Industrial use of microwave power has been increasing and has led to government evaluation of these systems. Results of a survey are reported which show that leakage of microwave radiation in industrial equipment has been reduced, and efforts in this direction are continuing.

Radiation Exposure from Industrial Microwave Applications

John A. Eure, M.S.; James W. Nicolls, M.S.; and Robert L. Elder, Sc.D.

Introduction

The use of microwave power in industrial processing has been minimal over the past quarter century, primarily because of the often unnecessary expense involved in conversion from conventional to microwave systems. In recent years, however, new processes and microwave systems have been developed to a point at which microwave power can economically compete with or supplement currently used industrial heating systems.[1]

Although the Bureau of Radiological Health of the Food and Drug Administration currently has no standard regulating the performance of industrial microwave heating equipment, the potential for human exposure as well as the growing use of these units has stimulated government evaluation of these systems. The two factors which have primarily stimulated additional scrutiny are: 1) the high power levels and potentially high leakage levels of industrial microwave units; and 2) the processing of large quantities of material often resulting in conveyor openings which could potentially be the source of user exposure.

Description of Equipment

Because of the great variety of applications and operating powers of industrial microwave systems, no single unit can be called typical of the industry. Most units are custom-assembled and, therefore, may differ widely from each other. Systems presently under investigation by the Bureau of Radiological Health are primarily conveyorized, with openings at the entrance and exit, and most have some type of side door assembly located in the middle of the unit for cleaning the cooking cavity.

Figure 1 represents a simplified sketch of a typical conveyorized heating system. Included is a cooking cavity, a cleaning door assembly, and buffer zones filled with microwave radiation absorbing material at the input and output of the cavity. In most cases water loading is used as the absorptive material although choke seal wave traps are sometimes included as an additional microwave attenuation measure. Water loading is effected through tubing helically wrapped around the conveyor belt. The leakage radiation from water loaded buffer zones can be determined by choosing the appropriate length of the buffer zone when designing the oven.

Because of the high power levels often involved, numerous safety features are incorporated into the equipment to protect operating personnel. Water circulation monitors are attached to the water loaded buffer zone systems to shut down the unit if water flow is inadequate to absorb excess thermal energy generated through attenuation of microwave radiation. Cleaning doors are equipped with interlocks which will interrupt operation if opened during operation. In cases where material being processed is flammable, detectors are installed inside the cooking cavity to shut down the system and activate fire extinguishers when arcing occurs. The master control panels of these units are equipped with warning lights to indicate when the system is operating and if safety systems are malfunctioning.[2]

Survey of Manufacturers

In the spring of 1970, the Bureau of Radiological Health completed an initial investigation concentrated on determining the major manufacturers of industrial microwave equipment and on the heating and drying applications for which this equipment was used. The industry itself was found to be quite small with annual sales estimated to be about $2,000,000.[1] The cost of a single industrial microwave heating unit is on the order of $100,000. The principal manufacturers of industrial microwave equipment are: Bechtel Corporation, Cryodry Corporation, Genesys Systems, Raytheon Company, Reeve Electronics, and Varian Associates. It was learned that industrial microwave equipment has output powers varying from 2 kW to 150 kW depending on the application, operates at either 915 MHz or 2450 MHz, and is almost all conveyorized to permit rapid assembly line processing. The applications for which microwave energy are being used vary widely and include: finish drying of potato chips; precooking chicken parts; donut cooking; thawing frozen food; veneer drying; paper drying; plastic sealing; pharmaceutical drying; filament drying; match head drying; as well as numerous other experimental drying and heating applications. Figure 2 shows a representative 50 kW, 915 MHz system used to finish drying potato chips.

Safety Features

On the basis of observations of equipment at manufacturers' facilities, it is evident that certain features could be incorporated to assure safe operation. These safety fea-

Figure 1—Sketch of Representative Conveyorized Microwave Heating System Showing Principal Components and Operator Position.

