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DAMAGED BUILDING REPAIR WITH POLYURETHANE FOAM.(U)
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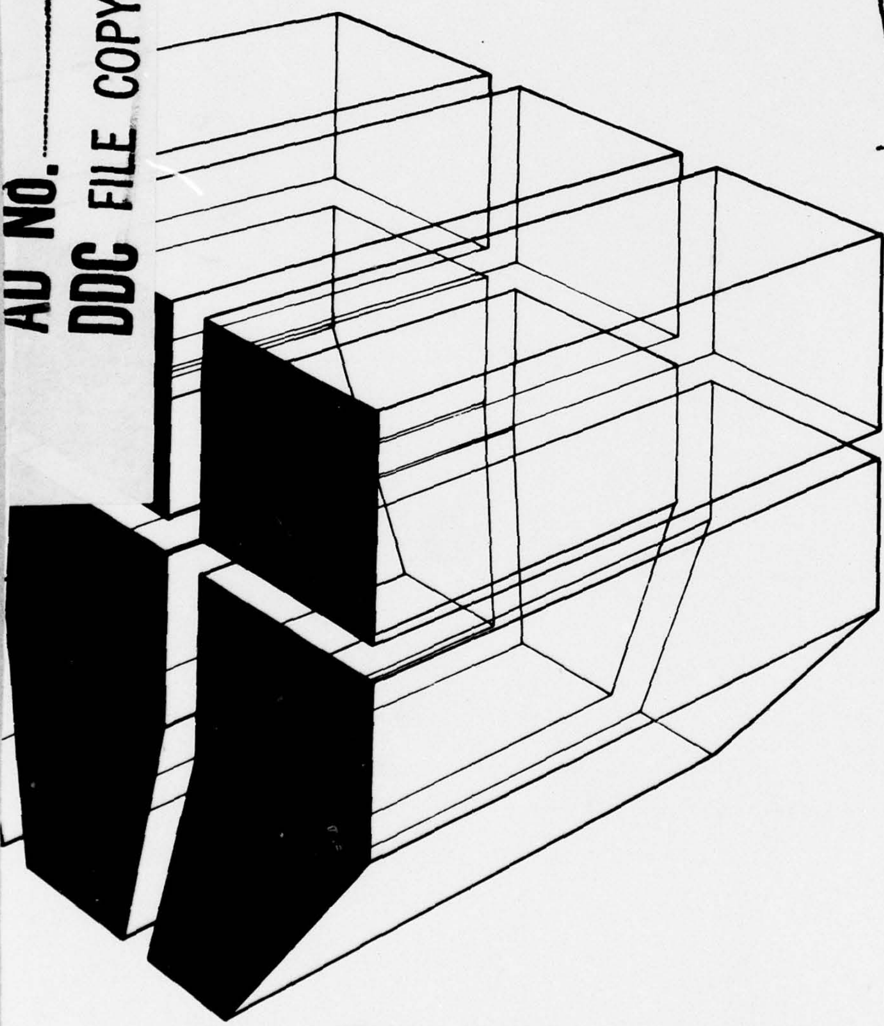
TECHNICAL REPORT M-245
June 1978
Foam Material Applications in Theater of Operations Construction

DAMAGED BUILDING REPAIR WITH POLYURETHANE FOAM



by
Alvin Smith

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The report evaluates and describes the use of foamed polyurethane plastic as a repair material in making expedient shelters from combat-damaged buildings in the theater of operations. The material was evaluated from the standpoint of use of troop labor, required substrate material, and the effect of adverse weather conditions.

This study led to the following conclusions.

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1. Spray-applied polyurethane foam is an expedient means of repairing damaged buildings. The buildings must be structurally sound, since the foam will contribute minimally to the strength of the building.

2. The foam will adhere to almost any building material and a variety of materials may be used to apply the foam to the opening. Plywood scraps, cloth, cardboard paper, and wire mesh were shown to be satisfactory substrate materials.

3. Troops with no prior experience in using foam equipment can become proficient foam sprayers with a minimum of instruction.

4. The foam can form satisfactory patches under adverse weather conditions.

FOREWORD

This investigation was conducted for the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE), under RDT&E Program 6.27.02, Project 4A762619AT41, "Research for Base Development in the Theater of Operations"; Task 08, "Base Development Design and Construction"; Work Unit 002, "Foam Material Applications in Theater of Operations Construction." The OCE Technical Monitor is Mr. G. E. McWhite.

The work was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL). Laboratory and developmental work was done at CERL.

Appreciation is expressed to SP4 Doug Stenger and SSG Doug Miezo of Company B, 747th Maintenance Battalion, and SFC Mack Davis of the 2nd Battalion, 130th Infantry, Illinois Army National Guard, for their participation in training demonstration exercises. Particular appreciation is expressed to MAJ Ed Miller for his help and enthusiasm in coordinating availability of these troops.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director. Dr. G. R. Williamson is Chief of EM.

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DAMAGED BUILDING REPAIR WITH POLYURETHANE FOAM

1 INTRODUCTION

Background

The use of existing buildings for various types of occupancy (command posts, hospitals, communication centers, etc.) has long been a common practice during war. In many cases, although buildings retain adequate structural integrity after bombardment by artillery or minor fires, they may not be habitable because they are not sufficiently weathertight. Efforts at making such buildings usable often result in makeshift repairs using any available materials.

Foamed plastic materials can be used to augment the present methods of Theater of Operations (TO) base development.[1] Foam material can be shipped in a dense (approximately 70 lb/cu ft [1100 kg/m^3], sp gr 1.12) form and foamed to a very low-density (approximately 2 lb/cu ft [32 kg/m^3], sp gr 0.03) material having usable structural properties. The conversion time is short—about 2 minutes—and the time from foam formation until it is an effective patch is less than 10 minutes.

Objective

The objective of this study was to evaluate and describe the use of foamed plastic as a repair material in making expedient shelters from combat-damaged buildings in the TO. The material was evaluated from the standpoint of use of troop labor, required substrate material, and the effect of adverse weather conditions.

