SOLUTIONS FOR RESISTANCE-AFTER-FIRE PROBLEMS IN AN ELECTRIC MATCH*

CONF-800713--13

By

A. A. Heckes and A. P. Montoya
Initiating and Pyrotechnic Components Division
Sandia National Laboratories
Albuquerque, New Mexico

To Be Presented at
The Seventh International Pyrotechnics Seminar
July 14-18, 1980
Vail, Colorado

Abstract

Current leakage in an electric match after firing is a problem if it drains power that can be used elsewhere or if it induces unwanted fluctuations in other electrical circuits. This paper describes two novel techniques which significantly reduce the RAF sensitivity of a $Ti/KC\ell O_4$ loaded electric match which is used to ignite the pyrotechnic materials in a thermal battery. In the first technique, a thin (less than 10 µm thick) film insulator, such as Parylene** or SiO_2, is vapor deposited within the match cavity prior to the loading the pyrotechnic. The insulator tends to smooth the cavity surface as an aid to ejection of firing residues and to decrease the exposed metal surface area to prevent pin-to-pin short circuits. The second technique involves placing a length of heat shrinkable tubing on the match so it extends from the output end so that the shrink tubing is activated by the heat of the match and the thermal battery when fired. The shrinkage of the tubing effectively decreases the cross-sectional area for mass and heat transfer from the battery back into the match.

---

*This work was supported by the U. S. Department of Energy.
**Trademark of Union Carbide Corporation.

SOLUTIONS FOR RESISTANCE-AFTER-FIRE PROBLEMS IN AN ELECTRIC MATCH

I. INTRODUCTION

Electrically actuated, pyrotechnic, fire-starting devices are known by the various names of electric matches, squibs, igniters (ignitors), and initiators. All names are synonyms for the purposes of this discussion as all function through the action of electrical heating of a resistive bridgewire to ignite a pyrotechnic charge so that ignition may be subsequently transferred to other reactive materials. The bridgewire is connected between two electrical leads which are separated from each other by an insulator. The insulator is usually located at the base of the pyrotechnic charge and makes up at least part if not most of the match body.

The preferred mode of operation for the electric match is that, after ignition transfer is achieved, the bridgewire and pyrotechnic "disappear" to give an open electrical circuit which serves to indicate that the unit has functioned. If the resistance after firing, as measured between the electrical leads, is not truly infinite so that a partially open circuit exists, then the resistance should be sufficiently large that an insignificant current flows with applied voltages similar to those used to fire the match.

A problem condition of <u>low</u> resistance-after-fire (RAF) exists when conductive materials are retained between the match leads (pin surfaces) after the match has been fired so that a significant current continues to flow. The current that is needlessly drawn tends to deplete the energy contained in the power supply or to place demand loads on the power supply so that it cannot perform other required functions. When the RAF problem is intermittent or noisy in character, the pulsations are capable of inducing unwanted fluctuations in other electrical components such as oscillators, amplifiers, transistors, transducers, and switches.

Techniques to decrease or eliminate RAF problems are required in order to be able to upgrade electrical matches with otherwise excellent firing characteristics but only marginal to poor RAF properties. For maximum effectiveness the technique used to improve RAF should not affect the end use and cause minimal changes in the firing characteristics of the match. Several such techniques have been investigated and found to be effective. Consequently, adaptation of these techniques may prove effective in other pyrotechnic devices with RAF problems.

II. Discussion

1. General

A low resistance RAF problem was encountered at Sandia National Laboratories where an electric match used to ignite the pyrotechnic heat source of a thermal battery gave unacceptable failure rates. The match, shown in Figure 1, gave after-fire current leakages of 10 mA or more in up to 60 percent of the battery test firing experiments and over 250 mA, which was a failure, in up to 2 percent of the experiments.

The match was loaded with 10 mg of $Ti/KC\ell O_4$ pyrotechnic. A standard 1 ohm, 1 watt no-fire bridgewire was used. The lead wires were nickel plated Kovar which were silver brazed in place. The match body was composed of $A\ell_2O_3$ ceramic which had been tungsten metallized and nickel plated. Match closure consisted of a Teflon disc pressed against the powder face and sealed with RTV silicone rubber.