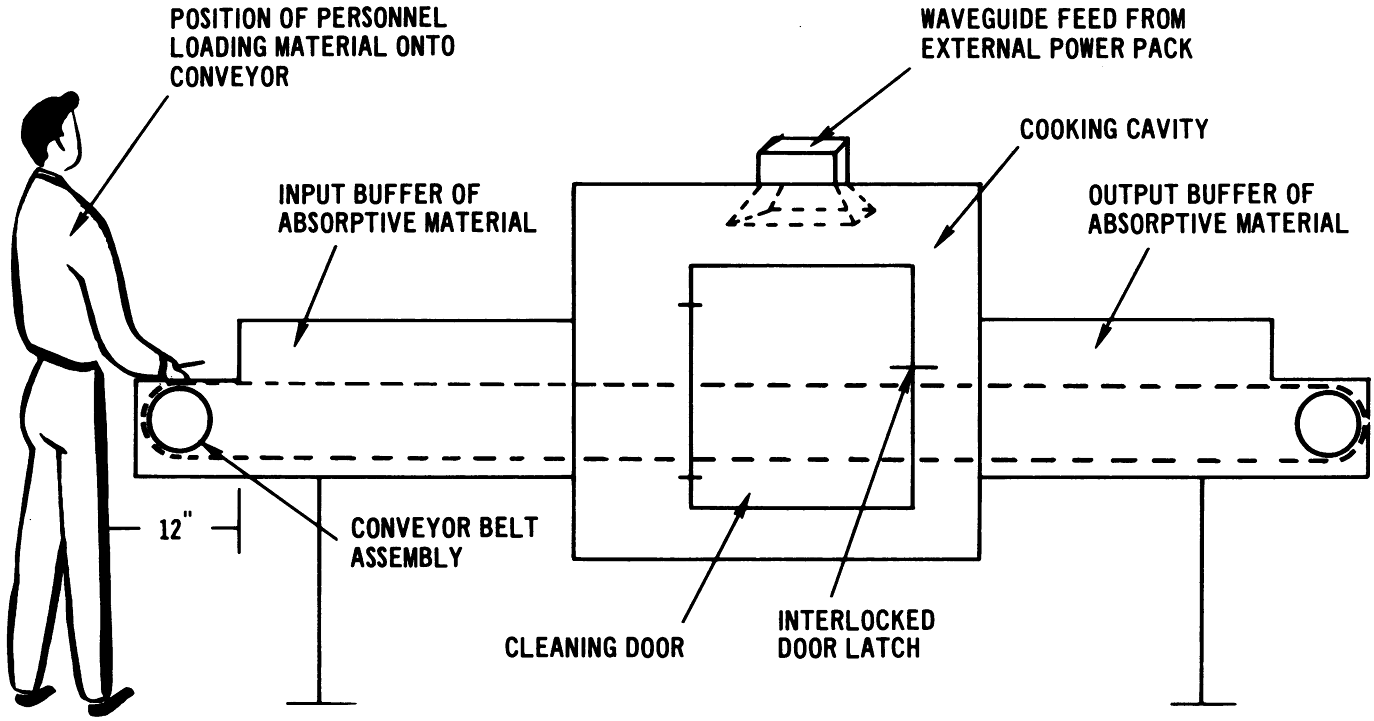