Approach

A method of repairing damaged buildings was developed based on considerations of the foam's physical properties, formwork and labor requirements, and flammability (Chapter 2).

Tests were conducted to demonstrate the adequacy of the fabrication techniques and materials (Chapter 3). Part of the testing involved a demonstration at CERL in which an experimental building was damaged to simulate combat-inflicted damage. Troops from a local Army National Guard unit were briefly trained and performed the necessary building repair (Chapter 4).

Scope

This study was limited to the evaluation of polyurethane foam, which provides the greatest potential (low shipping volume, easy conversion to foam, and low skill level requirements[2]) for repairing damaged structures.

Mode of Technology Transfer

The results of this study may have an impact on the following technical manuals:

TM 5-301, *Army Facilities Component System—Planning*

TM 5-302a,b *Army Facilities Component System—Designs*, Vols I and II

TM 5-303, *Army Facilities Component System Logistics Data and Bills of Materials*

TM 5-349, *Arctic Construction*

TM 5-809-9, *Structure Design: Thin Shell Construction*

TM 5-852-9, *Arctic and Sub-Arctic Construction—Building*

TM 5-882-2, *Engineering and Design-Structure Design—Emergency Construction*

Training may be implemented by appropriate entries in ARTEP 5-115, Engineer Combat Battalion (Heavy). Construction methods and materials described herein offer an alternative to temporary shelters described in FM 20-15, *Tents, Pole and Frame Supported.*

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[1] Alvin Smith, *Dome Shelter Construction With Polyurethane Foam*, Technical Report M-225/ADA044992 (U.S. Army Construction Engineering Research Laboratory [CERL], August 1977).

[2] Alvin Smith, *Dome Shelter Construction With Polyurethane Foam*, Technical Report M-225/ADA044992 (CERL, August 1977).

2 CONSIDERATIONS

Material Properties and Availability

Previous studies have shown the versatility of spray-applied polyurethane foam.[3–5] The foam is lightweight, strong, and weathertight, and adheres to most non-oily, reasonably clean materials. Elongation properties of the foam allow most thermally induced expansion and contraction rate differences with other materials to be compensated for within the foam. Table 1 gives typical properties of the kind of foam used in this investigation.

The spray foam components are readily available commercially in large quantities in preformulated two-part systems. These systems are stable and are dense in the shipping and storage condition (liquids). Upon arrival in the TO, the liquid components are easily and quickly expanded into foam using simple equipment. Appendices A and B discuss the foam material composition and spray equipment.

Foam repair patches are applicable to wall and roof areas of otherwise structurally strong buildings. The patches can withstand typical combined wind and snow loading of about 40 psf (195 kg/m^2) without any problem. Foam is not recommended for floor applications where it must support concentrated loading when spanning between two structural members. Roof repairs should not be walked upon since unreinforced foam may not support concentrated loads.

The foam can be painted to provide added durability and camouflage, and covered with a cementitious coating to provide fire/flame spread resistance.

Formwork

In repairing structures with foam, almost any material can be used as formwork to span openings. Plastic film, cardboard from boxes, insect screen, or any similar material that can be fastened to the edges of the existing structure is satisfactory. The formwork becomes part of the patch and cannot be removed. The formwork can be fastened to the structure by nailing, stapling, taping, or simply by holding it in place while the foam is applied.

Labor Requirements

Labor intensity for foam building erection is low. A three-person team is required to operate the equipment and coordinate repair activities.

Labor skill levels can also be low. The skills associated with paint spraying are easily related to foam spraying. After a training period of about 40 man-hours, an average individual can be reasonably proficient in operating and maintaining the equipment. Even a 2-hour familiarization period is satisfactory for initial skill development in spraying the foam. Maintenance of the spray foam equipment is very important, as are troubleshooting techniques. The non-commissioned officer in charge or team leader could be easily trained to direct these functions.

Flammability

Completed patches may leave foam exposed in the interior of the building. If the exposed area is less than about 50 percent of the total wall area and is in relatively small, discontinuous patches, the building will be satisfactory for temporary use. Long-term occupancy and large areas of exposed foam may represent a fire hazard, however, since the foam will burn in an established fire.

The flammability of foamed plastics has been the object of much discussion and research in the past few years. The extremely rapid burning and highly toxic combustion products have caused a great deal of concern about the use of foams in habitable structures.

Organic (polymer) foams will burn, as will most organic materials such as wood, paper, etc. The rates of burning and the flame spread along the surface of the material depend on many factors, whose interdependency makes it impossible to cite examples and results of foams in fires, or to predict exact performance of any particular foam.

Generally, foams burn more easily than their solid polymer counterparts because of the greatly increased surface area presented for thermal decomposition of the material. A coating which impedes the thermal attack on the foam will usually greatly reduce flame spread. Cementitious materials (cement, lime, sand, and water) brushed or troweled directly on the surface of the foam have been found effective in limiting the

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[3] Alvin Smith, *Dome Shelter Construction With Polyurethane Foam*, Technical Report M-225/ADA044992 (CERL, August 1977).

[4] A. M. Kao, et al., *Prefabricated Expandable Foam/Wood Structures for Theater of Operations*, Interim Report C-45/ADA044991 (CERL, September 1977).

[5] G. R. Williamson, et al., *Inflation/Foam/Shotcrete System for Rapid Shelter Construction*, Technical Report M-215/ADA-040789 (CERL, May 1977).

Table 1
Typical Properties of Commercial Foam Systems

Density, lb/cu ft (kg/m³)	2.0 (32)
Compressive Strength (10% strain), psi (kPa)	35 (241)
Compressive Modules, psi (kPa)	1000 (6895)
Tensile Strength, psi (kPa)	38 (262)
Shear Strength, psi (kPa)	25 (172)
Shear Modulus, psi (kPa)	400 (2758)
K Factor, Btu/hr/sq ft/F/in. (W/m K)	.12 Btu (0.02)
Water Absorption, lb/sq ft (kg/m²)	0.033 (0.161)
Maximum Service Temperature, °F (°C)	200 – 250 (93 – 121)
Coefficient of Linear Expansion, in./in./°F (mm/mm/°C)	6×10^{-5} (1.1×10^{-4})

foam's fire involvement.[6] Recent tests have indicated that 1 in. (25.4 mm) hexagonal wire mesh stapled to the foam surface should be applied prior to troweling the cementitious materials. The wire mesh assists in bonding the cementitious material to the foam, and is particularly important when significant ambient temperature changes are anticipated. Since the foam *will* burn in an established fire, it is extremely important that protective coatings be applied to exposed foam very soon after the foam application is completed, preferably before other finishing operations commence.