The conditions that caused the RAF problem were defined by trial and error experimentation. The investigation indicated that the failures were caused by high temperatures plus the deposition of residues from both the match and the battery between the pins of the match. Initial experimentation was performed in the apparatus shown in Figure 2. It was designed with removable parts so that various volumes within the battery could be simulated. The early experiments showed that varying the degree of confinement of the output from the match did not produce RAF even when the match was fired at elevated temperatures up to 300°C which were representative of battery equilibrium temperatures. Conversely, elevated temperature battery firings had increased the severity of the RAF.

Only after the test fixture was modified so that the match ignited a quantity of the thermal battery $Fe/KC\ell O_4$ pyrotechnic was any electrical conductance observed. Even then, the RAF condition was of a different character that observed in battery experiments. Finally, when small quantities of the thermal battery cell stack materials were added in the form of $LiC\ell$, $LiC\ell/KC\ell$ electrolyte, and/or DEB (depolarizer/electrolyte/binder) material, then the RAF conditions of the battery experiments were simulated. See Figure 3. These battery simulation experiments gave conditions more severe than those in actual batteries because the failure rate was now 100 percent for unprotected matches. The principal advantages of the simulation experiments were a much lower cost than battery experiments and the high failure rate so that major RAF improvements might be better compared.

2. Methods of RAF Improvement

The first successful attempts to improve RAF were those where the inner surface of the bridged but unloaded match was coated with an insulating material. Two different methods of applying the insulation were used. In one series, SiO_2 was vapor deposited to cover the exposed ends of the electrical leads in the match cavity. The other series used Parylene*, a chemically vapor deposited organic polymer, which was also deposited throughout the match cavity so that the exposed ends of the electrical leads and the bridgewire were covered. An example is shown in Figure 4. The principal differences in the materials were that SiO_2 is a high melting temperature inorganic material that is deposited line-of-sight while Parylene is an organic material with a lower decomposition temperature (but still quite thermally stable compared to other organics) that is uniformly deposited on all exposed surfaces so that it provides a completely conformal coating.

Two different thicknesses of Parylene were used, 0.34 μm and 1.2 μm. Also, two different thicknesses of SiO_2 were employed, 0.4 μm and 7 μm. Some of the bridgewires were masked to prevent deposition of SiO_2 on the center portion of the bridgewires so that the effect of coatings on the ignition characteristics could be determined. Later experiments showed that changes in ignition characteristics due to these thin coatings could be ignored but that RAF protection was significantly improved (probably due to the high dielectric strength of the materials).

---

*Parylene is a trademark of the Union Carbide Corporation.

These experiments suggested that RAF could be avoided by excluding battery residues from the match cavity. Complex trap doors and other mechanical schemes were considered but discarded for a simpler technique. A piece of shrink tubing placed on the outside of the match with a short length (2 to 4 mm) extending past the match face would be activated by the heat of the match and battery to cause it to shrink and greatly reduce the area for mass transfer. The shrink tubing technique is shown in Figure 5. The idea was tried with ordinary, unimproved matches in the battery simulation apparatus. The approach was more effective than the internal coatings were for the same type of experiment.

III. Experimental Results

Electrothermal response (ETR) experiments were performed on the internally coated matches both before and after loading. A control group of matches without internal coating was also included in the ETR experiments for purposes of comparison. Matches which had shrink tubing applied to the match exterior were not placed in the ETR experiments because it was believed that no measurable changes would be observed.

The ETR results are shown in Table I. Groups 1, 2, and 3 should have had similar SiO_2 coating thicknesses but had a range of 6.2 to 7.1 μm due to run-to-run changes in the vapor deposition process. Although large changes in the thermal conductance, γ, and the temperature rise, θ, were expected because of the application of a thermal insulator to conductive metal parts which were in contact with the pyrotechnic powder, such was not the case. The changes were relatively minor, presumably due to the very thin nature of the insulating film.