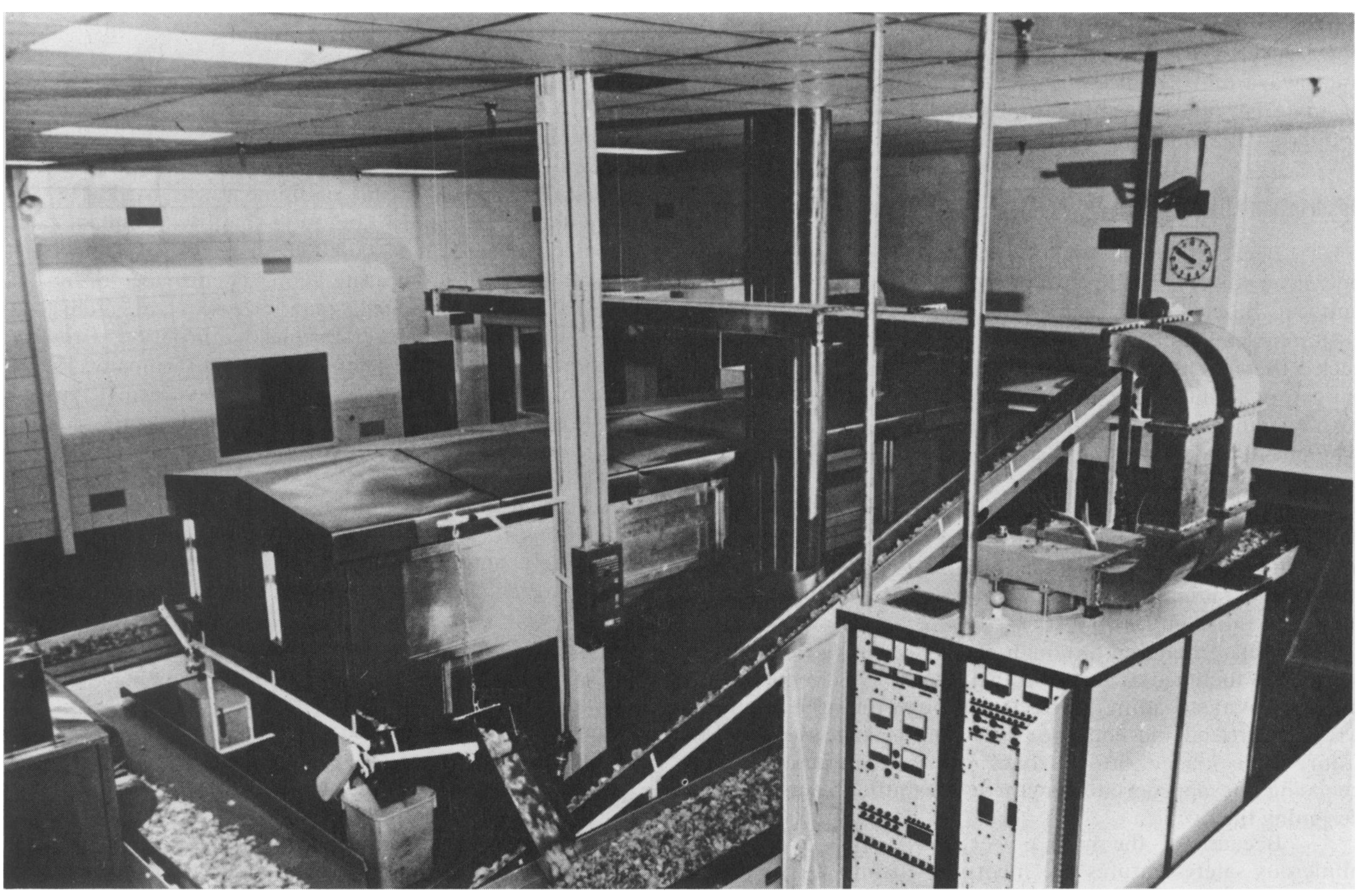