Combustion products, whether from complete or incomplete oxidation or the molecular fragments pyrolyzed from the polymer, may be toxic. As in any fire, the most serious component is usually carbon monoxide. Other toxic species such as hydrogen cyanide may be present, but the amount is typically about the same as or less than would be formed from wood, nylon, or wool burning under the same conditions. Smoke generated by burning or partially burning foams is another problem. Dense, black, sooty smoke capable of obscuring light and visibility can be reduced by limiting the foam's involvement in a fire; this can be done by applying an effective flame-resistive coating such as the previously mentioned cementitious coatings, by using plaster, or by using some other refractory coating. Steel mesh and glass or steel fibers improve coating adherence and durability.

The relatively small sizes of TO housing structures facilitate quick exit in the event of a fire. Personnel would thus be afforded additional protection because of short potential exposure time. In most fires the heat exposure and carbon monoxide present the greatest danger to occupants. Thus, fast egress is highly desirable for any building.

In summary, although foamed plastics generally will burn, effective fire/flame-resistant coatings can be made and applied in the TO from materials that are normally available there. These coatings will afford adequate protection to personnel in the event of a fire.

3 DEVELOPMENT

Repair patches using spray-applied polyurethane foam were investigated with respect to adherence to common building materials, patch substrate materials, patch size, weather conditions at the time of patch formation, and time and material required for patch formation.

Adherence to Building Materials

Polyurethane foam is sprayed as a liquid. When the liquid contacts a surface, it wets that surface and adheres by the same mechanisms as does a paint film. Foaming subsequently occurs, usually within 10 to 15 seconds, and the foam cures rapidly. The film bond to to the substrate is usually as strong as or stronger than the strength of the foam.

Greasy or oily films prevent bonding to most substrates; otherwise the foam will adhere to any material that is reasonably free from loose dirt. Free water on the surface should be removed to the greatest extent possible, since it reacts with the foam chemicals and

[6] Alvin Smith, *Fire/Flammability Test of Polyurethane Foams and Protective Coatings*, Technical Report M-129/ADA-028386 (CERL, July 1976).

may cause an inferior foam to be formed and/or reduce the strength of the foam-substrate bond. If no surface water is present, however, effective patches are possible even when the substrate is saturated with water.

The foam bonds extremely well to concrete, wood, glass, stone, slate, and felt-type roofing materials. It also adheres to most metals but with somewhat less tenacity; galvanized metals are the poorest for bonding. In many cases the combination of adhesion and mechanical blocking by structural members makes the bond to galvanized metal sufficient for patch-type repairs.

When a repair is to be made, as much advantage as possible should be taken of mechanical locking of the patch into place. For example, the foam should extend, if possible, a minimum of 4 in. (100 mm) onto both the inner and outer face of the surrounding structure. In this way the foam can effectively seal the ruptured area.

Patch Substrate Materials

Almost any material can be used to hold the foam in place until it has cured—for example, cloth, insect screening, cardboard, plywood, lath strips, plastic film, or interwoven tree branches. These substrate materials must be attached to the building only as long as it takes to apply a continuous layer of foam over them and onto the surrounding structure. Even holes up to several inches wide in the substrate material pose no significant problem since subsequent applications of foam will close them. The substrate materials become part of the repair patch and must be left in place.

Patch Size

Repair patches up to several feet wide are possible, although the foam layer must be thicker for larger patches. The practical thickness of small patches (up to 3 ft [1 m]) is 2 in. (50 mm) minimum, and of large patches (greater than 3 ft or 1 m) about 4 to 6 in. (100 to 150 mm). The foam thickness is dictated by the degree of strength and stiffness required of the patch.

Large patches will be somewhat flexible, which does not indicate an inferior repair as long as the patch is sealed sufficiently to exclude wind-blown rain or wind.

Weather Conditions

Foam patch repairs can be made with the fewest problems on dry, warm (above 50°F [10°C]), calm days, although repairs are also possible under much more adverse circumstances. Foam repairs are not likely to be successful at temperatures below −20°F (−28° C), winds greater than 35 mph (56 km/hr), and heavy drizzle precipitation. More foam material and time will be required when the conditions are furthest from the ideal.

Extremely adverse conditions can be overcome by providing temporary shelter around a repair site. Shelter halves or ponchos can provide wind or rain shields until repair work is completed. Herman-Nelson heaters or arctic stoves can be used to raise the temperature to tolerable levels.

The temperature of the foam materials and equipment must be maintained at 40°F (5°C) or above because lower temperatures increase the viscosity of the materials to the point where pumping and mixing become extremely difficult. A heated van truck or other vehicle can maintain the required temperature; the hoses and spray gun can be strung out into the adverse environment as much as 150 ft (45 m) without loss of effectiveness.

The foam equipment should also be kept dry, because water reacting with the foam materials will cause operation and maintenance problems.

Time and Materials Required

Patch repairs are very fast and require little material. For example, a 4 × 8 ft (1.2 × 2.4 m) patch, 3 in. (76 mm) thick requires:

1. Substrate material (insect screen) stapled to the structure—about 1 lb (.45 kg); 5 minutes for installation

2. Foam—22 lb (10 kg); 5 minutes for application

3. Total time from open area to effective, weather-tight repair patch, less than 15 minutes.

Under good conditions, typical patches can be completed in less than 1 minute per square foot (0.09 m^2), using less than 1 lb (.45 kg) of foam material per square foot. Longer times and about 20 to 30 percent more material will be required under poor conditions.