TABLE I

ETR Data Summary for Electric Matches

Group	Condition	Quantity	Average Values: Resistance R_o Ohms	Theta θ °C	Gamma γ W/°C	C_p J/°C	Tau τ msec
1	Unloaded*	25	1.068	105.6	659	20.78	31.97
2	"	24	1.067	109.2	631	20.68	33.01
3	"	25	1.049	137.0	504	19.39	39.13
4	"	25	1.064	134.8	509	21.19	41.93
5	"	20	1.024	142.1	466	19.70	42.68
6	"	50	1.032	141.6	465	19.49	41.98
7	"	50	1.039	142.9	467	19.13	41.20
1	Loaded**	25	1.085	85.0	4543	31.61	6.97
2	"	24	1.075	84.5	4527	31.13	6.88
3	"	25	1.076	80.7	4755	30.30	6.38
4	"	15	1.091	85.6	4568	29.93	6.58
5	"	20	1.033	83.2	4418	28.61	6.48
6	"	50	1.021	75.0	4834	30.51	6.32
7	"	40	1.043	87.3	4264	30.57	7.19

*Pulsed with 250 mA current for 200 msec.

**Pulsed with 600 mA current for 200 msec.

Group	Coating
1	6.8 μm SiO_2 with masked B.W.
2	7.1 μm SiO_2 with masked B.W.
3	0.4 μm SiO_2 no mask
4	6.2 μm SiO_2 no mask
5	None - Control
6	1.2 μm Parylene
7	0.34 μm Parylene

The firing characteristics of both coated and uncoated matches were determined for small samples of the matches. See Table II. Again, the changes, if any, were small enough to be within the experimental variation between samples. The difference could therefore only be determined through statistical measurements on large samples and these were unavailable.

TABLE II

Firing Characteristics of Electric Matches

	Average Values					
Group	R_o Ohm	τ_{ign} msec	E_{ign} mJ	R_{ign} Ohm	τ_{bw-brk} msec	Light Output τ msec
1	1.134	5.04	71.88	1.196	5.14	5.06
2	1.045	5.35	70.62	1.108	5.42	5.34
3	1.091	5.50	75.20	1.113	5.56	5.50
4	1.129	4.93	69.68	1.187	5.21	4.94
5	1.070	5.18	70.43	1.102	5.27	5.19
6	1.038	4.55	59.65	1.081	4.61	4.54
7	1.096	5.66	78.34	1.176	5.72	5.64

Group Code - See Table I.

Battery simulation experiments were performed with limited numbers of each match group. The shrink tubing technique was tried on matches from lots that had failed in prior battery applications and also on matches from groups 1 through 7 above. The shrink tubing technique was the only one that gave 100 percent protection in these experiments. Parylene coatings were second best. Silicon dioxide was third best. All were much better than the unprotected matches which showed 100 percent failure rates in the battery simulation experiments. Again, it must be emphasized that the battery simulation experiments produced a much more severe environment than that found in the actual battery.

The Parylene coating was tested in 10 batteries (considered to be a minimum number to show RAF problems, if present) and was found to show no current leakage. The shrink tubing is in the process of being evaluated in battery experiments as of this writing.

Postmortem analysis of the residues in the match tend to indicate that the coatings protect the match by changing the surface so that less powder residue sticks to the area between the match pins. The shrink tubing is believed to protect the match by closing off nearly 90 percent of the area for the transfer of mass and heat from the surroundings to the cavity. Residue deposition is greatly decreased and the transfer of heat into the cavity is blocked so that the electrical conductivity of the burned residues remains low. Parylene is resistant to thermal decomposition but may also absorb some heat to keep the electrical conductivity of the residue low.