Figure 2—A 50 kW, 915 MHz Continuous System for Finish Drying Potato Chips (Courtesy Cryodry Corporation)



tures would include the following:[1] 1) adequate input and output buffer of absorptive material (i.e., water loads, wave traps, etc.) to maintain radiation leakage from the entrance and exit slots of conveyorized units below acceptable limits; 2) properly constructed and well-fitting cleaning doors which limit radiation leakage at these sites to acceptable levels; 3) correctly functioning interlocks and safety monitors which in the case of fully conveyorized units would include all door and power pack interlocks, water load circulation monitors, arc detectors, etc.; 4) tubing used in water loads which is free of cracks and aging defects; 5) warning labels at all entrance and exit ports of conveyorized units to warn personnel not to insert stray objects or their fingers through these openings while the system is operating; and 6) warning labels cautioning personnel not to open access doors while the device is operating and thus prevent excessive exposure in the event of interlock failure.

Survey of Industrial Users

In order to assess the degree to which the above safety measures occur in practice and to realistically evaluate the industrial worker's exposure to microwave leakage, a further study of industrial microwave heating systems under actual use conditions was undertaken in November 1970 by the Bureau of Radiological Health and the Bureau of Occupational Safety and Health (now the National Institute for Occupational Safety and Health).[2] In this study a sample of industrial applications of microwave radiation was surveyed in order to determine potential health hazards associated with these processes. The primary objectives of the survey were to:

- Develop methods for surveying industrial microwave applications.
- Recommend modifications or changes in microwave equipment and in operating procedures which, when implemented, will reduce industrial personnel exposures, and
- Promote safe operating conditions for industrial microwave facilities.

The proposed Threshold Limit Values of the American Conference of Government-Industrial Hygienists for occupational microwave exposure is used as a guide for evaluating the work environment.[3]

The locations of the units surveyed were obtained over a six-month period from microwave manufacturers, from technical journals, from state health departments, and from regional health offices. During this period only a small number of operating systems could be located—15 in all. This small sample reflected the fact that the industry is considerably smaller than originally suspected.

The investigation did, however, uncover a sizable number of units operating in the 27 to 100 MHz region for such jobs as sealing plastics and gluing. In the State of Pennsylvania, for example, over 90 per cent of the 60 industrial RF heating systems located operated at frequencies of from 27 MHz to 100 MHz. No survey of this equipment was practicable at this time because of the current unavailability of adequate survey instrumentation for frequencies below 100 MHz.

All leakage measurements on the systems surveyed were made with the Narda 8100 survey meter. The system was operated at full power either under normal loading conditions, or if this was not possible, under no-load conditions. Microwave leakage measurements were made at a distance of 5 cm from all accessible surfaces, 5 cm in front of the conveyor slots, around clean-out doors, at waveguide flanges, and other areas where leakage could occur. Measurements were also made at eye level for the operators' normal positions to obtain occupational exposure levels.

All systems surveyed, outlined in Table 1, were fully conveyorized with output powers varying from 2 kW to 120 kW. The frequencies of operation were 915 MHz and 2450 MHz. The number of operating personnel varied from three full-time operators standing at the conveyor ends to load and unload the material being processed to a single individual periodically checking the system. Likewise, the length of time the units operated each day varied from intermittent use to continuous operation. It was noted that in general the units requiring the least operating personnel were in use almost continuously. For example, units used to dry potato chips required no full-time supervision although they were run continuously, while a unit used to heat school lunches required three operators to load and unload lunches, but was used no more than 15 minutes per day.

Microwave leakage intensity measurements were made with the unit as close to normal operating conditions as was practical. Maximum readings for each unit are listed in Table 1. Leakage intensities measured at eye level at normal working positions of personnel did not exceed 4.0 mW/cm^2 at 5 cm from surfaces. However, maximum leakage ranged from less than 1.0 to over 200 mW/cm^2; these intensities were primarily at cleaning doors and conveyor slots. In cases where maximum leakage occurred at the cleaning doors it was usually due to a correctable factor such as a loose door hinge, warped door, or other factor which periodic leakage measurements would reveal and routine maintenance could then correct. In cases where the maximum leakage occurred at the conveyor slots, modifications of the conveyor buffer zone design would be necessary to reduce the level. As noted in Table 1 none of the units surveyed which had been in use less than one year emitted more than 8.0 mW/cm^2 maximum leakage at the conveyor slot. Although some units which were less than a year old had higher maximum leakage intensities at points other than the conveyor slot, this leakage could have been detected through routine inspection and significantly reduced by proper maintenance. One can conclude from these survey results that it is now technically feasible to manufacture industrial microwave heating systems which, with proper maintenance and inspection, will approach a leakage level no greater than 10 mW/cm^2 at a distance of 5 cm from any accessible surface.