4 TESTS AND DEMONSTRATIONS

Actual repair techniques were evaluated to determine their effectiveness. Holes were prepared in existing structures to represent damaged buildings, wood frames with wire mesh stapled to them were used to simulate large holes, and foam was applied to various substrate materials conditioned to −20°F (−29°C) as a check on use of the foam in adverse environments.

Figure 1 shows a large hole in a shotcrete-covered dome structure. Thin strips of wood were bent and attached to the structure. Figure 2 shows the lattice work covered with common aluminum insect window screen fabric. Figure 3 shows foam being applied to the screen; a light layer was applied to seal the screen, allowing further build-up of foam to the required thickness (about 2 in. or 50 mm). Next, the structure was shotcreted to further cover the patch.

Figure 4 shows a short training session conducted to familiarize soldiers from an Army National Guard unit with the foam spray equipment and its operation. Although the trainees had never seen either foam spray equipment or application, they were able to perform satisfactorily after less than 1/2 hour of explanation and demonstration, and a brief hands-on performance period.

Figures 5 though 8 show holes prepared for repair using insect screen, corrugated paper box, plywood and burlap, respectively, as substrate. Figure 9 shows all four holes ready for repair work to begin.

In Figure 10, a trainee is applying foam to the insect screening material. Figure 11 shows an excess of foam, which can be trimmed off with a sharp knife.

The best repair procedure is first to apply foam around the edges of the hole in order to provide a good seal to the existing wall (Figure 12). The remainder of the patch can then be filled in from the edges, as shown in Figure 13. Figure 14 shows completion of the foaming.

All four patches were completed in less than 15 minutes. Figure 15 shows the finished work. The patches were immediately wind and rain proof.

Wood frames constructed of nominal 2 X 4 lumber with hexagonal (poultry) netting and aluminum insect screen stapled along the edges were coated with foam. Figure 16 shows two configurations of these frames. One is 4 X 8 ft (1.2 X 2.4 m) with the 2 X 4's only at the edges; the other has 2 X 4's on 2 ft (0.61 m) centers. Approximately 3 in. (76 mm) of foam was sprayed onto the wire mesh. Even with the longer span (4 ft [1.2 m]) frame, this amount of foam was adequate to make a rigid patch. Figure 17 shows the rear of the frame with the intermediate member.

To determine the applicability of foam repair in cold climates, foam was applied to various substrate materials conditioned to −20°F (−29°C). The foam machine and materials were kept inside the laboratory where the temperature was about 65°F (18°C).

The four substrate materials (plywood, corrugated paper, aluminum sheet, and gypsum wall board) were left outside overnight at ambient temperature (−10°F [−23°C]) (Figure 18). As shown in Figure 19, foaming occurred more slowly on the materials that provide the greatest heat sink effect. However, after the initial delay, foaming occurs much as it does under more favorable conditions (Figure 20). There is a slight increase in the density of the foam and it takes about twice as long to react. Otherwise the foam is essentially normal. If foam build-up is too rapid, the foaming action tends to pull the unreacted surface layer away from the surface, resulting in poor bonding.

Following the test of foam on cold substrate, some foam was sprayed directly onto a pile of snow. The first few layers did not foam, but after a thin layer of the foam material was deposited, the remaining layers foamed normally. The heat given off during foaming caused only slight melting of the snow. The initial layers of material cured into a hard, coarse surface on the underside of the foam.

The foam used in the cold weather application study was the same formulation as was used at the higher temperature conditions. No special precautions were used except keeping the machine and materials warm.

5 CONCLUSIONS AND RECOMMENDATIONS

1. Spray-applied polyurethane foam is an expedient means of repairing damaged buildings. The buildings must be structurally sound, since the foam will contribute minimally to the strength of the building.

2. The foam will adhere to almost any building material and a variety of materials may be used to apply the foam to the opening. Plywood scraps, cloth, cardboard paper, and wire mesh were shown satisfactory for this purpose.

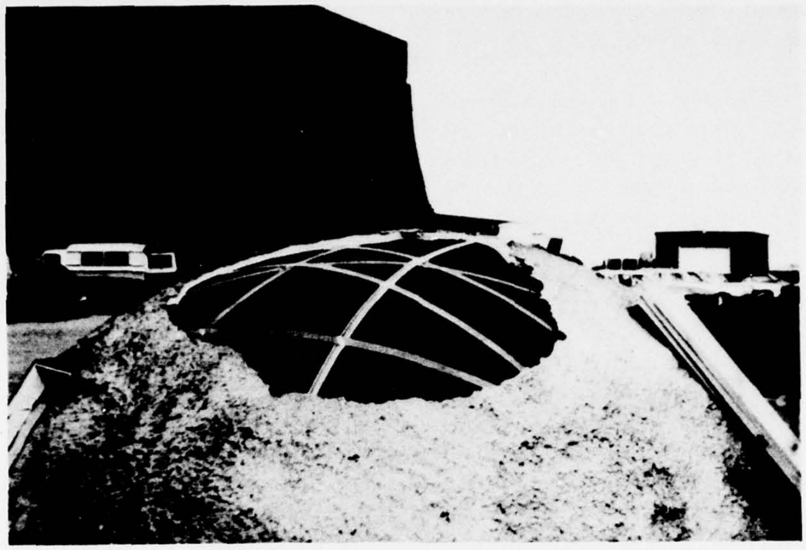

Figure 1. Hole in dome structure. Wood lath strips attached to give required shape.

Figure 2. Aluminum screen wire in place.