Comparison of the costs of the various techniques was made based on the small quantities produced for these experiments. The quantities ranged from 25 to 100 piece parts in each group. Production in large quantities would undoubtedly reduce the cost per piece to change the absolute numbers but probably not their relative positions. Fortunately, the most effective techniques were also cheapest. The cost of shrink tubing was estimated at 3 to 5 cents. Parylene coating, applied commercially, cost $2.50 for each piece part. Silicon dioxide, commercially vapor deposited, cost about $25.00 for each piece. This also included some non-recurring fixturing costs.

The compatibility of the coatings with the match components has not been measured to date. There is no obvious reason that they would not be compatible. The ability of the shrink tubing to withstand some of the battery processing and storage environments has been questioned. However, information exists which indicates that the shrink tubing has a strong chance of surviving these environments.

IV. CONCLUSIONS

1. Two techniques have been developed for protecting electric matches (squibs) from RAF problems. In the first, heat shrinkable tubing is placed on the outer match surface so that it is activated by heat from the reaction and acts as a trap door to exclude both heat and materials from the match cavity. In the second technique, the inner surface of the match is coated with an insulator to change the character of the conductive path. Parylene and SiO_2 are examples of insulators which can be applied in a sufficiently thin layer so that there is no significant change in the firing characteristics of the match.

2. The effectiveness of the materials evaluated were shrink tubing > Parylene > SiO_2 >> nothing.

3. The most effective techniques were also the cheapest. However, the cost of coatings depends on the number processed at a time and the development of the fixtures and methods of processing.