To evaluate occupational exposures, microwave leakage intensity measurements were made at eye level in zones near the industrial units where nearby personnel could receive a microwave exposure in the normal course of their duties. In most cases the zone where the measurements were taken represented the maximum possible, rather than the typical, potential exposures to microwave energy. As noted in Table 1, of the 15 units surveyed there were only two leaking above 1.0 mW/cm^2.

In view of the systems surveyed which exhibited leakage levels above the recommended safe value in ANSI Standard C-95.1 - 1966,[4] several recommendations can be made to improve the operating safety.[5]

1. For units with excessive leakage at conveyor openings, shielding of attenuation could be added in the entrance and exit tunnels leading into and out of the cooking cavity. This shielding could be in the form of a set of two electrically-grounded metal curtains (hinged along the top edge), one set at either end so that the entering or exiting item would lift only one curtain at a time. In addition, physical barriers could be used to prevent operating exposure to power densities in excess of 10.0 mW/cm².
2. All interlocks should be tested routinely at frequent predetermined intervals. The interlocks should be of the type which, when opened, will not automatically restore the power when shut again, but would require a normal startup sequence.
3. All units should have warning labels cautioning personnel not to insert their hands or other objects into the conveyor slot during operation and not to open cleaning doors while the unit is running.

It was noted during the survey that various protective methods were incorporated into the equipment to avoid excessive leakage, including protective monitoring of water flow in dissipative water loads, interlocking of cavity cleaning doors, and occasional warning signs and visible delineation of hazard zones. No positive methods of excluding personnel from access to areas of actual or potential excessive microwave leakage (e.g., barriers, interlocked gates, etc.) have been observed.

Table 1—Summary of Conveyorized, Industrial Microwave Heating Systems

Type of process	Manufacturer	Output power in kW	Frequency in MHz	Maximum leakage in mW/cm²	Source of maximum leakage	Max. leakage at conveyor slot in mW/cm²	Maximum potential occupational exposure at eye level in mW/cm²	Approximate years in use
1. Pharmaceutical drying	Litton	10	2450	190.0	Loose cleaning door	20.0	1.0	5
2. Food processing research	Litton	10	2450	70.0	Conveyor slot	70.0	3.0	5
3. Finish drying potato chips	Crydodry	60	915	20.0	Conveyor slot	20.0	1.0	3
4. Opening oysters	Holaday	6	2450	25.0	Conveyor slot	25.0	1.0	2
5. Filament drying	DuPont	2	2450	25.0	Conveyor slot	25.0	1.0	1.5
6. Film drying	DuPont	5	2450	50.0	Conveyor slot	50.0	1.0	1.5
7. Film drying	Cryodry	30	915	2.0	Conveyor slot	2.0	1.0	1
8. Precooking chicken	Varian	120	2450	70.0	Waveguide feed	5.0	1.0	1
9. Food processing research	Cryodry	5	2450	1.0	Conveyor slot	1.0	1.0	1
10. Opening oysters	Raytheon	5	2450	60.0	Loose door hinge	8.0	1.0	1
11. Precooking onion rings	Raytheon	4.5	2450	<1.0	—	<1.0	1.0	<1
12. Rapid heating of school lunches	Raytheon	15	2450	1.0	Conveyor slot	1.0	1.0	<1
13. Thawing frozen food	Raytheon	25	915	1.0	Conveyor slot	1.0	1.0	<1
14. Donut proofing	DCA Industries	5	2450	30.0	Warped cleaning door	2.0	1.0	<1
15. Macaroni drying	Cryodry	30	915	+200.0	Burned cleaning door	2.0	4.0	<1