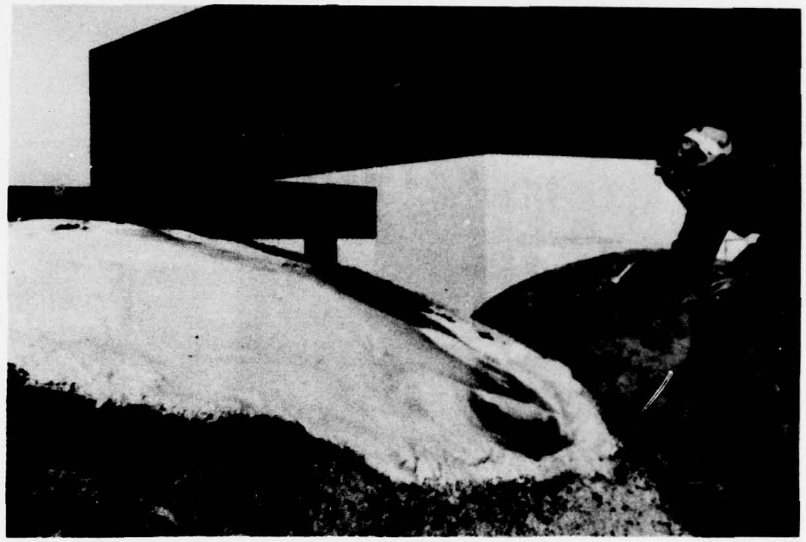

Figure 3. Foam spray application on screen wire to form patch.

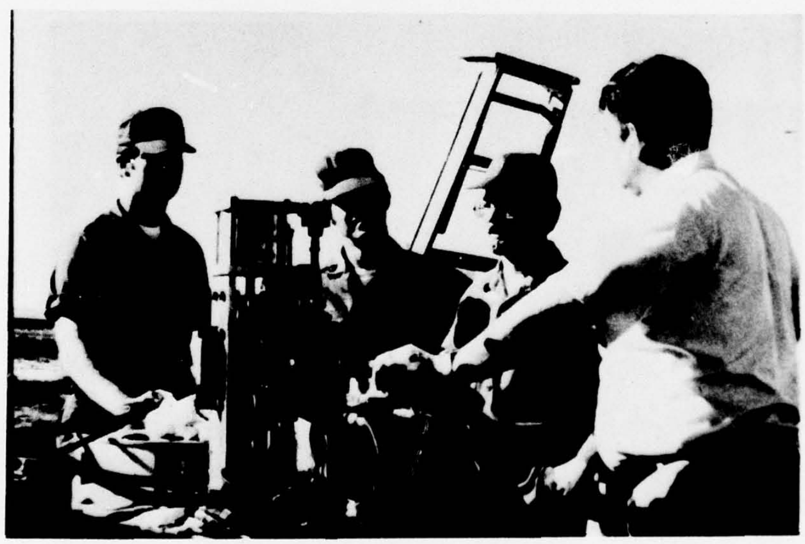

Figure 4. National Guardsmen participating in a brief training exercise.

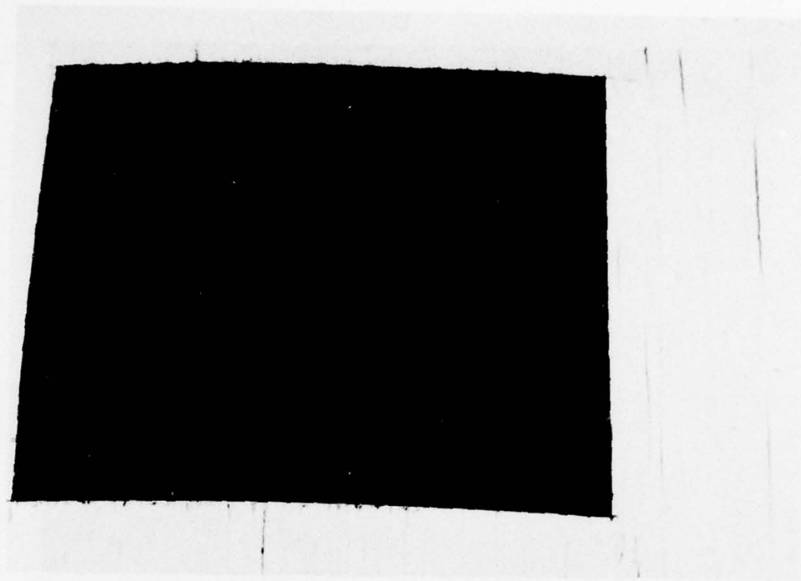

Figure 5. Prepared hole with insect screen substrate in place.

Figure 6. Prepared hole with corrugated cardboard substrate.

Figure 7. Prepared hole with plywood substrate.

Figure 8. Prepared hole with burlap fabric substrate.

Figure 9. A view of the four test holes.

Figure 10. Spray foam being applied to insect screen substrate to make patch.

Figure 11. An excess of foam may be applied and trimmed off, if desired.

Figure 12. Application of foam to the edge of the hole first.

Figure 13. Filling in the remainder of the repair patch with foam.

Figure 14. Completing the patch.

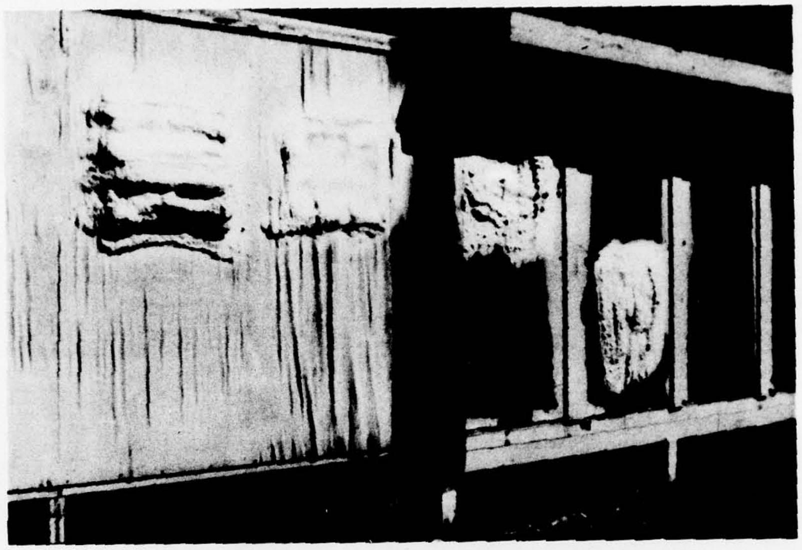

Figure 15. The four holes completely repaired.

