb Fuse Counterhack #1 Hack

Drill open the case of the bomb

- Melt out the amatol mix using high-pressure steam
- Scoop up the amatol/water slurry
- With bombs of 1+ tons size this could take awhile

Fuse activation now only detonated the gaine and booster charge

Steam method later adapted for discharging fuse capacitors

- Force steam into the fuse to heat the capacitors and prevent them from functioning

## Bomb Fuse Counterhack #1 Hack (ctd)

Slightly more alarming method: Set fire to the amatol

- Use thermite to burn through the case and ignite the amatol
- Pioneered by the Earl of Suffolk, eccentric daredevil bomb defuser

Much safer than it sounds, amatol (and TNT) are extremely insensitive

- Will burn happily without detonating
- Sometimes used as fuel for (military) camp stoves

Will eventually detonate when the burning reaches the fuse

- By then most of the explosive is gone

## Bomb Fuse Counterhack #2

Type 50 fuse

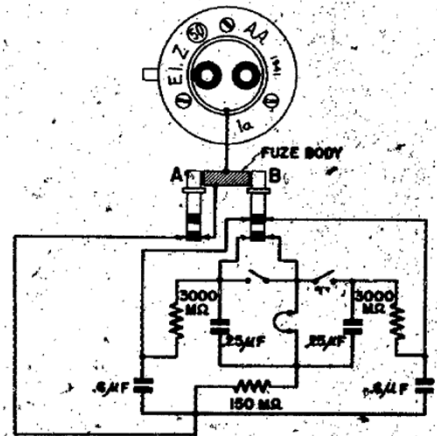
Split plunger detonates bomb instantly if depressed

- No more Crabtree

Circuitry laid out to fire fuse if shorted out

- No more liquid discharger

But wait, there's more...



## Bomb Fuse Counterhack #2 (ctd)

Fuse implements a very long arming delay to ensure the bomb is at rest before it arms

- Not a detonate-on-impact like the Type 15, 25, etc

Trigger was an extremely sensitive spring-contact

- Tapping the case with a pencil was sufficient to cause detonation

Sole purpose of the Type 50: Kill bomb disposal people

## Bomb Fuse Counterhack #2 (ctd)

Typically paired with a Type 17

- A fuse that detonates if you sneeze near it and a time fuse with optional ZUS 40

Oh yes: Using the clock-stopper on a Type 17 triggered the paired Type 50 via its steel leaf spring

- No more clock-stopper

## Bomb Fuse Counterhack #2 (ctd)

Naval mines were just as scary

- BM 1000 (1000kg Bombenmine/Monika/G Mine) naval mine had magnetic fuses to detonate it when a ship passed nearby...
- ... and an ELAZ impact fuse in case it was dropped on land...
- ... and a hydrostatic valve to detonate it if it was raised to the surface...
- ...and a photoelectric sensor to detonate it if the case was opened

(More on naval mines later)

## Bomb Fuse Counterhack #2 (ctd)

BM 1000 intended for use in the Clyde overshoot and came down near Dumbarton

- First one encountered, defusers didn't know how to deal with it yet
- Drilled holes in the case to see what was inside
- Shone a bright light in
- ... photoelectric sensor...

Luckily the impact had knocked wires and other circuitry loose...

- Complexity → more things to go wrong
- c.f. Mk.376 design

## Bomb Fuse Counterhack #2 Hack

Still steaming out the explosive



## Bomb Fuse Counterhack #3

### Type 50b or Y fuse

- Contains std. Type 50 sensitive spring switch and other fun bits and pieces
- Also three mercury tilt switches in X, Y, Z axis to detonate the bomb when it's disturbed
- Conventional long-delay upper fuse serves only to arm battery-powered lower fuse
- Collar on base prevents withdrawal

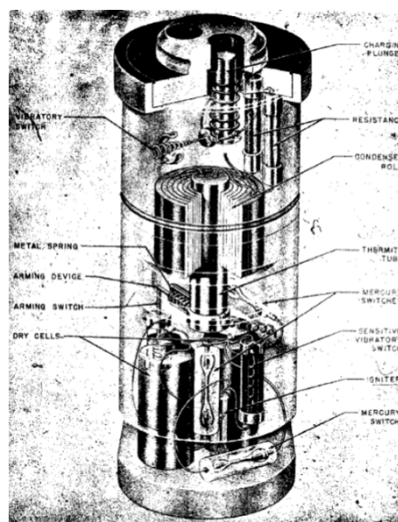


Figure 184A—50 b or "Y" Electrical Antidisturbance

## Bomb Fuse Counterhack #3 Hack

### Intact fuse captured in 1943 in Bakerloo line

- Secondary circuit was inactive, possibly due to sabotage
- Saved the defuser's life, since he attempted to disarm it with a liquid discharger
  - New fuse type, he assumed it was a Type 25(B)

