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Concepts and Approaches for Minimizing Excessive Exposure to Electromagnetic Radiation from RF Sealers

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Food and Drug Administration

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Concepts and Approaches for Minimizing Excessive Exposure to Electromagnetic Radiation from RF Sealers

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BRH
bureau of radiological health

WHO Collaborating Centers for:
- Standardization of Protection Against Nonionizing Radiations
- Training and General Tasks in Radiation Medicine
- Nuclear Medicine

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FOREWORD

The Bureau of Radiological Health develops and carries out a national program to control unnecessary human exposure to potentially hazardous ionizing and nonionizing radiations and to ensure the safe, efficacious use of such radiations. The Bureau publishes the results of its work in scientific journals and in its own technical reports.

These reports provide a mechanism for disseminating results of Bureau and contractor projects. They are distributed to Federal, State, and local governments; industry; hospitals; the medical profession; educators; researchers; libraries; professional and trade organizations; the press; and others. The reports are sold by the Government Printing Office and/or the National Technical Information Service.

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WHO Collaborating Center for Standardization of Protection Against Nonionizing Radiations;

WHO Collaborating Center for Training and General Tasks in Radiation Medicine; and

WHO Collaborating Center for Nuclear Medicine.

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John C. Villforth
Director
Bureau of Radiological Health

PREFACE

Studies and analyses of the radiation characteristics of electronic devices are a central part of the program of the Division of Electronic Products in the implementation of The Radiation Control for Health and Safety Act of 1968. Previous reports in this series have dealt with products as diverse as CB radios, microwave and shortwave diathermy, lasers, and television receivers. Because of the high power levels employed, the operators of radiofrequency (rf) dielectric sealers can be exposed to electromagnetic field strengths that exceed, by far, all existing personnel exposure standards. The studies described in this report were undertaken to assess various means for reducing exposure to these operators. Some of the methods reported have been used by industry (both user and manufacturer) to reduce radiofrequency interference but, in some cases, appear to be effective in reducing personnel exposure as well. One method in particular, that of shielding the active electrode of the sealers, offers the most promise and is discussed through photographic examples, analytical assessment, and field-strength measurements.

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ABSTRACT

Ruggera, Paul S. and Daniel H. Schaubert. Concepts and Approaches for Minimizing Excessive Exposure to Electromagnetic Radiation from RF Sealers. HHS Publication (FDA) 82-8192 (July 1982), 25 pages.

Radiofrequency (rf) dielectric plastic sealers are used to bond together or emboss plastic materials. During the process, operators of the sealers can be exposed to high levels of radiofrequency radiation. This report addresses means by which an operator's exposure can be reduced and discusses some of the various approaches taken by both users and manufacturers of rf sealers to reduce that exposure.

CONTENTS

LIST OF FIGURES

CONCEPTS AND APPROACHES FOR MINIMIZING EXCESSIVE EXPOSURE TO ELECTROMAGNETIC RADIATION FROM RF SEALERS

INTRODUCTION

Radiofrequency (rf) dielectric sealers and heaters, referred to hereafter as rf sealers, have been identified as sources of potentially excessive exposure to rf radiation (1). Because of the possible health hazards to rf sealer operators and to other personnel who may be in the vicinity of the machines, the Bureau of Radiological Health (BRH), the Occupational Safety and Health Administration (OSHA), and the National Institute of Occupational Safety and Health (NIOSH) have been gathering data on the rf leakage from sealers (2). In addition, BRH has recently conducted a survey of 5 rf sealer manufacturers to determine the state-of-the-art in techniques for protecting operators from excessive exposure to rf fields.

This report describes the 2 basic approaches to operator protection, emission controls and exposure controls, and presents (through manufacturer-supplied photographs) some specific examples of methods for properly shielding an rf sealer. Furthermore, the results of testing by BRH, OSHA, and NIOSH of 2 well-shielded units are presented, including dramatic evidence that misuse or abuse of properly designed shields can result in increased operator exposure. Finally, a few simple analytical methods for estimating the effectiveness of some shielding techniques and for determining operator exposures are presented.

BACKGROUND

In recent years increased public awareness of the potential health risk from electromagnetic radiation has surfaced. This has come about as a result of (1) a better understanding of the interactions of electromagnetic energy with the human body, (2) the vast increase in the use of consumer electronic products that use other-than-conventional energy transfer (microwave ovens, for example), and (3) the development of new measurement instrumentation which enables the quantification of rf radiation in the vicinity of the user.

RF sealers are not new products. (A schematic diagram of an rf sealer is shown in Figure 1, and a complete description of an rf sealer operation is presented in the Encyclopedia of Polymer Science and Technology (3)). In the past, shielding has been incorporated by rf sealer manufacturers primarily for two purposes: (1) to prevent interference with communications when the sealers are operated outside the Federal Communications Commission (FCC) assigned ISM bands (ISM frequencies of interest here are centered at 13.56 MHz, 27.12 MHz, and 40.68 MHz), and (2) to "cool" hot units operating at ISM frequencies but exhibiting extremely high emission levels. These emission levels were high enough to actually be "felt" (as heat or tingling) by those who were constructing and testing the sealers in the manufacturing plant. These shielding techniques have been demonstrated to be effective for the two purposes cited, and it is likely that they also would be effective in radiation protection for the operator.

Five companies were contacted and they have supplied photographs of shielded products for this report: Radio Frequency Company, Inc., Medfield, Massachusetts; Compo Industries, Inc., Waltham, Massachusetts; Cosmos Electronic Machine Corp. and Kabar Manufacturing

Corporation (merged), Farmingdale, New York; Solidyne, Inc., Bay Shore, New York; and High Frequency Technology Company, Inc., sales division of Hall Dielectric Machinery Company, Inc., Deer Park, New York. The discussion that is incorporated in this report should not be singled out to reflect the views of any one of the companies listed above, as it represents the results of information received by the authors during visits with manufacturers, together with 5 years' experience conducting measurement surveys in user facilities.

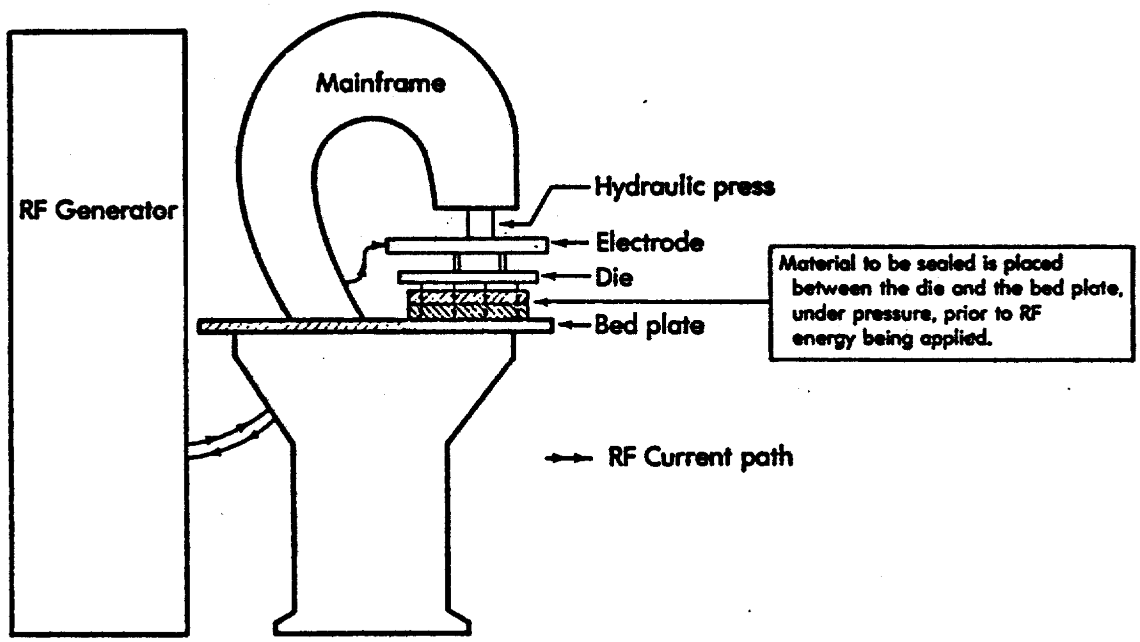


Figure 1. Schematic diagram of rf sealer components and path of rf current.

METHODS OF SHIELDING AND THEIR EFFECTIVENESS

In general, shielding for operator protection can be accomplished in two ways. First, the operator can be physically moved away from the rf sealer to a distance that is sufficient to reduce the exposure field to acceptable levels (through radiation attenuation in free space). This technique will be referred to as exposure control. Second, the radiation may be contained at the source so that exposure fields above acceptable levels are not encountered at any distance. This technique will be referred to as emission control. These techniques can also be stated in terms of exposure standards and emission standards. Exposure standards follow the first technique; that is, exposure to personnel will not occur above a predetermined level. Examples are the American National Standards Institute (ANSI) radiation protection guideline (4) and the OSHA standards (5). On the other hand, a product emission standard is based on performance of the unit itself, and specifies the maximum radiation field permitted at a given distance from the product, without regard to the position of the operator. An example of this is the microwave oven emission standard which sets the measurement distance at a fixed distance from any surface of the product. (Even though the product emission standard is an effective means of controlling operator exposure, the term exposure control is reserved, in this document, to refer exclusively to control of the environment of the radiation device, and not to control of machine design.) The majority of measurements taken to date to assess rf sealer radiation have been on an "exposure" basis.

The operator location is the key factor in this type of assessment. Exposure control is instituted anywhere personnel might be located.

The remainder of this report presents examples and discussions of methods that have been and are being applied to achieve emission control and exposure control during the use of rf sealers.

EXPOSURE CONTROL

During a visit to a user facility a large banner was observed hanging from the ceiling. It was intended to warn the operators not to come within 3 feet of the rf sealer when it was on. This method of exposure control could have been effective, since the "on" and "off" controls of the rf sealer were located on pedestals that had enough connecting cable to allow them to be placed 3 feet from the machine. It was observed, however, that the operators were located approximately 1 foot in front of the unit where exposure fields were higher than the ANSI recommended maximum rf field strengths (4). During the radiation measurements one of the operators remarked that the investigator should go behind the machine to measure the fields - the sign was hanging above the back of the machine and the operator had assumed that the high fields to be avoided were under the sign (that is, behind the sealer near the AC power lines).

The warning sign for exposure control was relatively ineffective for this particular operation because the operation was a repetitive one that used large pieces of material which were drawn through the unit between sealing cycles. It was obviously inconvenient for the operators to set the material in place, step back 3 feet, activate the sealer, return from the 3-foot distance and set the next piece to be sealed. Since efficient production depends on minimum delay between cycles, fewer steps by the operator contribute to time saved. This example illustrates that signs may be the simplest method of exposure control, but they are not necessarily the best. The signs may be ignored or misunderstood. It does not seem that signs alone will protect the worker who works on a production basis.

Another method of effecting exposure control, which removes the operator from the vicinity of the source of rf radiation (and which has been in use for some time), is the "shuttle tray." Figure 2 shows an example of the shuttle tray sealer. Two operators are required instead of one. Each occupies a position at one of the two control locations shown in the figure. The shuttle tray design was originally introduced to increase efficiency in production, because the shuttle tray could be loaded from one side, while the other tray was being sealed. In terms of reducing radiation to the operators, however, this design resulted in a greater distance between the operator and the active electrode (compared to the "normal" position directly in front of the sealer). This type of exposure control does offer some benefit, provided that proper care has been taken to attach the shuttle mechanism to the sealer to assure that the shuttle "wings" don't act as antennas.