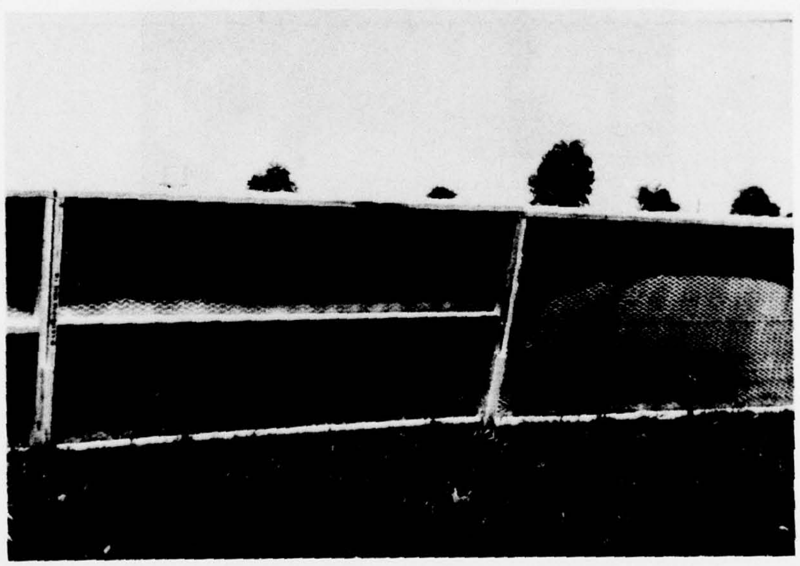

Figure 16. One large frame with an intermediate stud and one without.

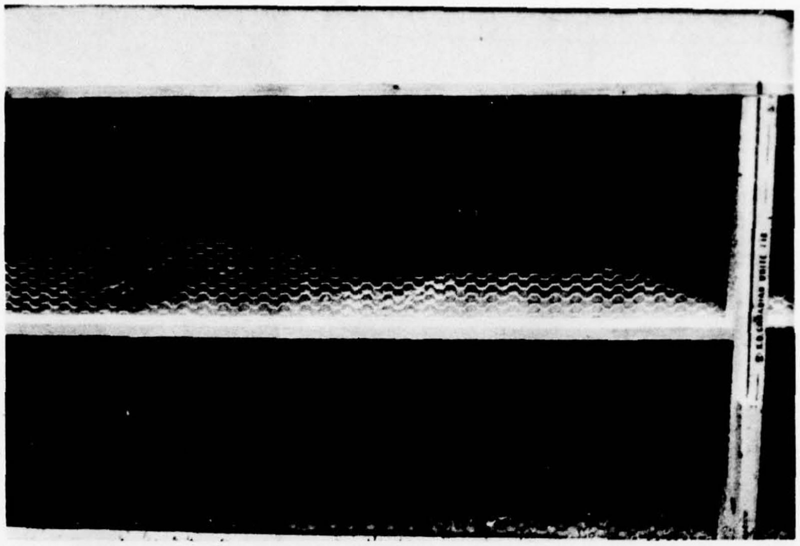

Figure 17. Rear view of large frame with intermediate stud, showing more detail of hexagonal netting substrate.

Figure 18. Four substrate materials (plywood, corrugated paper, aluminum sheet, and gypsum board, from front to rear) conditioned and ready for foam spray.

Figure 19. Heat sink effect on foaming. All four materials were coated with the same approximate thickness of foam spray.

Figure 20. After initial material layer is deposited, foaming of the sprayed material proceeded essentially normally.

3. Troops with no prior experience using foam equipment can become proficient foam sprayers with a minimum of instruction.

4. The foam can be applied under adverse weather conditions to form satisfactory patches.

It is recommended that the techniques described be added to the appropriate technical manuals and training doctrine and that the necessary equipment and materials be added to the inventory to allow the rapid repair of structurally sound, perforated buildings in the TO.

APPENDIX A: POLYURETHANE FOAMS AND FOAM SYSTEMS

Formation

Polyurethane foams result from a set of carefully controlled chemical reactions and physical phenomena. This section describes the materials and reactions used in forming polyurethane foams.

"Polyurethane" refers to a family of polymers based on the reaction of an isocyanate group with some other reactive group, particularly the hydroxyl group. The resulting polymer is not a foam; it may be in any form from a soft, flexible rubber to a hard, glassy material. Polyurethane foams are formed by generating a gas within the polymer as polymerization reactions occur. The gas forms bubbles which are entrapped until the polymer is completely formed, resulting in a cellular structure.

The gases generated in a foam polyurethane mixture arise from (1) reaction of a calculated amount of water with an equivalent excess of isocyanate (above that required for the polymer) proceeding through several steps and ultimately producing carbon dioxide gas, or (2) including in the mixture a predetermined amount of a low boiling point liquid such as a halocarbon (Freon), which is volatized by the heat from the exothermic polymerization reactions, thus creating a gas which is trapped in the polymer mass.

The constituents of a typical polyurethane foam mixture include:

1. Isocyanate. The isocyanate group consists of R - N = C = 0, in which the single bond from the N is attached to a larger molecule R. In order for polymer chain growth to occur, two or more isocyanate groups must be attached to each larger molecule.

2. Polyol. Often referred to as the "resin," it consists of R′ - OH groups attached to a larger molecule R′. As with the isocyanate, it is necessary for two or more OH groups to be attached to the same molecule for the polymer molecule to grow to great length.

3. A foaming agent—either water or halocarbon as previously described.

4. A cell control agent or surfactant is usually required to modify the viscosity and/or surface tension of the mixture to insure that gases formed are trapped and retained and that the bubbles will generally be of the same size. Certain detergents and silicone oils are used widely as surfactants.

5. Catalysts are used to regulate the start and the rates of reactions leading to the polyurethane polymer. Often two or more catalysts are required to achieve the desired results. When water is included in the formulation to cause foaming, a catalyst favoring a water-isocyanate reaction is required.