### Target the batteries

- Freeze them to the point where they become inert
  - c.f. pressurised steam to disable capacitors
- (Assuming that messing with the bomb to do this doesn't kill you first)

## Bomb Fuse Counterhack #3 Hack (ctd)

Build a clay or plasticine dam around the fuse head



- Add liquid oxygen until a 1' frost ring forms around the fuse
  - Typically takes about 2 hours work next to the bomb
- Crowbar out the fuse

## Bomb Fuse Counterhack #4

LOX apparatus isn't very portable

- Use dry ice instead
- Easily made on site from pressurised liquified CO<sub>2</sub>

In October 1944 improved Y fuses with low-temperature batteries were introduced

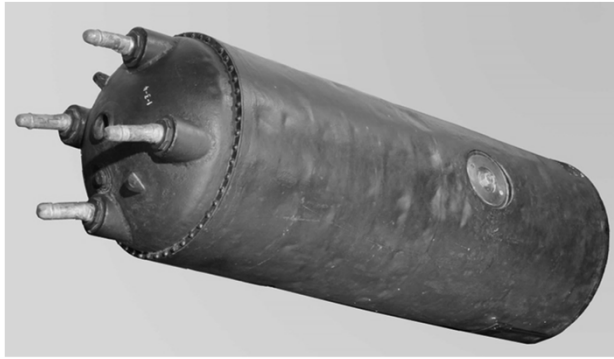
- Dry ice couldn't cool them

Go back to LOX, but even then safe period for the cooled fuse has halved

- 10 minutes instead of 20

## Naval Mine Fusing

Somewhat different to bomb fusing, but subject to the same arms race



- (Contact mines are so WWI)

## Magnetic Mine

Detects iron objects passing nearby

### Hack #1

- Towed/aerial electromagnetic emitters
- Degauss ships



### Counterhack #1

- “Clicker” requires 1-15 magnetic activations
- A single sweep will no longer clear a minefield

### Hack #2

- Make multiple passes

## Acoustic Mine

Tuned to the sound of a ship's engines

### Hack #1

- Depth charges or other wide-spectrum noisemakers

### Counterhack #1

- Requires slowly increasing volume

### Hack #2

- Project constant noise in front of the minesweeper
- Kango road-drill in a box



## Statistics for 1940

10,000 UXBs

8,000 defused

1,000 detonated

## Made in Germany

These devices are remarkably reliable and long-lived

- Some are still fully functional after more than sixty years

London  
**Evening  
Standard**

### The ticking Blitz bomb that threatens London

ROB SINGH

Published: 05 June 2008

A huge operation will take place tonight to disarm a German bomb that threatens up to two square kilometres of east London.

The 2,000lb device, believed to contain 1,000lb of high explosives, has been encased in a sand and wood "igloo" to absorb any blast if it goes off.

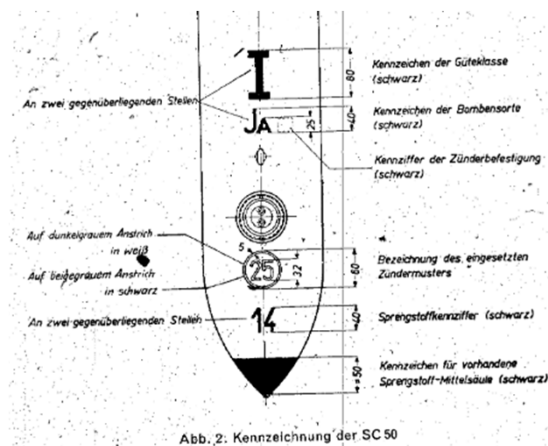
Tonight Royal Engineers plan to cut through the metal casing of the 60-year-old device, which measures 5ft by 2ft. They will "steam" the explosive so it becomes a safe liquid.

Disposal experts have already disabled its fuse after it began to tick. At one point they asked police to consider evacuating up to 1.7 square kilometres - an area which includes thousands of people, schools, key parts of the rail and Tube network and much of the Olympic site. Putting aside standard procedures, one bomb disposal officer was sent back to the device to deal with its fuse.