EMISSION CONTROL

Some sealers are designed with a large metal trough behind and below the bed plate to accommodate a roll of plastic. In some cases "warmth" can be felt at distances of up to 5 feet from this type design. (This is referred to by the industry as a "hot" sealer.) At the request of one plant manager, the manufacturer corrected the problem by placing additional grounding plates and straps on the unit.

We have learned, through recent visits to sealer manufacturers, that "hot" units usually come into existence when specially designed units are produced. In most instances, the leakage problems are detected at the factory while the sealer is being manufactured and additional efforts are taken at that time to "cool" the sealer. This is how sealer manufacturers gain experience with shielding.

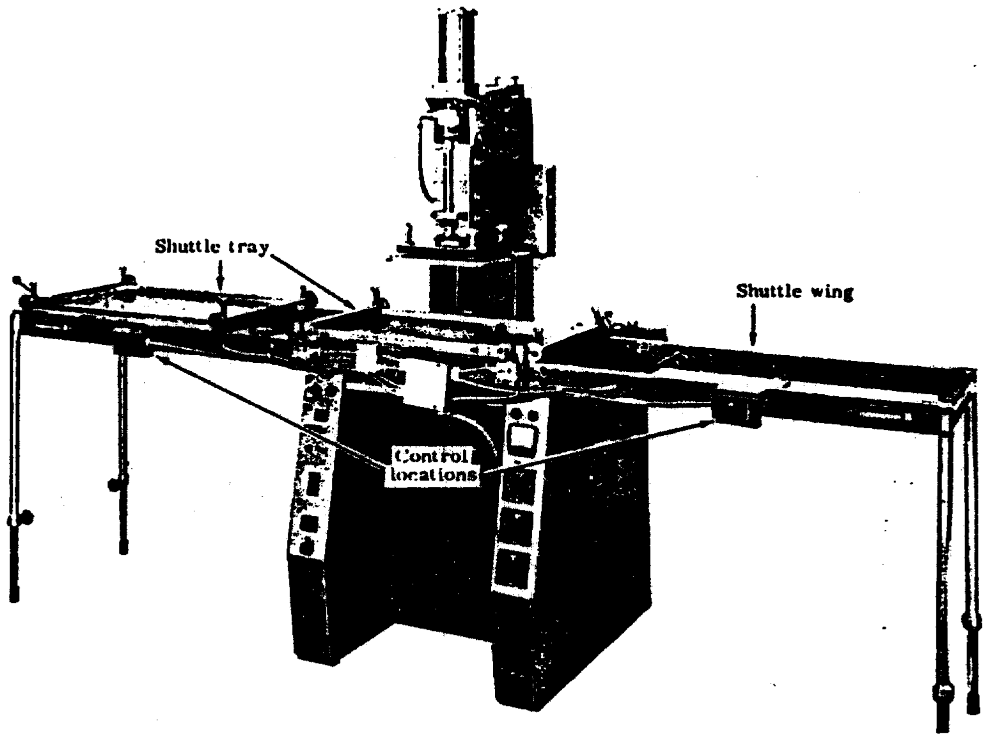


Figure 2. Thermatron shuttle tray sealer without rf shielding.

Another form of emission control in widespread use by rf sealer users is screen-room enclosures. In almost every user location visited, a metal screen-encased room that usually housed the older models of rf sealers--and of course, their operators--was observed. In terms of radiation control for the rest of the plant, and for the outside world's communications (FCC considerations), this is a very effective solution. However, the operators of these "noisy" units, which would not comply with FCC regulations outside the screen room, may receive a higher dose of rf energy than they would had the screen room not been constructed. This increase in exposure will be discussed further in the section on "Effects of Ground Planes and Reflectors on Operator Exposures."

Just as the screen room may enhance exposure to operators, improper "shielding" by "instant experts," armed with inadequate knowledge and inappropriate instrumentation, may create a worse exposure situation. Portions of a formerly well-shielded machine could also be rendered ineffective and cause more radiation by simple misuse or partial removal of the shield. In order to determine the effectiveness of the shield, it is essential that both the electric and the magnetic components of the radiation be measured. The shielding removal experiment, to be discussed, will also show that while one may reduce the electric field to quite a low level, the magnetic field could be amplified when compared to the unshielded case, and vice versa. Due to this measurement requirement, instrument manufacturers are now responding by making available new instrumentation that operates in this frequency range. Manufacturers who have (or plan to have) such instruments include the following: Narda Microwave Corporation, Instruments for Industry, Holaday Industries, Amplifier Research, and General Microwave Corporation. These instruments, along with some being designed by BRH (6), have been (7) or will be evaluated by the Bureau to determine if they are suitable for accurately measuring these fields.

Specific examples of shielded machines were provided by the 5 rf sealer manufacturers that were visited, and photographs of these shielded machines were given to BRH for publication. Many of the units pictured are in use in the customers' plants and we were unable to go to these facilities to make radiation measurements. However, it is the purpose of this report to present what has been done (and could be done on a wider scale) to reduce radiation through "emission control" shielding. Thus, these photographs and the available measurements are used to document the "state-of-the-art."

EXAMPLES OF SHIELDED RF SEALERS

Radio Frequency Company, Inc., produces primarly customized, one-of-a-kind systems. The only model this company has that might be considered a "standard" rf sealer is their Temple Heating System shown in Figure 3. This unit is used to heat the center core of eye-glass temples prior to insertion of the wire that is the means of attachment to the remainder of the eyeglasses. As can be seen in Figures 4 and 5, the "rf chamber" is automatically sealed once the temple to be heated is in place. This unit operates at a frequency of 90 MHz with 2 kW of power. Since the unit operates outside of an ISM band, shielding was required because of FCC interference considerations; however, the shielding appears to have served the purpose of reducing operator exposure as well. Similar to the microwave oven design, the emission control feature of the Temple Heating System is a "box enclosure" of the entire rf system. This type of control is quite effective. In addition, the machine is automated and thus the operator has no means of defeating the emission control mechanism. Also, he has no reason to defeat this mechanism in order to make his job of loading materials easier since the automation does just that.

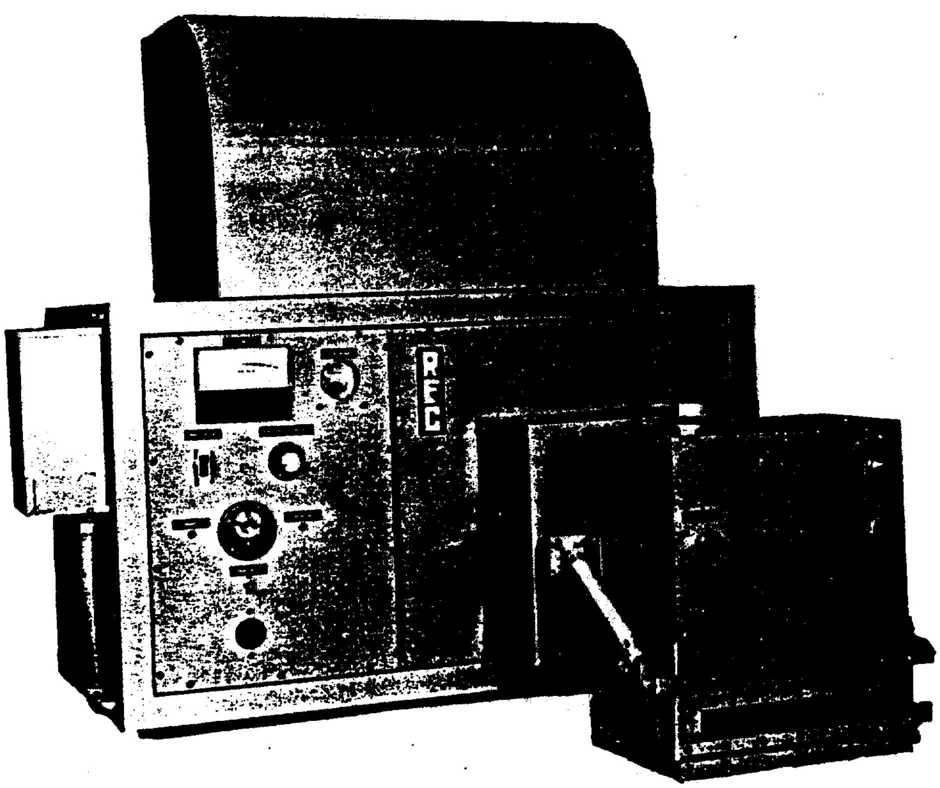


Figure 3. Radio Frequency Company automatic rf shielded temple heating system incorporating a box shield.

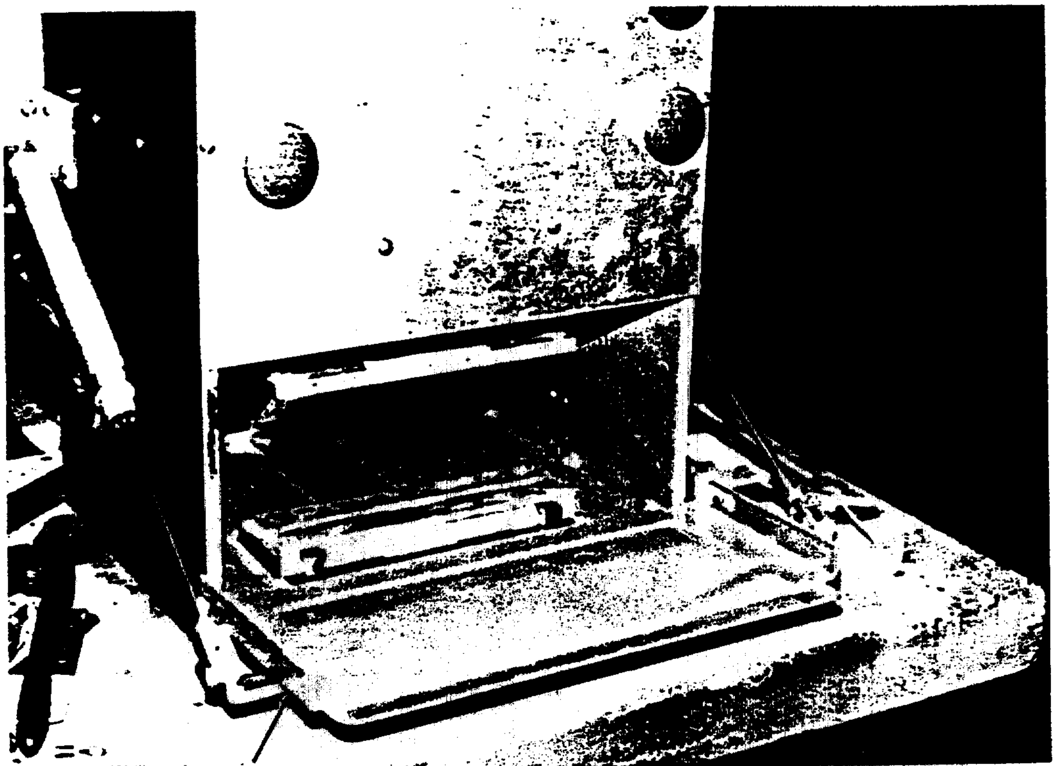


Figure 4. Open rf shield system of unit shown in Figure 3.