4. Compatibility of the materials in the usage environments was not evaluated, but is expected to be acceptable.

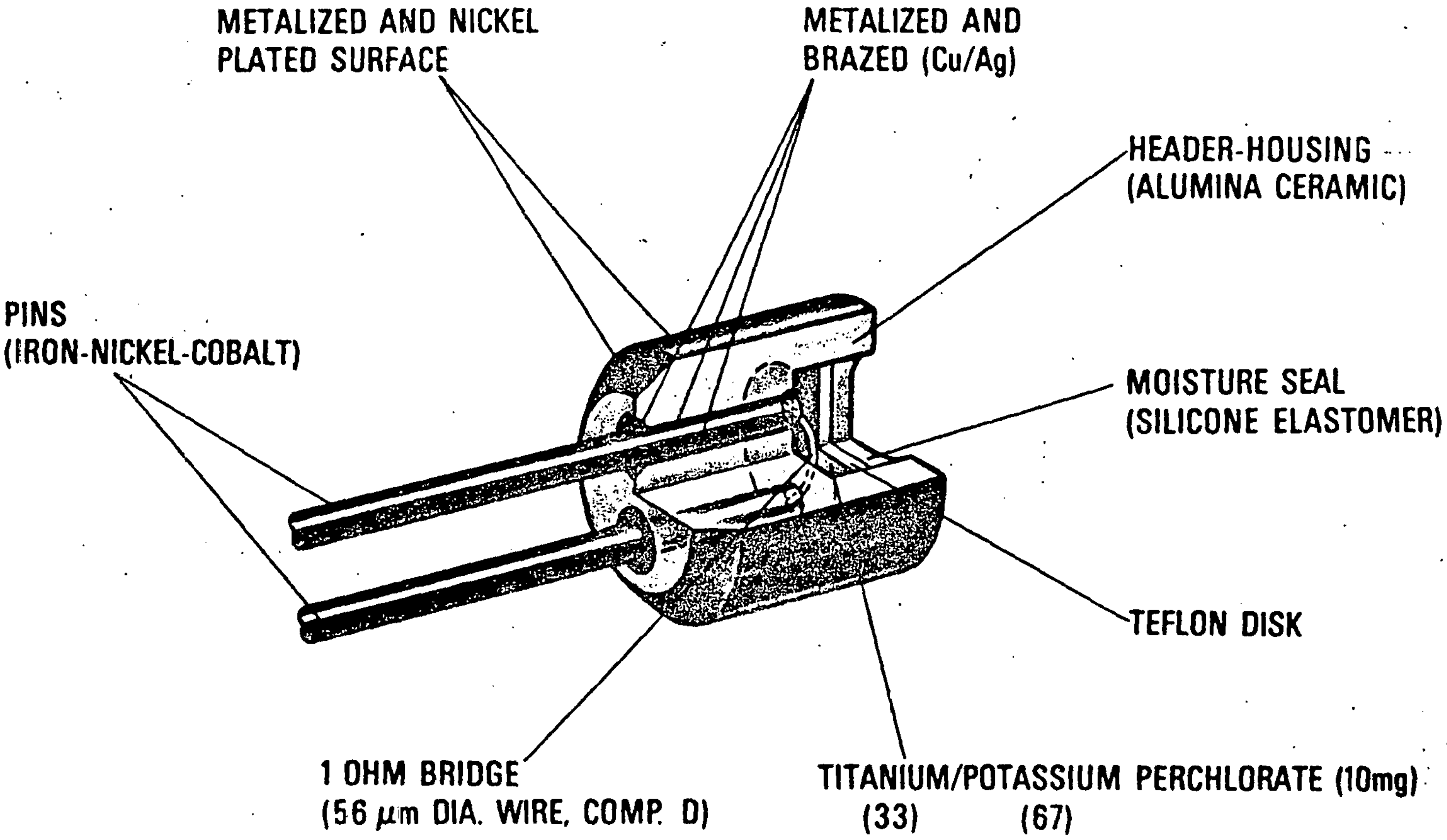

FIGURE 1. Electric Match

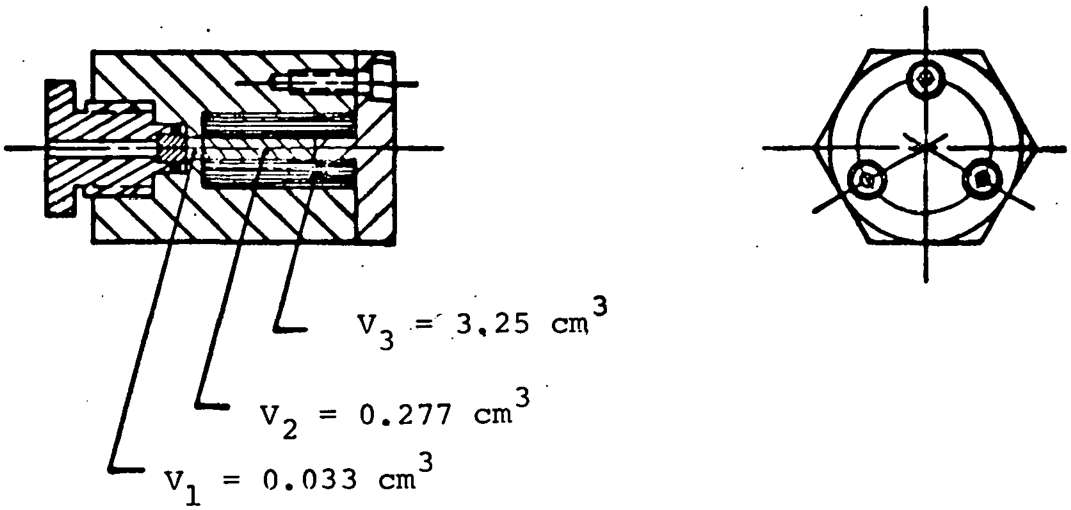

FIGURE 2. Igniter Test Fixture to Allow Changes in Confinement