Comparison of Industrial Heating Systems and Microwave Ovens

While the purpose of commercial and household microwave ovens is similar to some industrial processes, the conditions of operation vary significantly. In the household and in some commercial situations, microwave ovens are operated in a predominantly uncontrolled environment, whereas in the industrial situation controlled access can be implemented if necessary. Another significant difference between the industrial and nonindustrial use of microwave heating is in the potential number of individuals exposed. It is estimated that less than 300 industrial microwave power units are currently in use[6] with a potential risk of exposing less than 3,000 persons,[1] whereas approximately 150,000 household and commercial microwave ovens are currently in use.[7,10]

On October 6, 1971, the new federal standard for control of microwave oven radiation safety went into effect under authority of the Radiation Control for Health and Safety Act of 1968 (P.L. 90-602).[7] This standard is designed for commercial and household ovens used in the preparation of food and among other requirements, limits the maximum power density leakage at a distance of 5 cm from the oven to 1.0 mW/cm² before sale and to 5.0 mW/cm² thereafter. It also includes provisions for safety interlocks and for inhibiting insertion of an object into the cavity which would cause greater microwave leakage. The microwave oven standard is intended to regulate the radiation safety of closed cavity ovens used for preparation of food in the home or in commercial and institutional facilities.

The industrial units which have been discussed do not meet this definition. Industrial heating systems generally have open apertures to the cavity to permit conveyorized continuous processing. It is further noted that the cost of these units render them too expensive for other than large-scale industrial operations.

Another major difference between the industrial and other uses of microwave power concerns the users of the equipment. The average housewife or vending establishment patron generally knows little about the operation of the microwave oven and the safeguards associated therewith. In industrial applications, however, a piece of equipment often represents a significant investment, and an untrained operator can pose a substantial liability. Since unsafe industrial operation can result in financial penalties, worker and union dissatisfaction, and downtime due to injury of skilled operators, it is important to assure adequate safeguards and to educate personnel in safe operating procedures.[1]

An industrial operator of microwave equipment is less likely to be inadvertently exposed to unnecessary radiation as a result of lack of training, warning devices, and controlled access to hazardous areas than is the nonindustrial user. From a public health standpoint, the industrial operator constitutes a very small fraction of the total population of individuals exposed or potentially exposed to radiation leakage from microwave devices. On the other hand, the duration of exposure of industrial and commercial users can be on the order of hours, while in the household situation human exposure would be expected to be on the order of minutes. Nevertheless, in an industrial situation precautions can be taken to prevent personnel from coming into close proximity to the device and to use protective shielding, thus preventing exposure to critical portions of the human body.

Future Investigations

It should be noted that this study of industrial nonionizing radiation applications is by no means inclusive of all industrial RF heating devices. Measurements were restricted to devices operating at electromagnetic frequencies of 915 and 2450 MHz. As previously indicated, evidence shows that a comparatively greater number of nonionizing radiation industrial applications, such as plastic sealing and gluing, involve other radio frequencies; e.g., 27 to 100 MHz. The unavailability of field instrumentation was the major reason for not including these radio frequency applications in this study. Present field instrumentation is limited to measuring radiation intensities within a fixed range of energies. The Bureau is currently developing instrumentation for these longer wavelength applications.

Conclusion

The results of the joint survey by the Bureau of Radiological Health and Bureau of Occupational Safety and Health indicate that the still emerging industrial microwave heating equipment industry has done much during the past two years to reduce the leakage of microwave radiation from its equipment. In concluding, it should be emphasized that the spirit of our efforts in radiation control of industrial microwave power is to encourage the manufacture of inherently safe electronic products and to further ensure their proper maintenance and use. It is through the close cooperation and voluntary efforts of manufacturers, industrial users, and state and federal agencies that we anticipate this goal can be met.

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Mr. Eure is Chief, Compliance Operations Section, Mr. Nicolls is a former Staff Engineer, and Dr. Elder is Director of the Division of Electronic Products, Bureau of Radiological Health, Rockville, Maryland 20852.

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