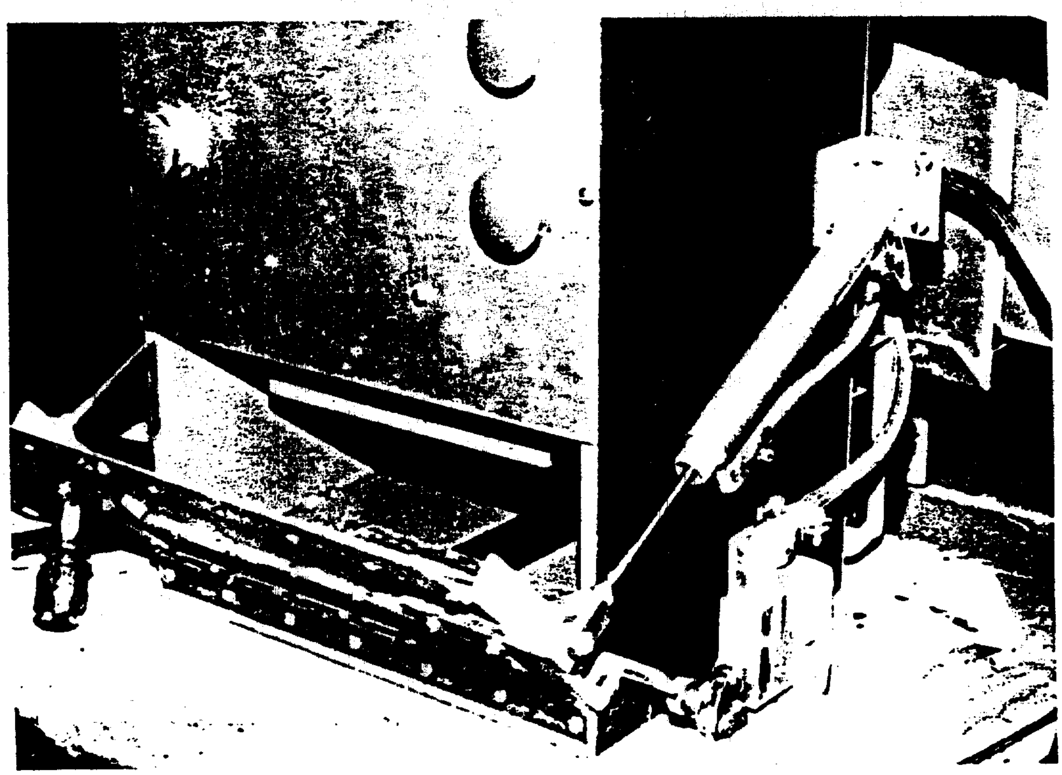


Figure 5. RF shield system of unit shown in Figure 3, partially closed.

Figure 6 shows an edge glue dryer that dries the glue binder between multiple sheets of paper or interleaved sheets of carbon and paper. It operates at 40 MHz and uses 7 kW of power. The paper to be joined is fed in one end of a hooded enclosure, which contains the sealing equipment, and out the other end in a continuous roll. The cover, shown open in the picture, is closed and locked via the hinge clips on the front of the unit prior to activation. Complete "boxing in" of the rf energy is again accomplished.

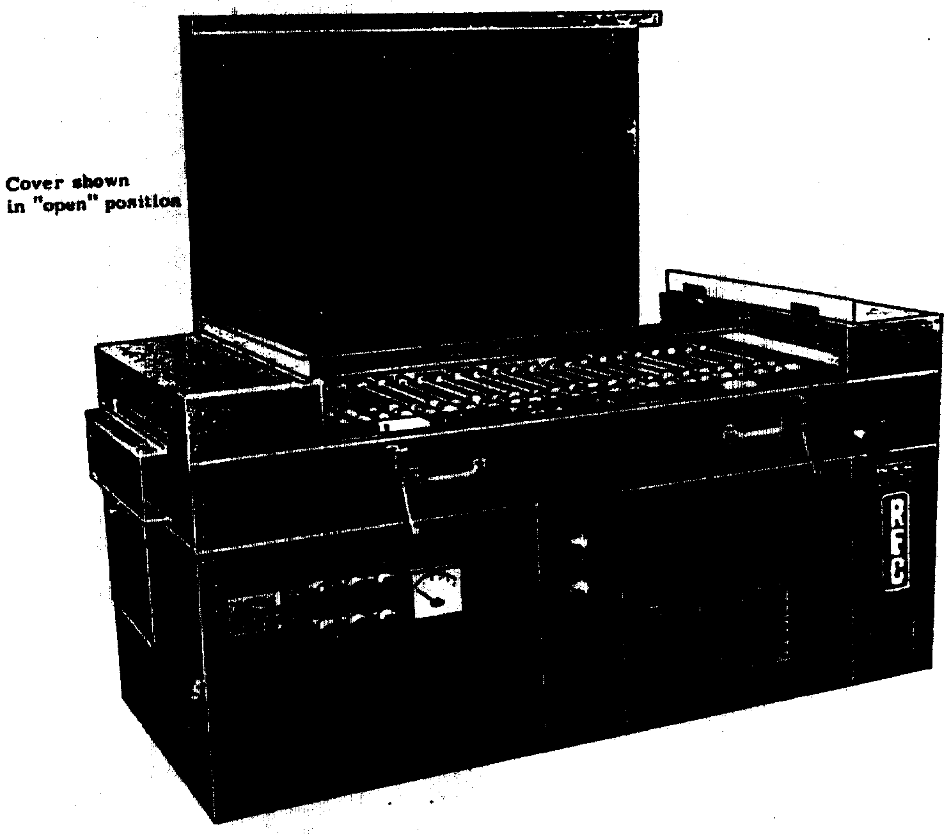


Figure 6. Radio Frequency Company edge glue dryer incorporating a box shield.

A method of shielding that does not require a completely closed box is the "Waveguide Below Cutoff." A waveguide below cutoff is a metallic tunnel that permits raw and processed materials to enter and leave the heating region but does not permit high-level fields to escape. If the height and width of the tunnel are much smaller than a wavelength, and if the tunnel is sufficiently long (see section on "Predicted Effectiveness of Simple RF Shields"), the waveguide below cutoff is an effective rf shield. The 40 MHz, 10kW cigar dryer shown in Figure 7 is an automated system using a conveyer belt through the unit. The waveguide below cutoff, which appears as a tunnel on the left side of the unit, has been added to contain rf emission.

Compo Industries produces an rf-sealer that is used by the shoe industry for the "flow molding" process. Flow molding makes use of a rubber mold as the master "form" for the molding of plastic products. This method gives a plastic product the surface texture of the "master" that was used in creating the original rubber mold. It is used primarily to manufacture shoe tops, but this technique could also be used for purses, wallets, and so forth. Since the maximum shoe sizes are known, the maximum material dimensions that

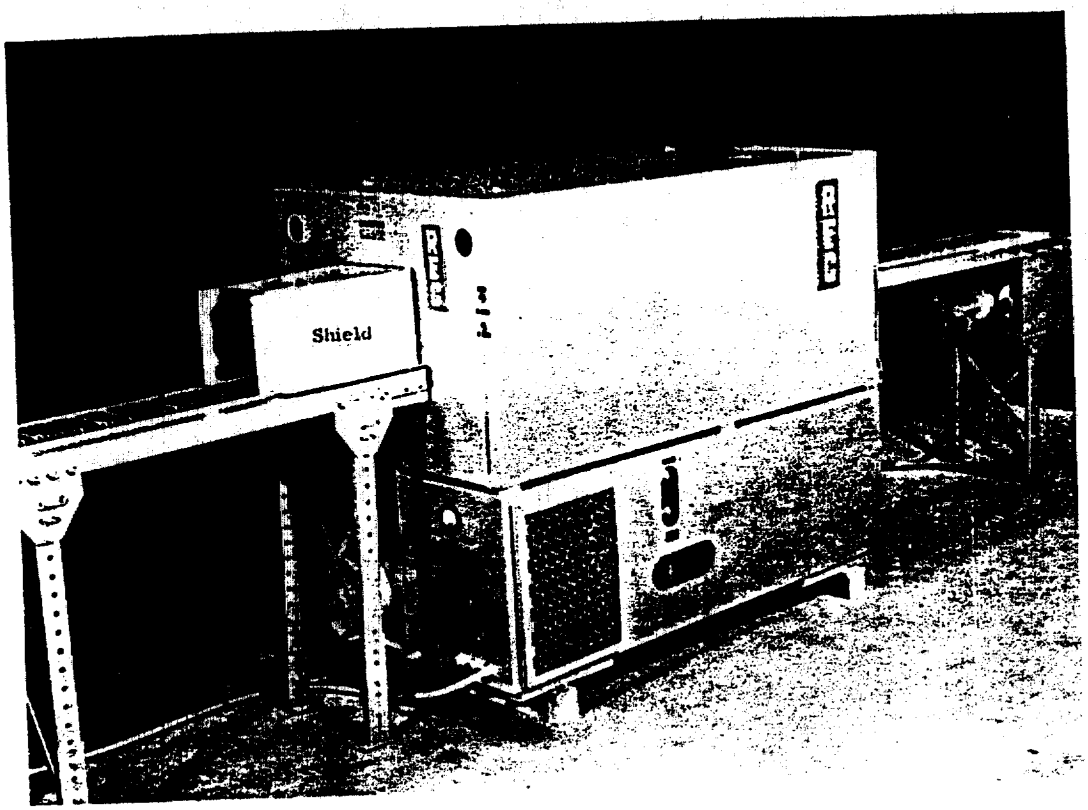


Figure 7. Radio Frequency Company cigar dryer shielded by waveguide below cutoff.

will ever be used on these units can be determined. As can be seen in Figure 8, this unit uses a turntable to move the material, previously placed by the operator under one of the several insulated plates, beneath the sealer press. Since this process uses components with well-defined dimensions and, since it is automated, a box can be built around the sealer's electrode system to contain the rf energy. The rf load that the shoe top presents to the machine is also relatively constant and, therefore, this system's design and load lead to consistency in unit production. This type of shielded unit has repeatedly been shown to provide very effective shielding. (Do not confuse this unit with similarly constructed turntable types which are not shielded. These devices do exist and can create higher than recommended exposure levels.) Close inspection of the rf electrode enclosure visible in Figure 9 shows the overlap design of the contacting phosphor-bronze shielding fingers. This overlapping was considered essential by this manufacturer for effective rf shielding for FCC purposes. (Other manufacturers believe it is not necessary to overlap the fingers.)

This unit also offers a good opportunity to show the cabinet shielding that is incorporated around the rf generator itself. This manufacturer uses 2 shielded cages for this cabinet. Figure 10 shows a photograph of the 2 access doors to the rf generator. In terms of an emission control to protect the operator (who is on the opposite side of the sealer), this technique would offer little benefit. In terms of emission control for other persons, it is very effective. For electrical safety reasons and to accomodate FCC requirements, most components of the rf generators have been enclosed in at least a single-shielded cabinet.