6. Flame retardants of phosphate character, antimony oxide, chlorine, or bromine are frequently used to reduce the foam's ease of ignition or rate of burning. They will not, however, prevent burning of the foam in a sustained fire. The high surface-to-volume ratios of foams tend to increase flammability problems.

When the materials listed above are mixed in the proper proportions, reactions, typified by

isocyanate polyol

-R - N = C = O + HOR′-

```
      H   OR′-
      |   /
 -R - N - C = O
 polyurethane
```

occur. The resulting group is called a urethane. Formation of many such groups results in a polymer network. The average chain-to-chain connection (crosslink density) and the average distance between urethane groups gives the final polymer its rigidity properties.

The amount of gas formed determines the density of the foam; density may be varied from about 1.5 to 50 lb/cu ft (24 to 980 kg/m^3).

Physical Properties

The foam's physical properties depend on rigidity and density. Commercial foam systems are normally preblended into two materials—isocyanate and resin blend (polyol, surfactant, blowing agent and catalyst) designed to give 2 lb/cu ft (32 kg/m^3) density foams. This combination yields foams that have the typical properties listed in Table A1.

These values in Table A1 can be used for estimating purposes. Since these properties are considered typical, however, a particular foam system should be specifically evaluated for a particular application.

Higher density foams are generally stronger structurally but have poorer insulating qualities.

Cost

In general, commercial foam systems for 2 lb/cu ft (32 kg/m^3) foam cost between \$.60 and \$.70/lb (\$1.32 and \$1.54/kg). Special formulations may cost more, and a premium is usually added for small quantity orders. Since the isocyanate and resin are derived from petroleum or natural gas, the price may vary accordingly.

Shelf Life

The effective shelf life of a foam system depends largely upon two things—storage conditions and catalyst deterioration. Storage conditions will shorten the shelf life if the materials are stored at either extreme of the optimum storage temperature range—50° to 90°F (11° to 32°C). More critical is the deterioration of the catalyst in the resin blend. If long storage is anticipated, the catalyst should not be blended in until ready for use, and the entire resin blend should be agitated and stirred thoroughly.

Most commercial formulations are guaranteed for at least 6 months in original unopened containers. Many foam systems are dependable for much longer than that—in some cases up to 3 or 4 years.

Sources

There are numerous producers of polyurethane foam systems in the United States. Representative companies include:

1. Cook Paint and Varnish Co.
   1412 Knox St.
   P. O. Box 389
   Kansas City, MO 64141

2. Freeman Chemical Corp.
   P. O. Box 247
   Port Washington, WI 53074

3. General Latex and Chemical Corp.
   666 Main St.
   Cambridge, MA 01922

4. Isochem Resins Co.
   99 Cook St.
   Lincoln, RI 02865

5. Mobay Chemical Corp.
   Division of Baychem Corp.
   Penn Lincoln Parkway West
   Pittsburg, PA 15205

6. PPG Industries
   P. O. Box 127
   Springdale, PA 15144

7. Reichold Chemicals, Inc.
   525 N. Broadway
   White Plains, NY 10602

8. Sherwin-Williams Co.
   11541 S. Champlain Ave.
   Chicago, IL 60628

9. The Upjohn Company
   CPR Division
   555 Alaska Ave.
   Torrance, CA 90503

10. Witco Chemical Corp.
    Isocyanate Products Division
    900 Wilmington Rd.
    New Castle, DE 19720

APPENDIX B: POLYURETHANE FOAM-MIXING EQUIPMENT

Generating a good quality foam requires that the foam system components be properly mixed in the proper proportions. Improperly mixed foams may appear to be good but not be stable over a long period of time, or they may not possess the desired strength or insulative qualities.

Numerous manufacturers of paint-spraying equipment have made and sold foam-spraying equipment. Foam-spraying equipment, however, is considerably more complex and requires better maintenance than does paint-spraying equipment. Since isocyanates react with moisture in the air, the equipment must be cleaned after each spray period.

Basically, a foam-spraying machine must do several things: (1) it must accurately and dependably deliver the foam material components in the proper proportions; (2) it must provide adequate mixing to assure near homogeneity of the blend, and (3) it must be manageable by an operator; i.e., the operator must be able to spray the mixed material without excessive difficulty.

Both portable and "stationary" units are commercially available. Most models can accomodate up to 150 ft (45 m) of spray hose. Additional features may be incorporated into the machine design. Heaters may be provided to raise the material temperature. Hoses may also be heated and/or insulated. Some circumstances (spraying foam in cold weather) may make such features necessities rather than optional items.

Figure B1 shows a typical foam sprayer in schematic form. Table B1 provides a partial list of companies which market equipment and can provide information concerning operation, cost, and maintenance. Most sprayers require compressed air at the rate of about 15 cfm (0.42 m^3/minute) at 100 psi (689 kPa) pressure and 220 V, single-phase electrical power.

While foam spraying is relatively straightforward, operators should be trained in the proper use and maintenance of the equipment. Normally, a 1-week course can provide all necessary training in setup, operation, troubleshooting, and maintenance procedures.

Maintaining a ready supply of repair and/or replacement parts is advisable to avoid downtime in case of a malfunction. Experienced manufacturers are aware of the more common high-mortality parts and can suggest a basic stockage list. They also usually offer quick response to orders for repair parts. Proper training will provide the operator with enough knowledge to replace parts as needed.

The industrial/commercial users of spray foam equipment recommend purchasing and maintaining the simplest piece of equipment capable of doing the desired job. Options on the machine can often cause problems in handling, operation, and maintenance. In addition, these options may represent a substantial increase in the original cost of the equipment.

Spray foam equipment usually costs from $3000 to $10,000, depending on the volume capability and the extra items included.

Foam production capability ranges from about 2 to about 20 lb/minute (0.9 to 9.1 kg/minute). Larger outputs are possible, but may cause problems, in that the operator may not be able to move about fast enough to make full use of the output. For example, a 20 lb/minute (9.1 kg/minute) machine can produce 10 cu ft (0.28 m^3) of 2 lb/cu ft (32 kg/m^3) foam per minute. If a 1-in. (25 mm) layer is being applied, the 10 cu ft (0.28 m^3) would cover an area of about 60 sq ft/minute (5.6 m^2/minute) of operation. Area coverage at this rate would obviously require frequent movement.