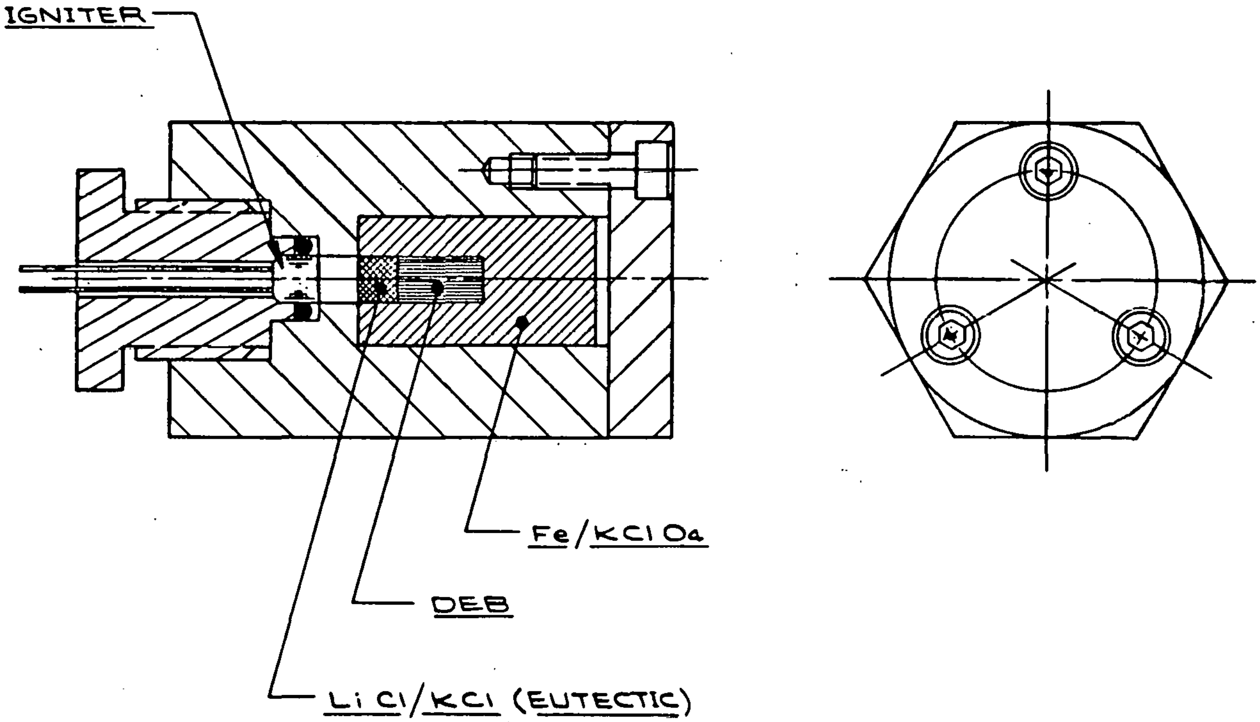

FIGURE 3. Igniter Test Fixture for Simulation of Battery Environment

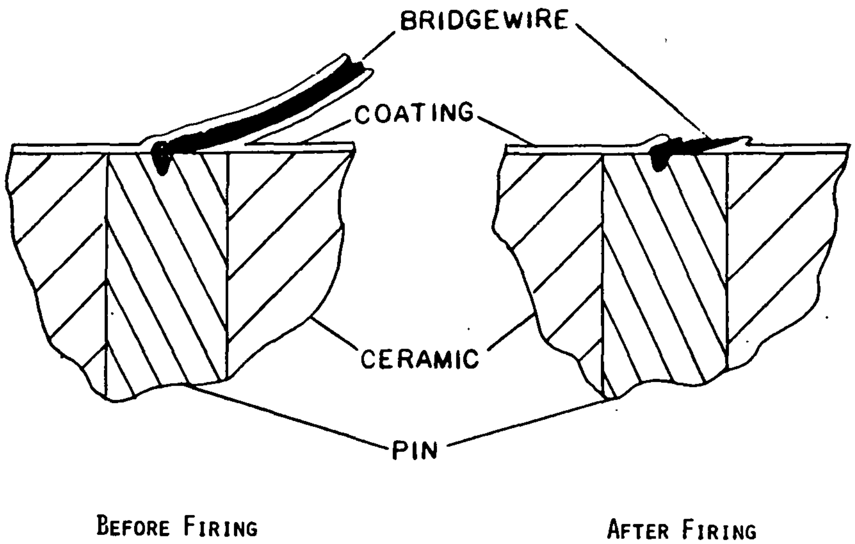

FIGURE 4. Cross-sectional Views of Pin Area of Electric Match Showing Conformal Coating