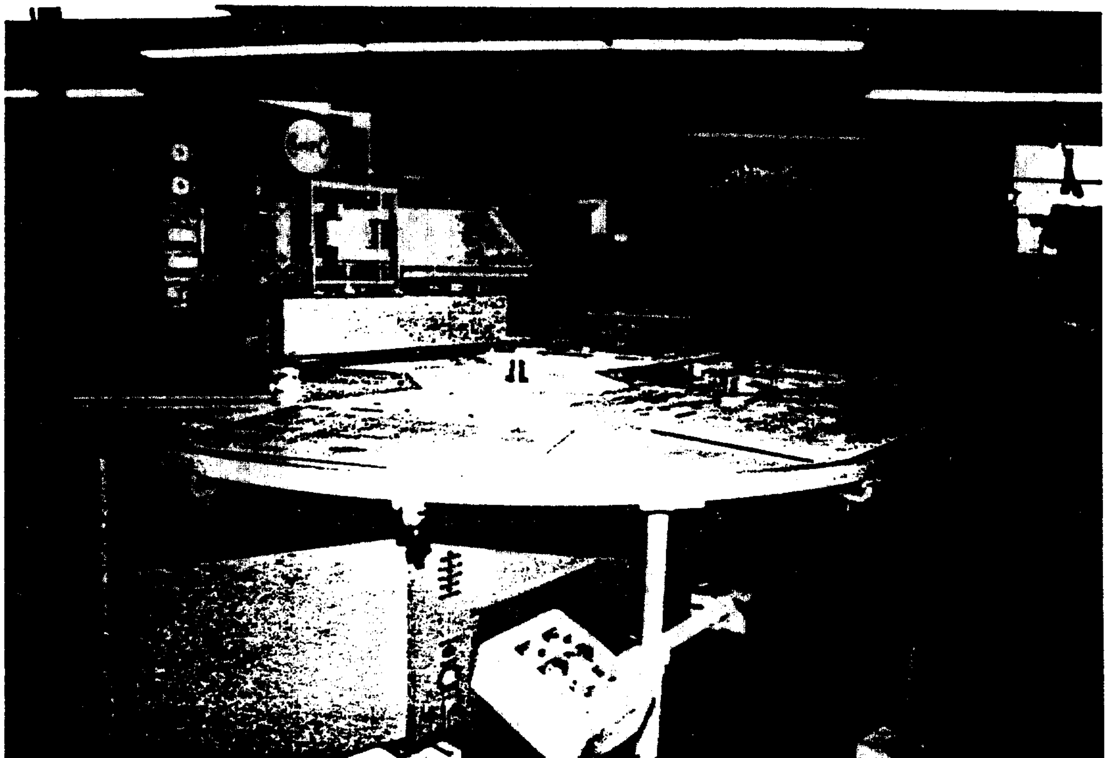


Figure 8. Compo 30 kW shielded flow molding system with box and turntable.

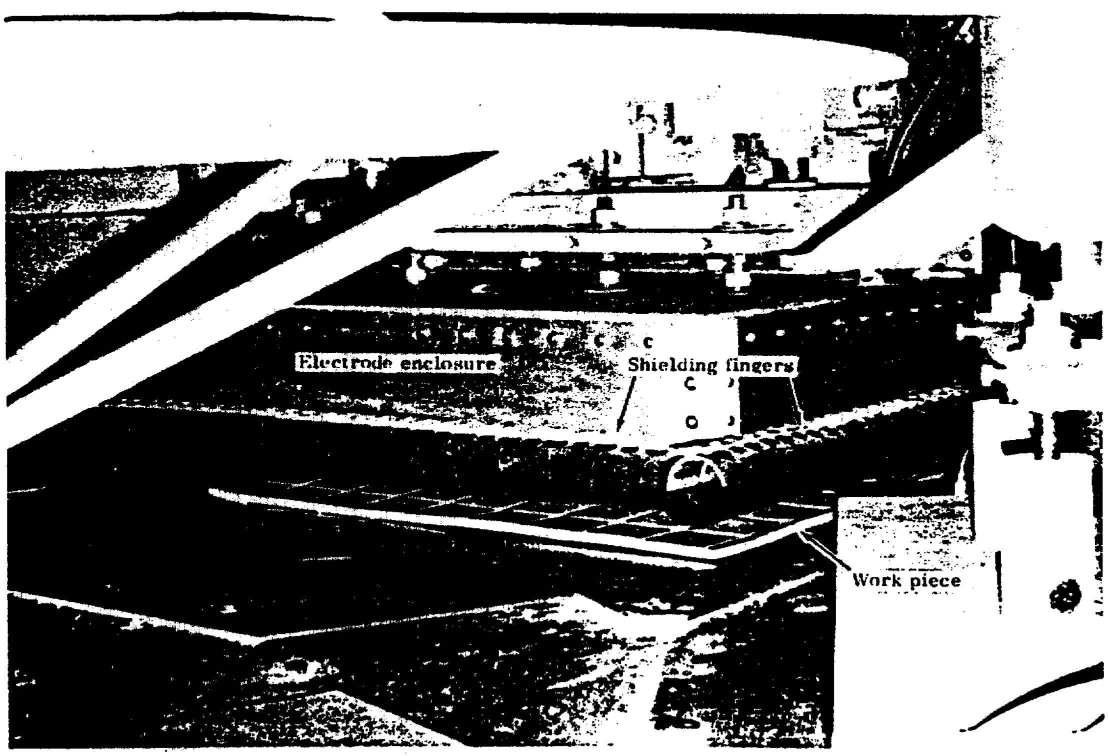


Figure 9. RF electrode enclosure system of Figure 8.

Figure 10. RF generator shielding for system of Figure 8.

Cosmos Electronic Machine Company, which merged with Kabar Manufacturing Corporation, produces standard, as well as special, rf sealers under both brand names. A special 35 kW unit is shown in Figure 11. It provides emission control by enclosing the electrodes in a box, and exposure control by the shuttle system. (The shielding of this 35 kW unit (and virtually all units operating above 12 kW of power) has apparently been a standard practice in the industry for some time.) As can be seen in the closeup view of the box in Figure 12, when the press plate with the electrode comes down, the ends of the box are sealed to create a closed cavity.

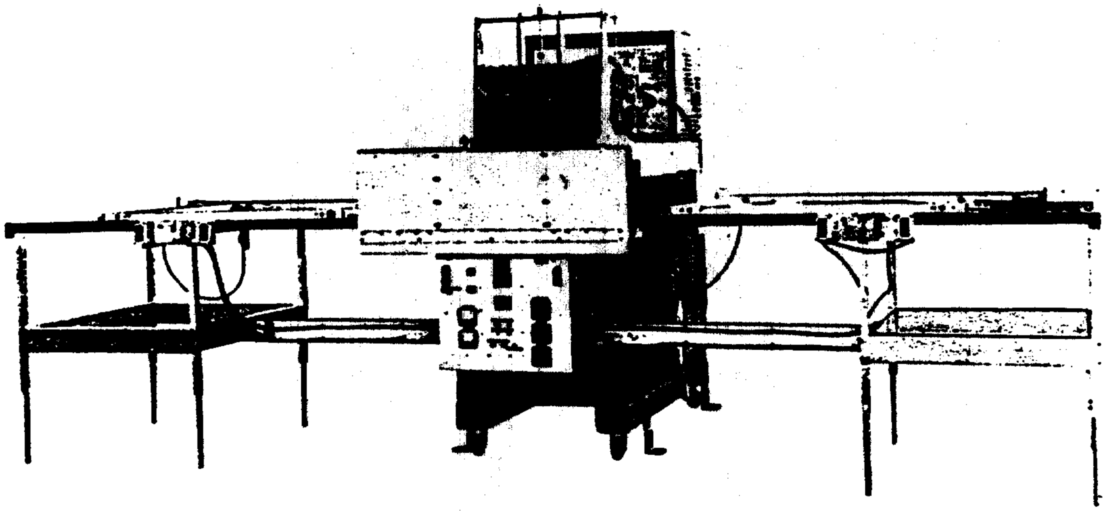


Figure 11. Kabar 35 kW shielded system with box and shuttle tray.

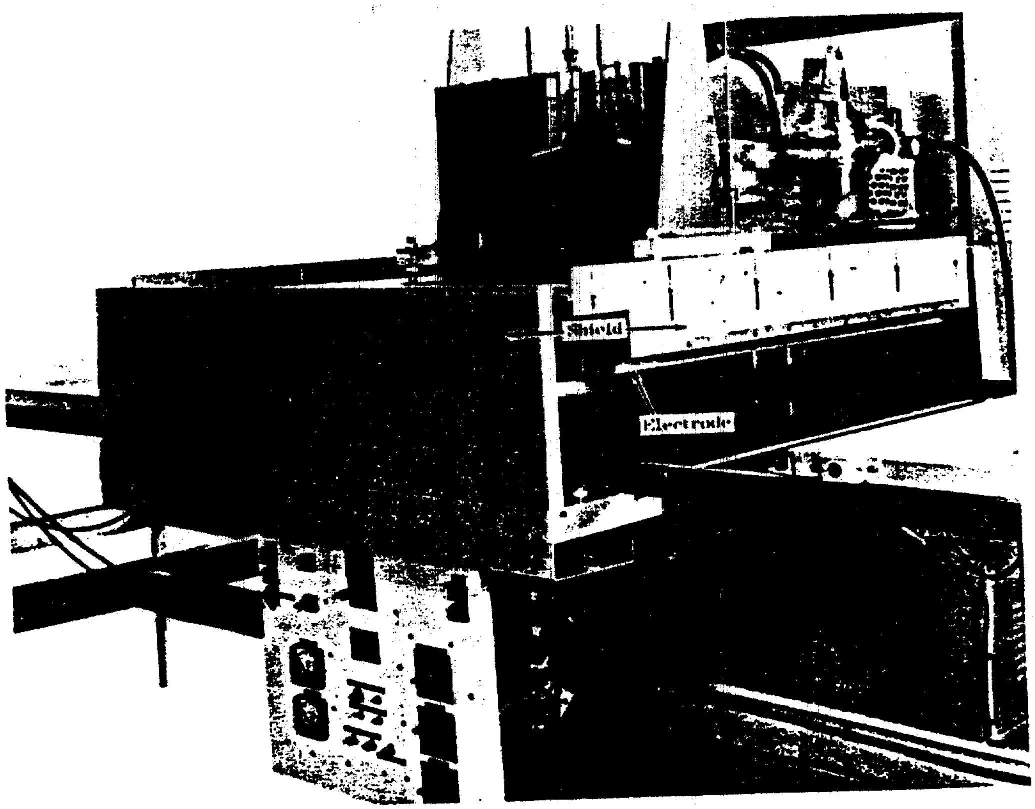


Figure 12. RF electrode enclosure system of Figure 11.

This manufacturer also sells standard units (under both brand names) in both shielded and unshielded versions. The unshielded Kabar unit is shown in Figure 13 and the shielded Kabar unit is shown in Figure 14. The shielded Cosmos device is shown in Figure 15.