Table B1
Partial List of Foam Spray Equipment Manufacturers

Accuratio Systems, Inc.
1472 South Floyd St.
Louisville, KY 40208

Admiral Equipment Division
Upjohn Co.
305 West North St.
Akron, OH 44303

Binks Manufacturing Co.
Plastic & Resin Equipment Division
9201 West Belmont Ave.
Franklin Park, IL 60131

Glas-Craft of California
9145 Glenoaks Blvd.
Sun Valley, CA 91352

Graco, Inc.
60 Eleventh Ave. NE
Minneapolis, MN 55441

Gusmer Corp.
P.O. Box 164
414 Rt. 18 Spring Valley Rd.
Old Bridge, NJ 08857

North American Urethanes, Inc.
Keytum Engineering Division
1717 Boettler Rd.
Uniontown, OH 44685

The Martin Sweets Co., Inc.
3131 W. Market St.
Louisville, KY 40212

Venus Products, Inc.
1862 Ives Ave.
Kent, WA 98301

A good, practical output is about 8 to 10 lb/minute (3.6 to 4.5 kg/minute), representing 25 to 30 sq ft/minute (2.3 to 2.8 m^2/minute) of coverage.

Foam spray systems are also available in throwaway dual aerosol container kits in sizes producing 9.5 board feet* (0.88 m^2), to 180 board feet (16.7 m^2) and 600 board feet (55 m^2) of 1.75 pcf foam (28 kg/m^3). These kits weigh about 2, 30, and 95 pounds (1, 13.6, and 43.2 kg), respectively, and are available from Insta-Foam Products, Inc., 2050 Broadway, Joliet, IL 60435.

The throw-away packaging increases the cost of usable foam from about $.70 per pound to as much as 20 times that amount.

*A board foot is 1 ft square by 1 in. thick (0.093 m x 0.093m x 25.4 mm).

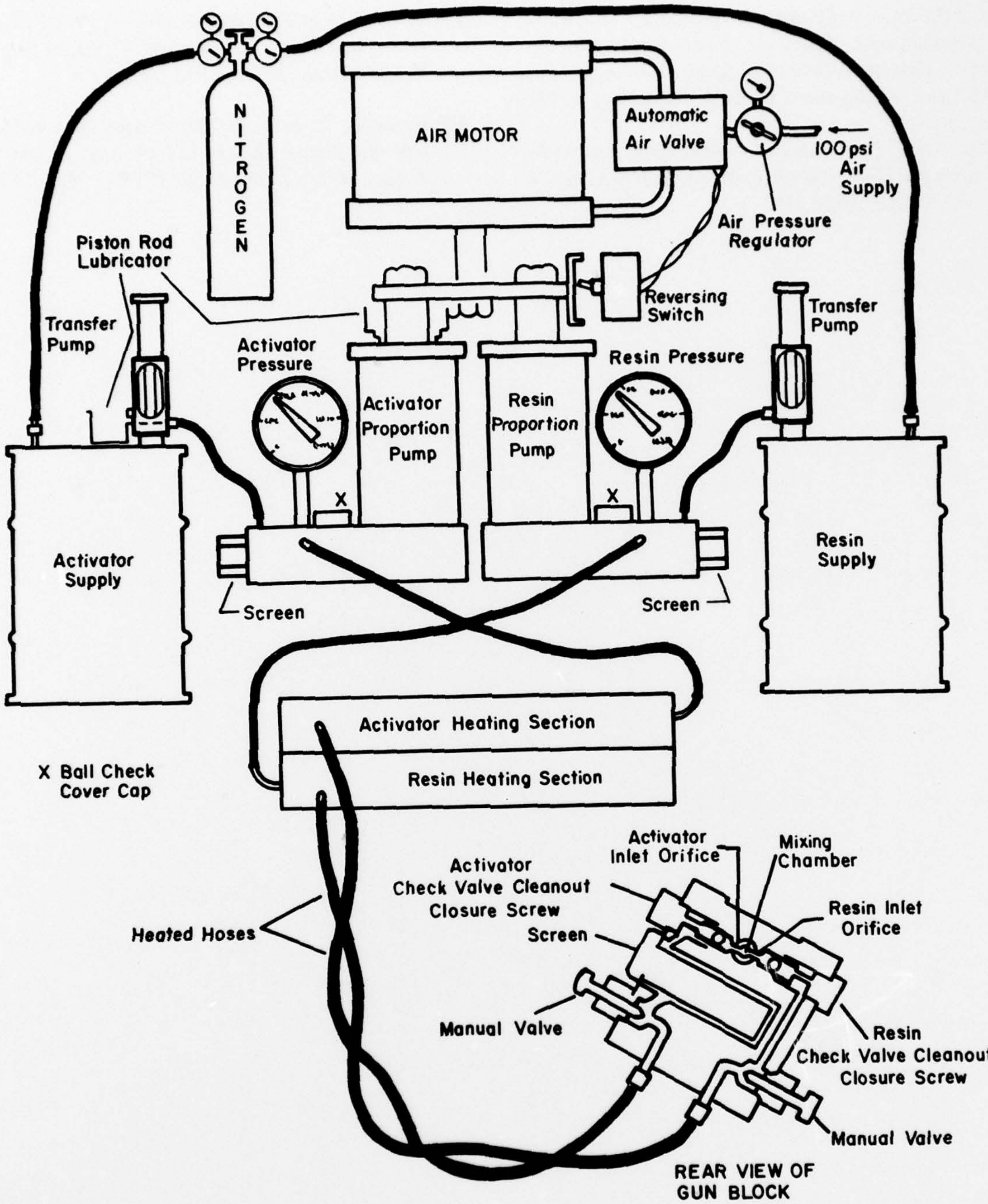

Figure B1. Basic component schematic (spray equipment). This model is manufactured by Gusmer Corporation.

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