He poured a salt solution on to it to "freeze it" and then deployed a powerful magnet in case a timer had also been set off.

## Things that Helped the Defenders

All fuses were carefully labelled...



## Things that Helped the Defenders (ctd)

... according to precise instructions

53. Nach dem Fertigmachen ist die Musterbezeichnung der eingesetzten Zünder, z. B. (15) oder (25) auf die Bombe vor dem vorderen Einsatzstück in Richtung zur Bombenspitze in weißer Deckfarbe anzubringen. Die Zahl ist in fetter Mittelschrift 32 DIN 1451 anzubringen und mit einem 5 mm breiten Kreis von 60 mm mittlerem Durchmesser zu umranden.

- Defenders knew exactly what to do for each bomb that they encountered

## Things that Helped the Defenders (ctd)

Numbering was “inflexibly methodical”

- 0 suffix = antisturbance fuse
- 5 suffix = impact fuse
- 7 suffix = delay fuse
- (Other suffixes 0-9 identified other purposes)

Type 50b marked as 25(B), but still had the additional ‘Y’ marking

Possibly done to help the German armourers, but the single biggest flaw in the system

## Things that Helped the Defenders (ctd)

Other requirements...

16. Die Bombentörper müssen außen frei von Beschädigungen sein und einen zusammenhängenden, gut bedeckten Farbanstrich haben. Beistohene Stellen sind mit Schlosserhammer und Feile zu glätten; Rostansatz ist mit Drahtbürste zu entfernen. Beschädigter Anstrich ist auszubessern.

Dents must be smoothed out [...] damaged paintwork must be corrected

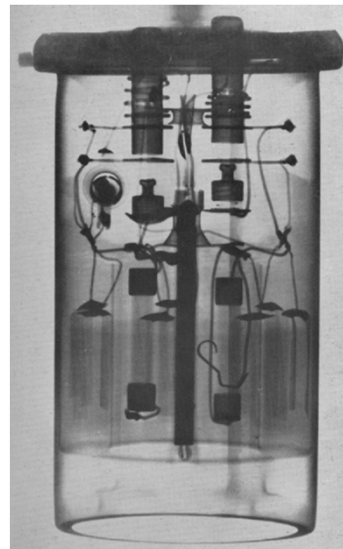
- What would the enemy think if we dropped a bomb with scratched paintwork on them?

## Things that Helped the Defenders (ctd)

Without this, each fuse would have to be identified through a radiograph

- Use radon as radioactivity source
- Photos developed on conventional film

Became standard practice for Y fuses and other potentially booby-trapped devices



## Things that Helped the Defenders (ctd)

Initial successes by defusers were publicised to help morale

- Theorised that sympathisers were leaking defusing details back to Germany
- After the appearance of the ZUS 40 and Type 50, details were kept secret
- Attackers no longer knew what worked and what didn't

Luck

- Discovery of the ZUS 40
- Discovery of the Type 50b / Y fuse

## Things that Helped the Defenders (ctd)

Side-channel attacks, circa 1940

- Treat the fuse components as artefacts with distinct physical characteristics, not abstract black boxes
- Change the operating conditions to move them outside their design parameters
- Heat/freeze the fuse components

## Things that Helped the Attackers

Decision to use electronic fuses was a good one

- Highly reliable
- Flexibility allowed for novel designs/uses
- Something as exotic as a Type 50 could never be implemented chemically or mechanically

Impact changed operating characteristics of fuses

- Type 17 erratic countdown

## Things that Helped the Attackers (ctd)

Initial successes by defusers were publicised to help morale

- Theorised that sympathisers were leaking defusing details back to Germany
- Type 15 was replaced by the Type 25 for which the Crabtree discharger didn't work
- Type 17 was redesigned to run far more silently
- Type 50 countermeasures to kill users of standard disarming methods

## Conclusion

Average life expectancy of a bomb defuser: 10 weeks

- Officers were granted instant commissions
- No point in putting them through regimental training, they'd be dead before they could be put into practice

A member of the Bomb Disposal Squad [...] should be of excellent character and prepared for the afterlife

— Answer to Royal Engineers exam for the Bomb Disposal Unit

## Conclusion (ctd)

Reading material: Proceedings of the Annual Fuze Conference

- Now in its 58<sup>th</sup> year
- Recent highlights: Problems due to cracking of lead-free solder joints in high-G environments
- When your children are maimed by cluster munitions, at least it'll be lead-free/RoHS compliant

Chances of me ending up on various watchlists due to research activity for this talk: ~100%