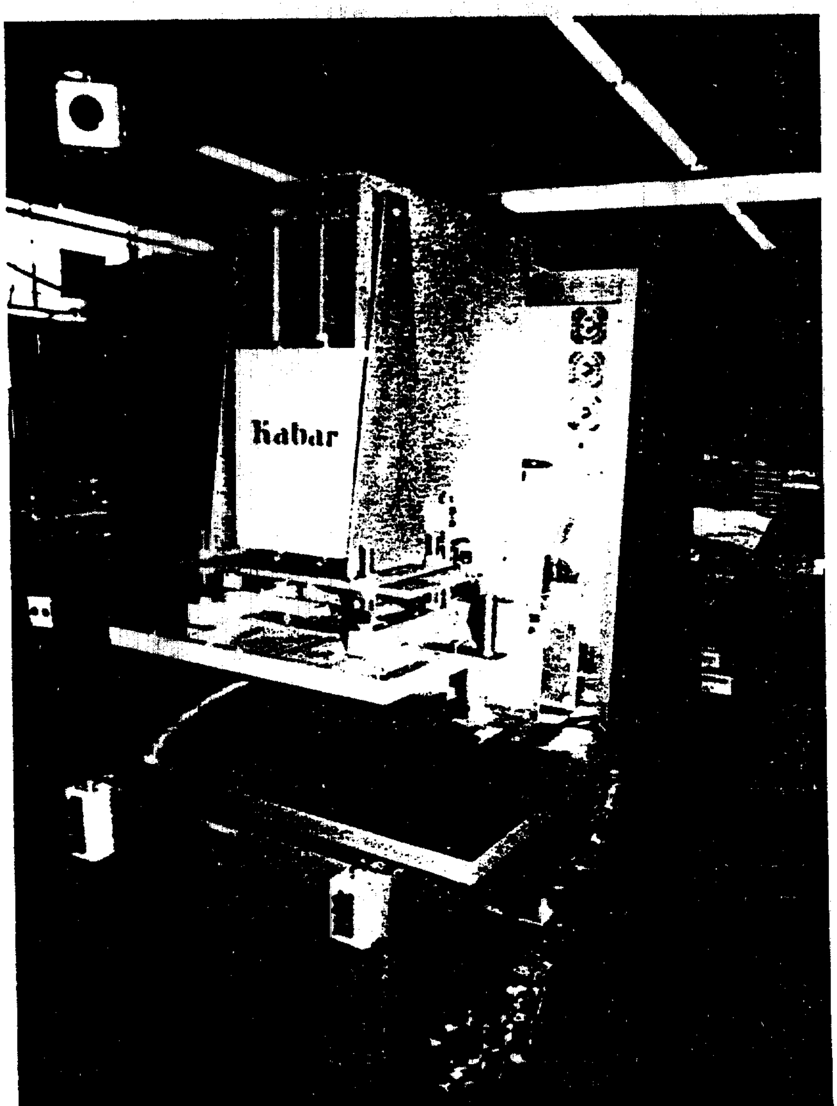


Figure 13. Kabar 10 kW unshielded standard sealer.

This manufacturer has also incorporated a radiation measurement procedure for each unit before it leaves the factory. Measurements are taken at a fixed distance from the sealer (approximately 6 inches) at preselected locations on the unit. The data are recorded, and if any of the observed values exceed the recommended OSHA standard exposure field level (5), the manufacturer takes steps to bring the emission level down to OSHA's specification for radiation emission. As can be seen in Figures 14 and 15, the shielded units incorporate the boxed-in approach that has been seen before.

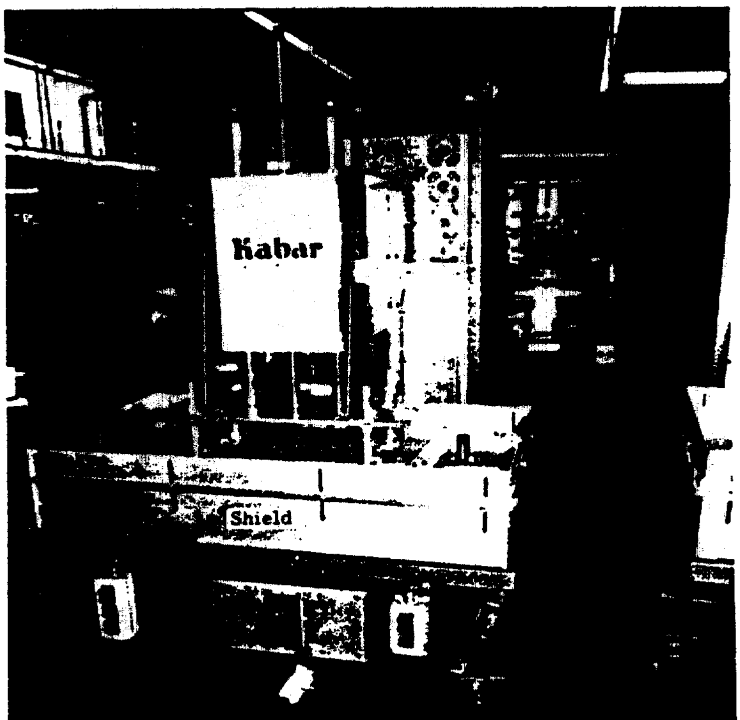


Figure 14. Kabar 10 kW box-shielded standard sealer.

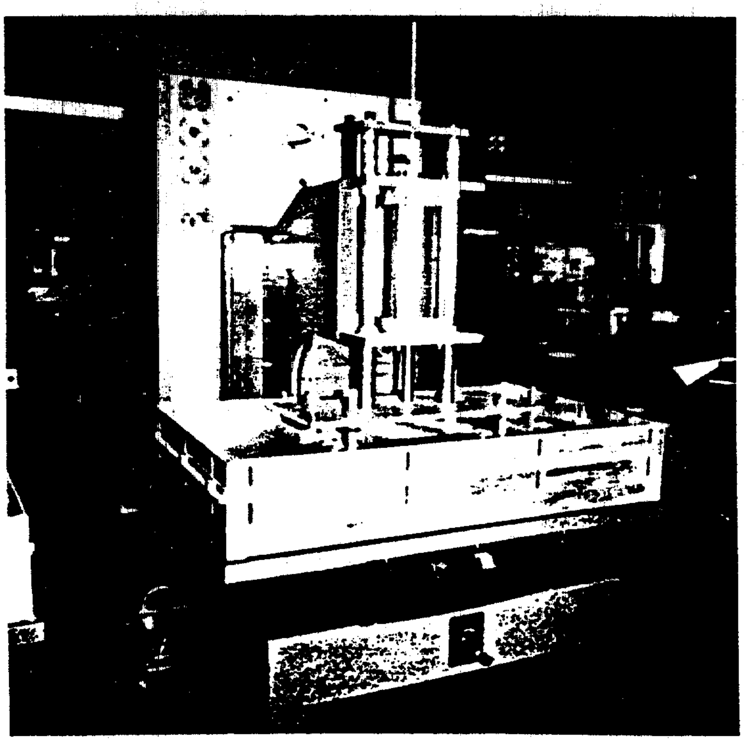


Figure 15. Cosmos 10 kW box-shielded standard sealer.

Solidyne manufactures units under the brand names of Thermatron, Sealomatic, Faratron, Stanelco, Ltd., and Colpitt, B.V. They have manufactured the flow molding, shielded type turntable units, and the shuttle type units, with and without shielding (depending on their output power). One of their larger "shuttle type" units is shown in Figure 16. Note the large shielding box in the center and the operator controls on the extreme ends of the shuttle. Figure 17 shows a unit used to make waterbeds. Here again, even though the material is quite large, some shielding (the plates enclosing the presses) has been incorporated.

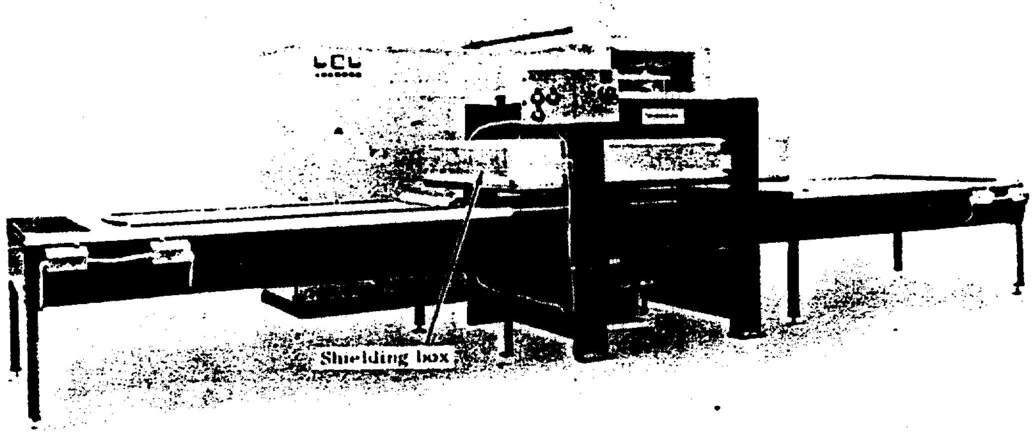


Figure 16. Colpitt 40 kW shielded system with box and shuttle tray.

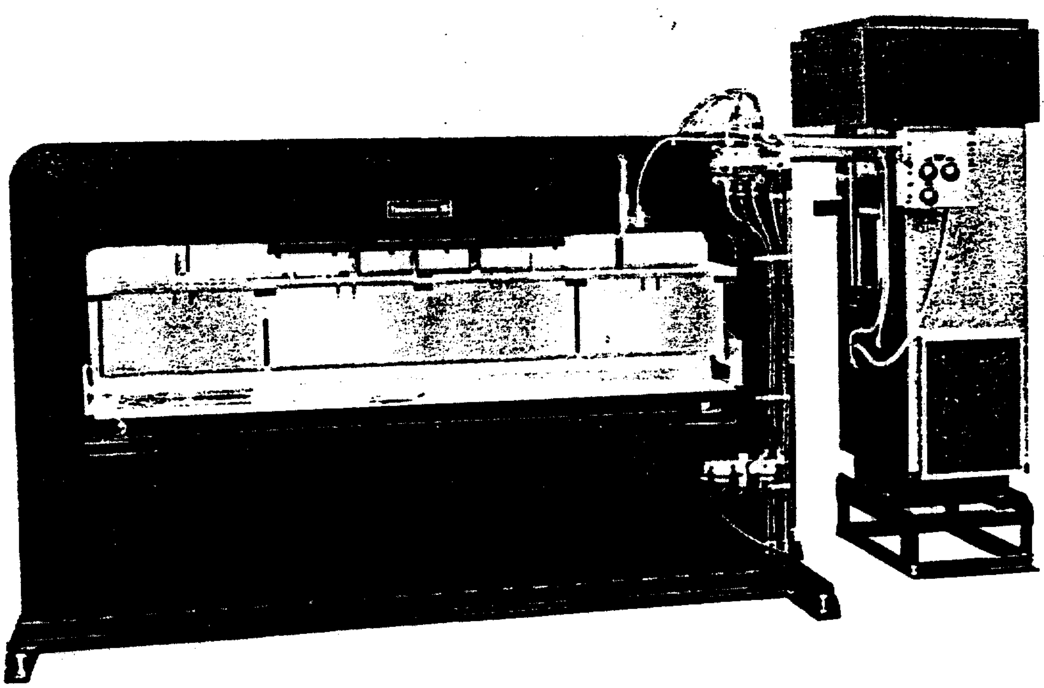


Figure 17. Thermatron 20 kW waterbed sealer with plates instead of complete box.

Figure 17 illustrates one problem with rf sealers used for processing large pieces of material. Unlike the shoe industry, which has a specified maximum size for the piece of plastic to be molded, the waterbed industry cannot completely place its raw materials into the sealer. This, of course, means that the box shield cannot be constructed without gaps, which may lead to excessive levels of rf emission. In these kinds of sealers it may be necessary to use, along with partial shielding, the exposure control concept discussed earlier; that is, to place the operator some distance from the rf emission area. This unit, for example, has "on" buttons that could be on the console to the right of the press itself. These waterbed sealers are specialized cases. On the other hand, during visits to several manufacturers it was learned that approximately 80 percent of the units produced annually could be shielded with the box type enclosure.