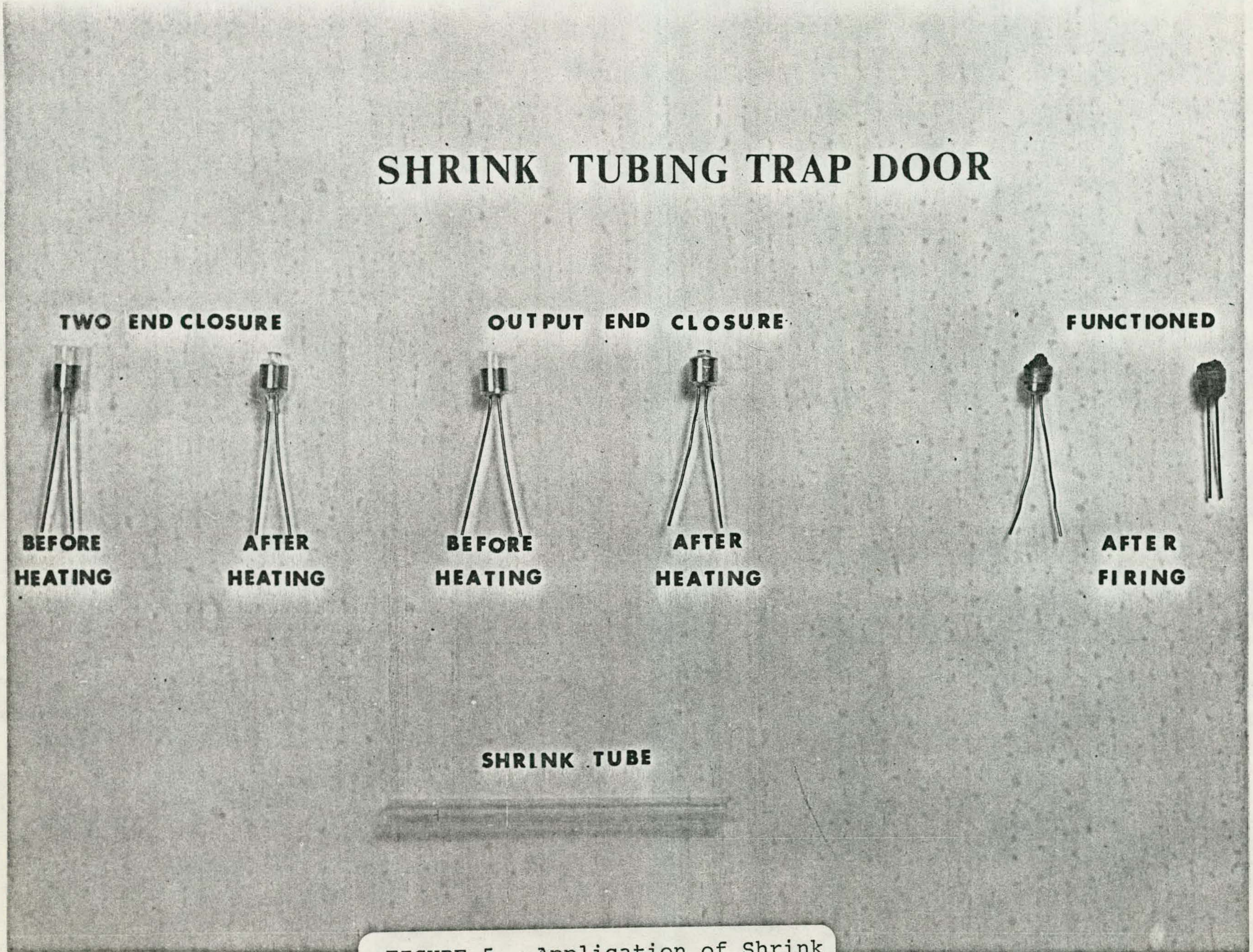

FIGURE 5. Application of Shrink Tubing to Prevent RAF