Solidyne's standard new model, with shielding, is shown in Figure 18 (for the photograph, the shielding plates in front were removed). It is interesting to make comparisons between this model and the others that have incorporated the box-type shield. As can be seen, this box is not completely continuous as are other models from this company and other manufacturers. In this unit there are openings in the box. Note also that there is spacing between the phosphor bronze fingers—a construction technique that Compo does not use. This unit has another unique feature that aids in further reducing the rf radiation emission in the vicinity of the operator. Interchangeable capacitors may be inserted at the prongs shown in Figure 18. These capacitors help to balance the flow of rf currents in a way that reduces

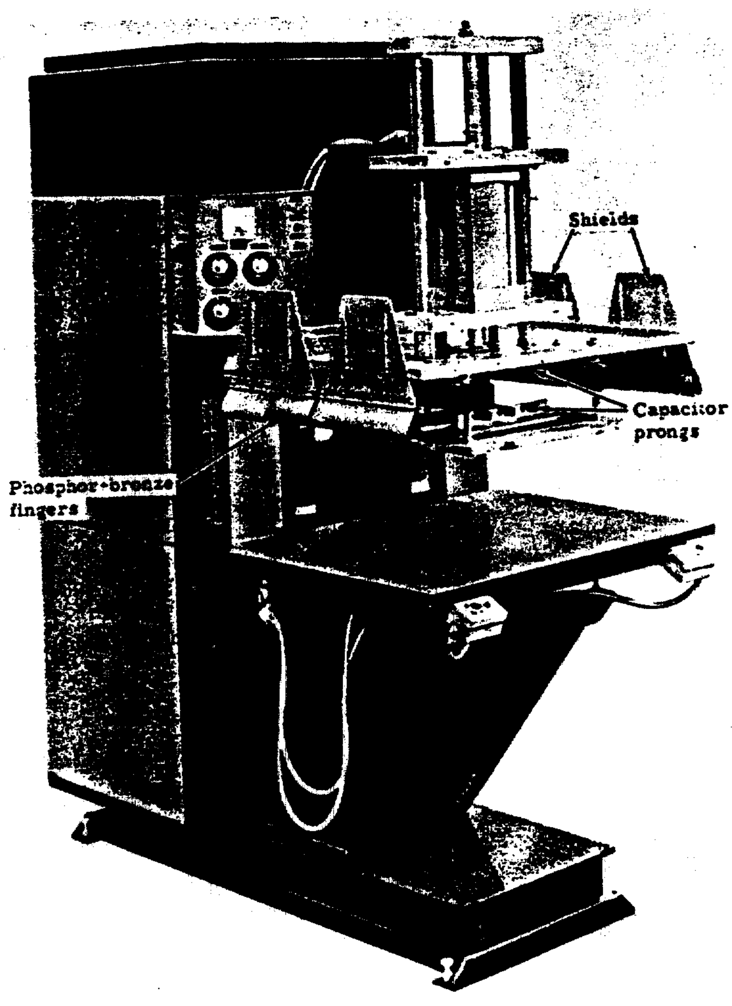


Figure 18. Solidyne 10 kW standard sealer with box shield.

the operator's exposure. With the manufacturer's cooperation, emission measurements were performed. During the testing, experiments were conducted to determine what might happen in industrial use if plastic material were allowed to extend beyond the side and/or front shields or if the shield plates were removed.

High Frequency Technology Company, Inc., (a division of Hall Dielectric Machinery Company, Inc.) produces both standard and special sealers and has supplied photographs of their Series "FS" models. Figure 19 shows their 15 kW unit that is equipped with both a turntable and a non-continuous box-type shield, which is referred to by this company as a "top hat" radiation shield. (A similar 10 kW unit without the turntable was loaned to OSHA for radiation studies. A comparison of the emission with and without the top hat radiation shield will be presented in the next section of this report.) The reason this top hat shield was designed not to be continuous, according to the manufacturer, is that it allows adjustments which may be necessary to conform to different products being sealed.

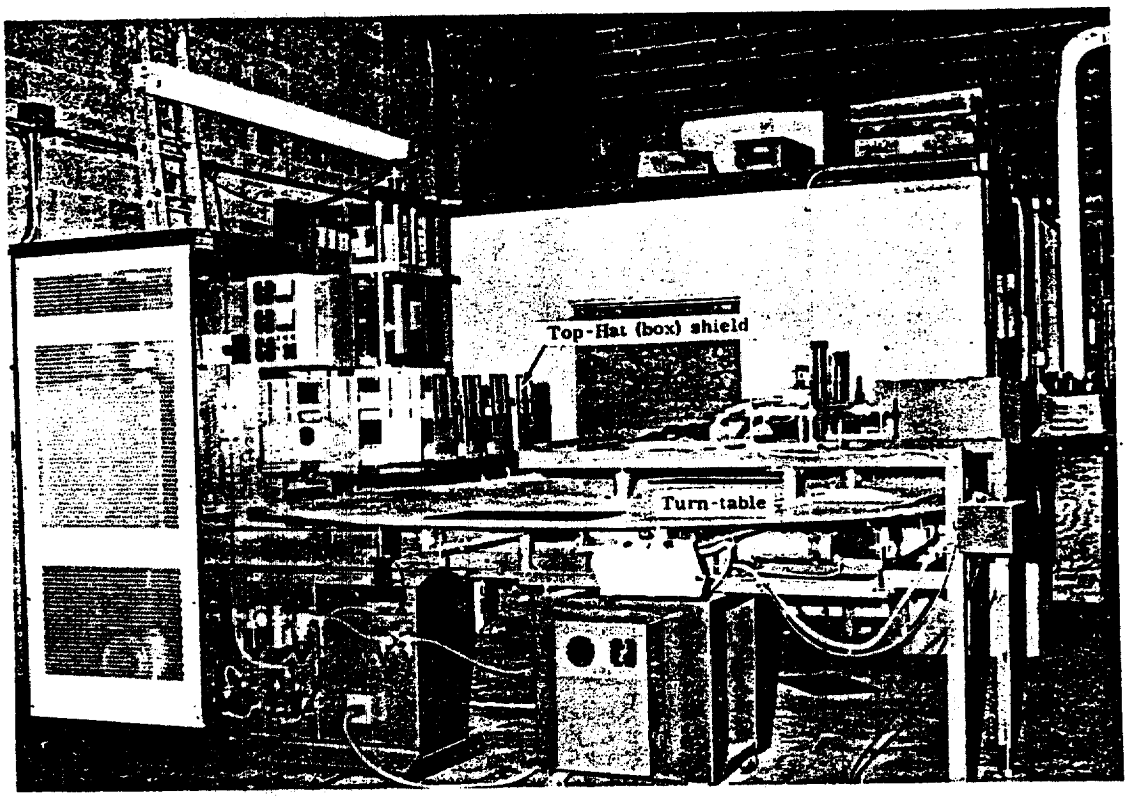


Figure 19. High Frequency Technology Co. and Hall Dielectric Machinery Co. 15 kW sealer incorporating turntable and top-hat (box) shield.

Barsealers use long and relatively narrow dyes (electrodes) to join together large pieces of material. Figures 20 and 21 are 2 examples of this company's barsealers. The 48-inch barsealer is shown in Figure 20. It uses 2 electrodes rather than the more conventional single electrode-bed-plate system. The upper electrode is passive and can be touched during the welding cycle; the lower electrode is the active one and is located in a compartment within the bedplate. With this integral radiation suppression design, emission levels have been measured, according to the manufacturer, that do not exceed an equivalent free-space power density of 1 mW/cm^2. The barsealer shown in Figure 21 has a 74-inch-long barholder and electrode. Emission levels from this unit are claimed to be below the 10 mW/cm^2 equivalent free-space power density level, which is achieved by circuit tuning of the press members along with "rear-deflection" (manufacturer's term) type radiation shields.

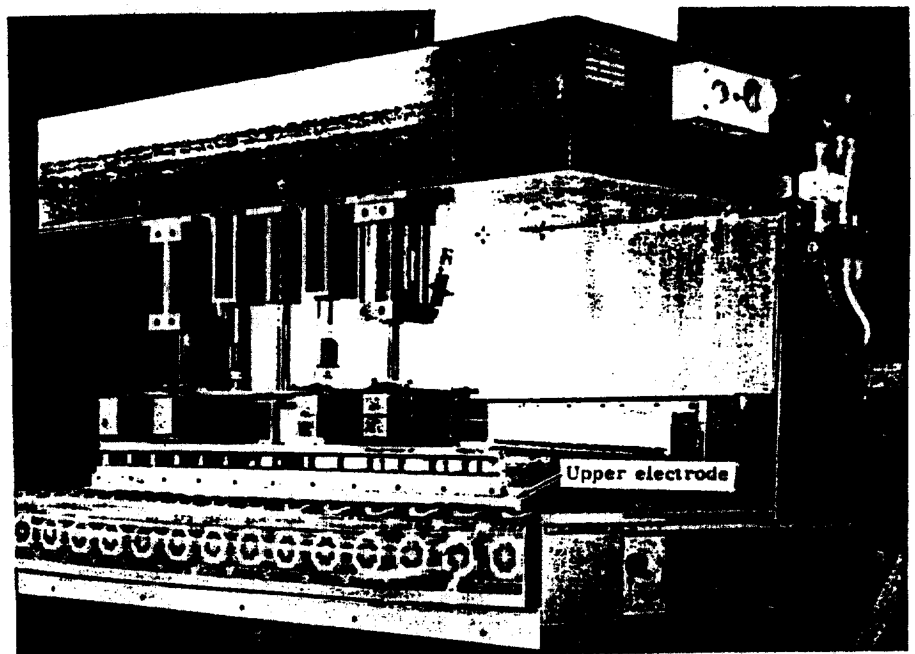


Figure 20. High Frequency Technology Co. and Hall Dielectric Machinery Co.
10 kW 48-inch barsealer with integral radiation suppression.

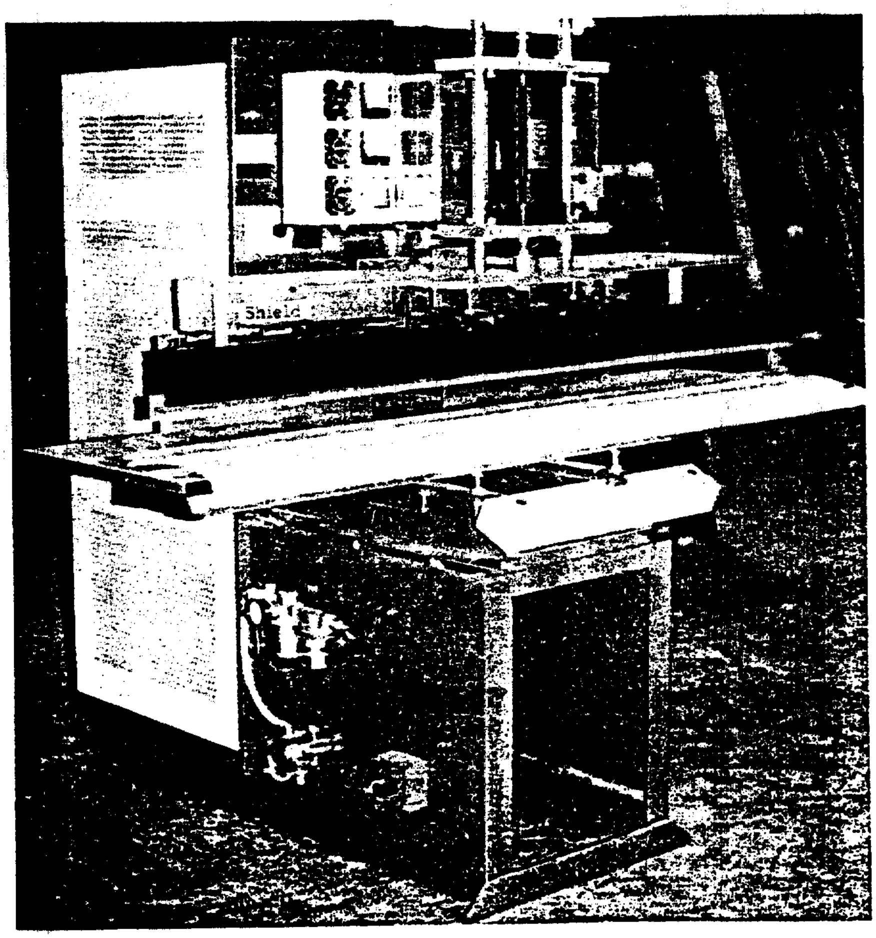


Figure 21. High Frequency Technology Co. and Hall Dielectric Machinery Co.
10 kW 74-inch barsealer incorporating "rear deflective" shielding.

MEASUREMENTS OF RF SEALER EMISSIONS WITH AND WITHOUT SHIELDING

The results of the measurements that were taken around the Solidyne rf sealer are presented in Table 1. With the shielding in place, the highest emission level was located in front of the machine and could only be detected by placing the instruments at a distance of 10 cm (4 inches), or less, from the shields. The equivalent free space power densities in mW/cm^2 of the measured electric and magnetic field strengths at this distance (10 cm) were 0.01 and 0.27, respectively. (These values were obtained when the rf power was on. For comparison to the OSHA and ANSI exposure guidelines, the effective field strengths would be lowered by the "duty factor": rf "on" time divided by the time of one complete cycle of product production.) In any event, they are well below the 10 mW/cm^2 equivalent power density level recommended at the present time for maximum permissible operator exposure, and certainly would be negligible at the "typical" 20 to 30 cm operator distance. To simulate material hanging out of both sides of the sealer, plastic strips approximately 0.02 inches in thickness were placed between the bed plate and the phosphor bronze fingers of the shields on each side. As can be seen from the table, the electric field remained the same; however, the magnetic field intensity increased by about a factor of 2. Leaving these strips in place and putting an additional strip in front (to completely break the shield's contact) produced the reading shown in the third column of the table. By breaking the shield's contact all the way around, the electric and magnetic fields increased substantially. However, under this condition at the normal operator's position, and with duty factor included, the levels would still be below the current standard. Upon removing the shielding plates, measurements had to be made at 30 cm because the field strengths at 10 cm exceeded the instrument's maximum measurement value. The table shows that both fields exceeded 10 mW/cm^2 and, even assuming a low duty factor of 0.2, the electric field would still have exceeded the ANSI standard. The result is that the shield, even though it was being abused by material hung through its sides, was still more effective than no shielding at all.

Table 1. Effect of protruding materials breaking shield contact with bed plate

Condition	Shielding in contact	Plastic strips breaking contact on both sides	Plastic strips breaking contact on both sides and in front	Shielding removed
Measurement Distance	10 cm	10 cm	10 cm	30 cm
Electric field* (mW/cm^2)	0.01	0.01	2.6	130
Magnetic field* (mW/cm^2)	0.27	0.40	32	14

*Equivalent free-space power density

Anatomically related measurements with and without the top hat (box) shield were made on the High Frequency Technology Company, Inc. supplied unit that was on loan to OSHA. Table 2 shows a comparison of the measurements expressed in terms of equivalent free-space power density (mW/cm²) for both electric and magnetic-field components at two possible operator locations—one approximately 20 cm in front, and the other 20 cm to the side of the bedplate. The effectiveness of the box-type shield, even though it is not continuous, is clearly evident from the data. The highest electric field measured (mid-calf, front) was reduced by 32 dB; the highest magnetic field measured (waist, side) was reduced by 22 dB.

Table 2. Anatomically related measurements of emission levels with and without a box type shield expressed in units of equivalent free-space power density (mW/cm²)

	Electric field		Magnetic field	
	Without shielding	With shielding	Without shielding	With shielding
Location: Front				
Anatomical site				
head	90	0.07	26	0.15
neck	93	0.11	68	0.49
chest	90	0.05	105	0.60
waist	105	0.03	52	0.34
gonad	31	0.07	5	0.04
mid-thigh	15	0.07	5	0.03
mid-calf	164	0.11	16	0.02
Location: Side				
Anatomical site				
head	118	0.36	79	0.23
neck	146	0.40	84	1.06
chest	117	0.36	126	1.96
waist	68	0.23	308	2.18
gonad	6	0.11	105	0.34
mid-thigh	4	0.07	59	0.23
mid-calf	14	0.07	21	0.04

PREDICTED EFFECTIVENESS OF SIMPLE RF SHIELDS

The shielding effectiveness of two of the techniques described above, metallic boxes and waveguides below cutoff, can be estimated from simple theoretical analysis (8). The results of this analysis for metallic boxes are illustrated in Figure 22. The total shielding effectiveness expresses the ratio (in dB) of the power density that penetrates through the shield to the power density incident upon the shield. For example, a 0.001 inch-thick sheet of copper reduces a 30 MHz plane-wave field by 115 dB. This corresponds to reducing an incident power density of 3 billion watts/cm² to 10 mW/cm². Similar reductions of power density would also be achieved in nonplane-wave fields, as is the case for rf sealers. Also, thicker material provides even more shielding.

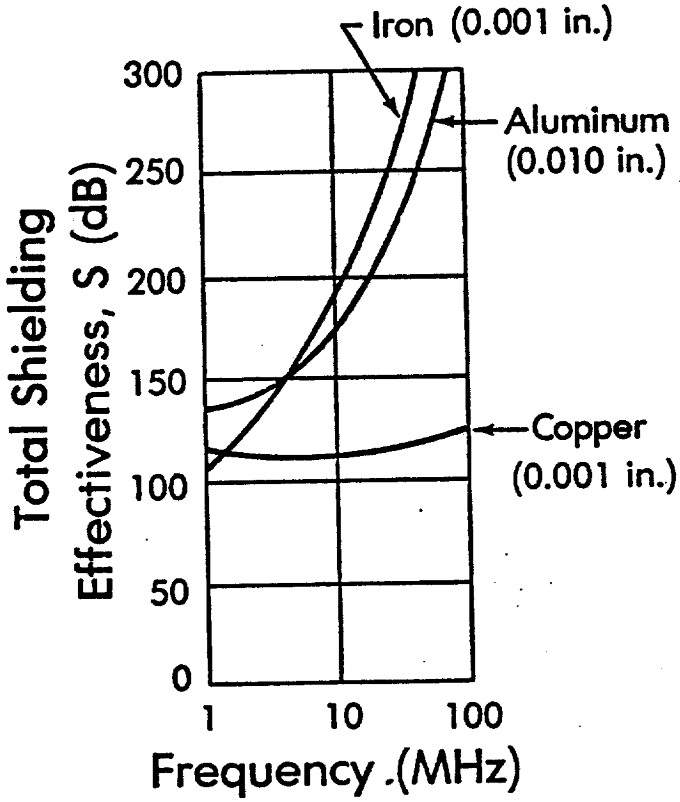


Figure 22. Chart depicting plane-wave shielding effectiveness of metal sheets (White (8)).

If an rf sealer could be completely enclosed by a perfect metal box (one with no holes, rivets, seams, or other places for rf energy to escape), the leakage would be insignificant. However, the sealer cannot be shielded in this ideal manner. The objective of rf sealer shielding, therefore, is to reduce the emitted power to acceptable levels while maintaining the effectiveness and efficiency of the machine.

The shielding enclosures that have been shown in the figures in the section on "Examples of Shielded RF Sealers" can be very effective for reducing emission from rf sealers. However, the data in Table 1 demonstrate that a small gap in the shielding can create significant increases in radiation leakage. One possible mechanism for these increases is represented in Figure 23. If the gap in the shielding interrupts current flow, it can behave very much like a slot in a metallic screen. In this case, the amount of power radiated by the gap will be approximately proportional to the conductance of the equivalent slot (9). Therefore, a gap of length 2 L will radiate 4 times the power radiated by a gap of length L.

The shielding effectiveness of rectangular and circular waveguides below cutoff is illustrated in Figure 24. When the wavelength of the radiation is much larger than the cross-sectional width, a, of the waveguide, the shielding effectiveness is proportional to the ratio of the length of the guide to its width. This result is useful for estimating the effects of many practical configurations. For example, the waveguide below cutoff in Figure 5 has an L/a ratio of approximately 1.5. Therefore, it should provide approximately 40 dB of shielding.

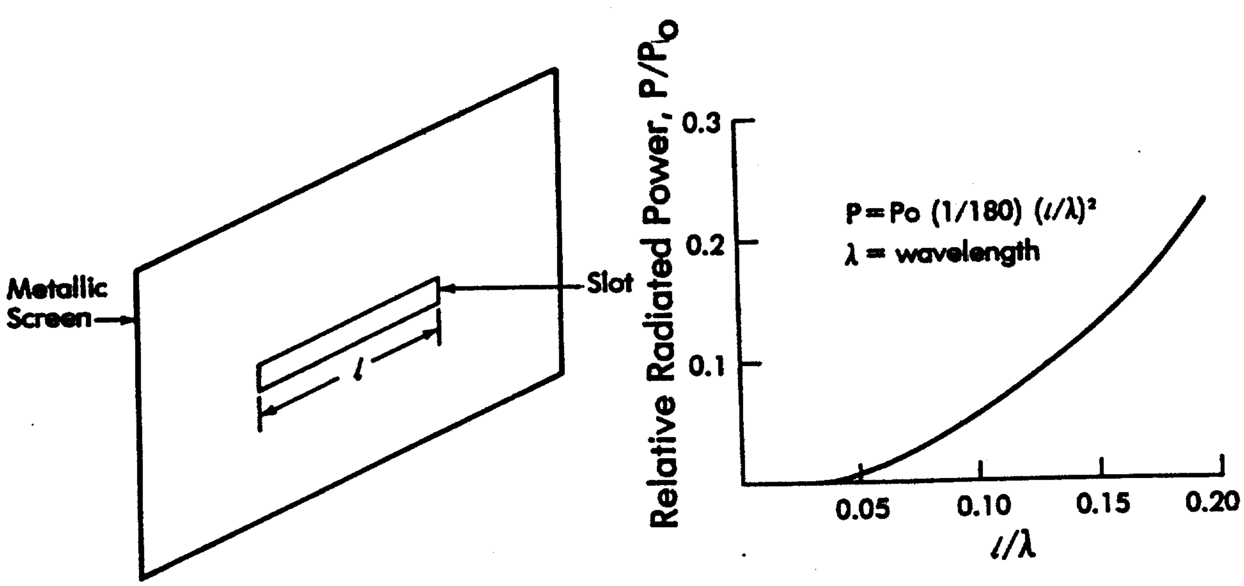


Figure 23. Slot radiator model for gap in shielding box (Jasik (9)).

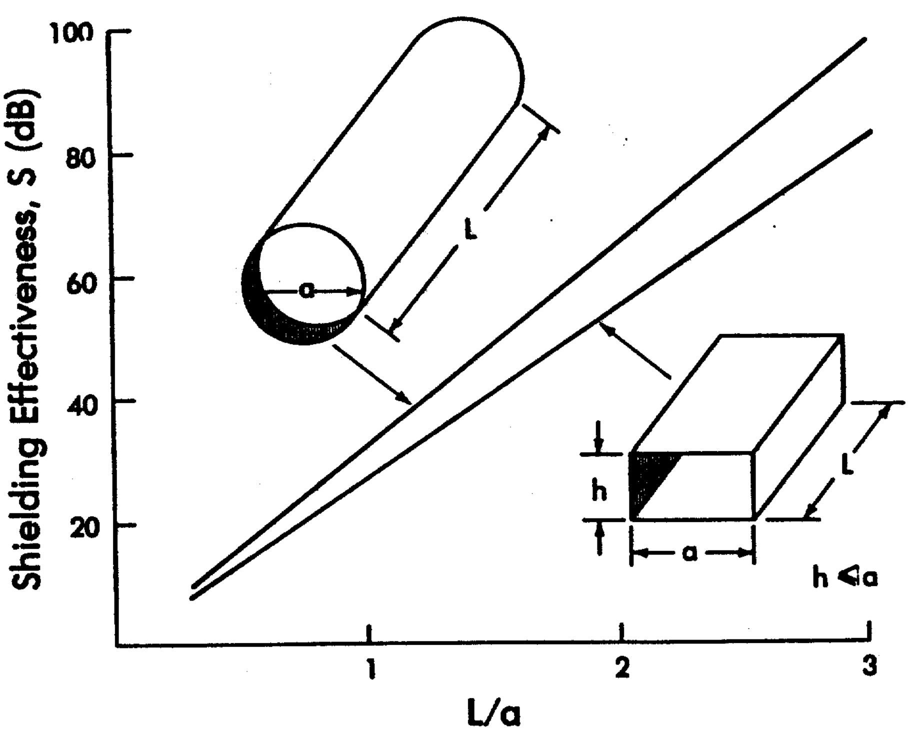


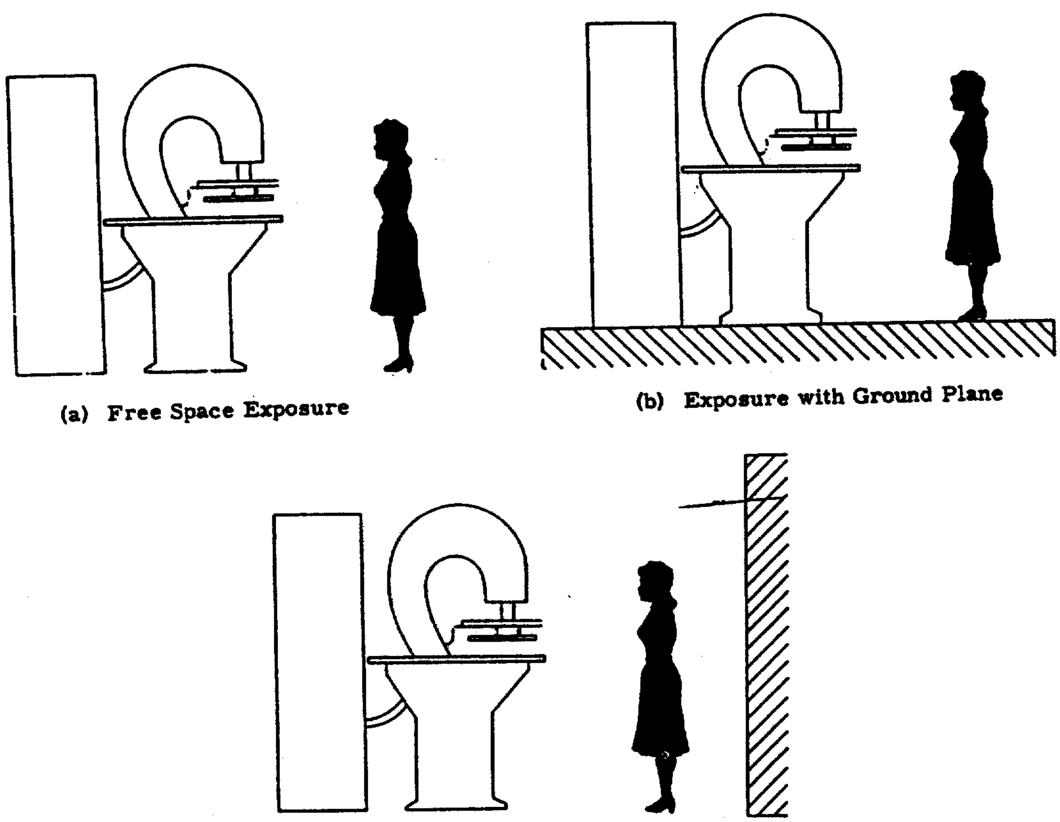
Figure 24. Shielding effectiveness of hollow waveguides below cutoff (White (8)).

EFFECTS OF GROUND PLANES AND REFLECTORS ON OPERATOR EXPOSURES

The previous section has discussed simple models that may be useful for assessing the effectiveness of some of the emission controls that have been used on rf sealers. There are also some simple models that may be useful for assessing the effects of large metallic objects upon the exposure of operators and other personnel. In particular, the effect of metallic walls and floors (as in a shielded room) can be analyzed to give useful information about the exposures encountered by operators located near large metallic objects.

A simple analogy to antenna theory is useful for estimating the potential increase in absorbed power due to the energy that is reflected from the conducting walls and floor of the shielded room. At radiofrequencies the human body absorbs energy from an incident electromagnetic field in much the same way that a simple dipole antenna does. That is, the incident electromagnetic field causes currents to flow in the body. Because the human body is a lossy conductor, these currents heat the tissue. The amount of heat deposited in a particular part of the body is proportional to the square of the current density in that part of the body. Therefore, maximum heat is deposited where there is maximum current density.

Figure 25 depicts three exposure situations that may be encountered in the use of rf sealers. Figure 25a corresponds to the case of a sealer and an operator in a room with no metallic objects. Figure 25b corresponds to the case of a sealer in a room that has a metallic floor. (The steel reinforcing that is used in concrete floors may create the effect of a metallic floor.) Figure 25c corresponds to the case of a sealer and an operator located in a room with a metallic wall. Of course, there may be situations, like the shielded room, where the operator is exposed to the combined effects of a metallic floor and a metallic wall.



(a) Free Space Exposure

(b) Exposure with Ground Plane

(c) Exposure with Reflector

Figure 25. Simplified representations of rf sealer exposure situations.

The analogy between the operator and the dipole antenna predicts a frequency dependence of the absorbed power. This frequency dependence is associated with the whole body resonance of the operator, and it predicts (Figure 26) that the greatest absorption occurs at 70 MHz to 80 MHz for the ungrounded operator (Figures 25a and 25c) and 35 MHz to 40 MHz for the grounded operator (Figure 25b). Furthermore, because of the distribution of current within the operator's body, the grounded operator can be expected to absorb more energy in the ankle and lower leg than can the ungrounded operator. Detailed calculations (10) have shown that a grounded individual in a 27 MHz field will absorb 5 to 7 times the power absorbed by an ungrounded individual in this field. Also, the individual in front of the reflecting wall (Figure 25c) could absorb 5 times the power absorbed by an individual without the reflecting wall (10).

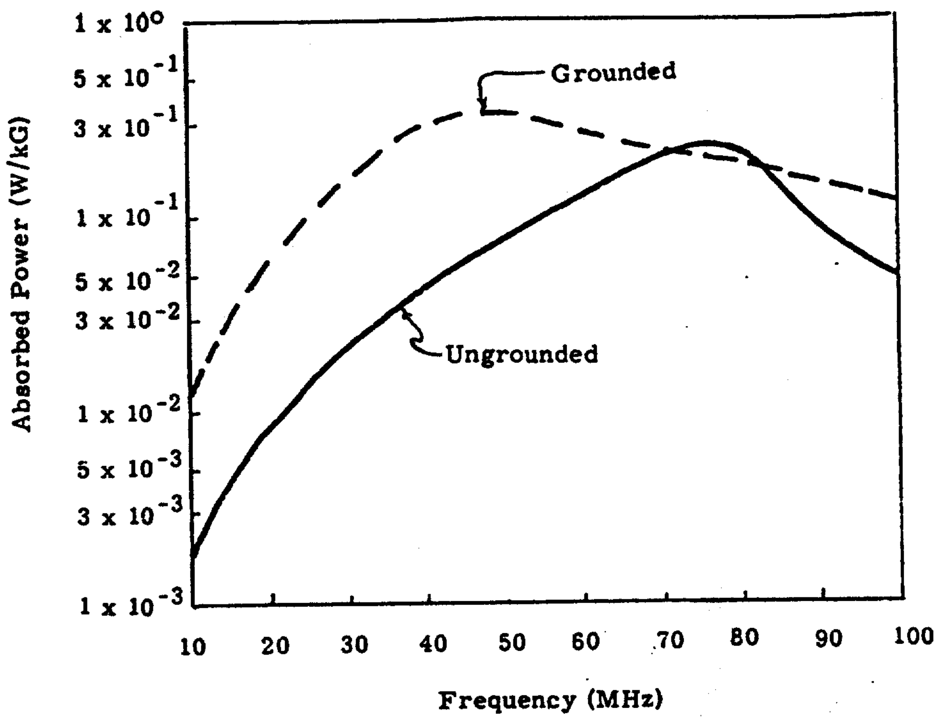


Figure 26. Frequency dependence of absorption by grounded and ungrounded man. Incident plane-wave power density = 1 mW/cm (Gandhi et al. (10)).

These examples illustrate what can happen under certain adverse situations. However, the presence of ground planes and reflectors may also reduce the total absorbed power. This can occur when the wavelength of the radiation is such that the reflector creates a minimum of the dominant exposure field at the operator's location. Furthermore, if the individual is elevated more than 1 or 2 inches above the ground plane, the effects of the ground plane will be minimal (11). Likewise, if the operator is very close to the radiating source (the usual case for rf sealers), the effects of the reflector behind the operator may be lessened. Since the exact exposure condition for any particular sealer and its operator is difficult to predict, the wide range of estimates indicated by these examples must be taken only as guidance. However, they do demonstrate that incident power levels that are safe under one set of conditions may not be safe under other conditions.

SUMMARY

Several methods for protecting personnel from the excessive levels of rf energy that may exist around sealers and heaters have been discussed. The methods that have been presented represent current practices among rf sealer manufacturers and users. Exposure controls, which are usually effected by moving the operator away from the rf electrodes during sealer operation, can be effective but they may also hinder the operator's performance. Shuttle trays, however, have been shown to provide some operator protection while simultaneously increasing the machine's productivity.

Emission controls, which are implemented to reduce the radiation from the sealers, consist primarily of box enclosures and grounding. Grounding can be effective for reducing rf emission but care must be exercised, and E and H fields must be measured to insure that a reduction, and not an enhancement, has occurred. Box shields that completely enclose the rf electrodes can significantly reduce radiation, and they can probably be used on approximately 80 percent (according to some of the sealer manufacturers) of the new and existing rf sealers. Also, screen rooms are used to reduce the environmental levels of radiation being emitted by rf sealers, but they can greatly increase the power absorbed by the operators who are inside the rooms.

Measurements of radiation fields around a shielded sealer indicate that the conditions of use can significantly alter the performance of the shield. These data, as well as other data and observations, emphasize an important feature of rf sealer shielding, i.e., the electric <u>and</u> magnetic field power densities can change dramatically when the equipment's configuration or use is altered. Therefore, radiation from rf sealers and heaters <u>must</u> be monitored to insure that leakage does not exceed acceptable levels as usage and wear occur.

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