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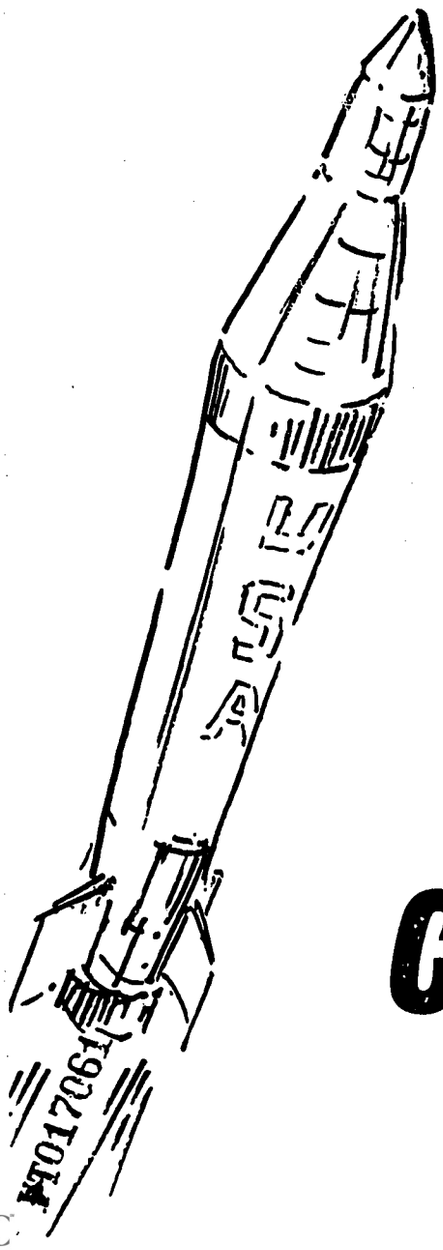
ABSTRACT

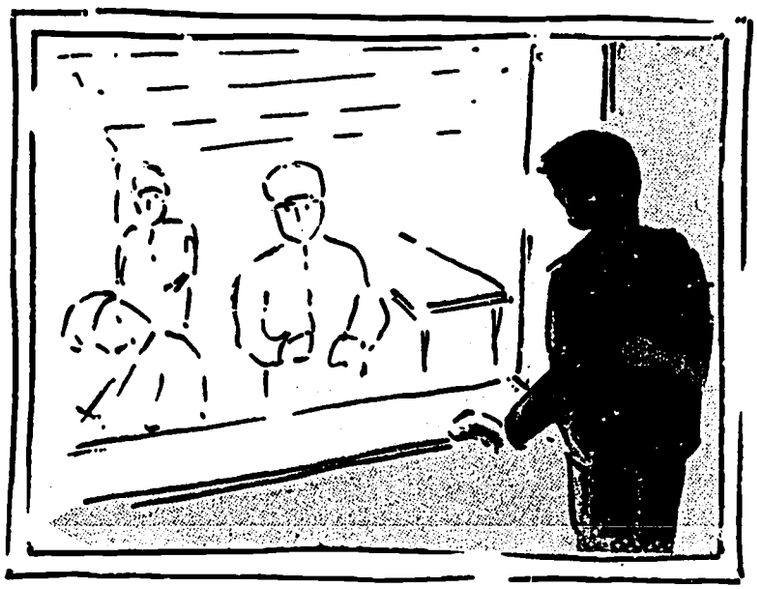
The purpose of this publication is to present information concerning the environmental conditions imposed upon workers in industries which require clean room facilities to eliminate particle-caused equipment failure. The information, which was collected through interviews, observation, and other standard job analysis techniques, discusses these topics: (1) history of clean rooms, (2) degrees of cleanliness in clean room installations, (3) industrial use of clean rooms, (4) general working conditions, (5) job requirements, (6) employee qualifications, with respect to interests, temperaments, and aptitudes, (7) selected occupational activities in the aerospace industry and medical apparatus manufacturing plants, including descriptions of nature of work, working conditions, physical demands, entry level training and qualifications requirements, and advancement opportunities for an aerospace assembler and assembler of implantable devices, and (8) employment outlook for clean room occupations. (SB)

Wisconsin Occupational Analysis Field Center

SERIES 1010 - 3 - 69

THE WORLD OF WORK...





INDUSTRIAL CLEAN ROOMS

WISCONSIN STATE EMPLOYMENT SERVICE
A Division of the Department of
INDUSTRY, LABOR & HUMAN RELATIONS

This publication is presented by the
WISCONSIN OCCUPATIONAL ANALYSIS FIELD CENTER
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Acknowledgement is also made to the use of the following text as an aid in preparation of this report.

DESIGN AND OPERATION OF CLEAN ROOMS

by Austin and Timmerman

200-45

C O N T E N T S

I

INTRODUCTION

The purpose of this publication is to present information concerned with clean room occupations. More specifically, to make known the environmental conditions imposed upon such workers in those industries requiring clean room facilities. To that extent, the product-oriented occupational data is presented in rather general terms, with emphasis on those tasks which are direct results of clean room procedures.

The information presented has been collected through interview, observation, and other standard job analysis techniques. In addition, specifications covering the construction and equipping of clean rooms have been reviewed and such data is presented where relevant in the text.

It is hoped that this brochure will be of value to both employers and prospective employees, by providing general background data which is based on clean rooms in operation at various specified levels of cleanliness.

II

CLEAN ROOM HISTORY

The old axiom, "History repeats itself," has definite application to this subject. The repetition is within the development of clean rooms

as used in the medical profession and those of industry. For illustrative purposes the term "operating room" shall indicate a medical area designated for surgical operations. "Clean room" will be used to denote industrial areas which have a controlled atmosphere.

Although operating rooms were developed first, some of today's modern clean rooms exceed the cleanliness requirements of operating rooms. Modern-day operating rooms had their start in the late 1800's when the main items of equipment were the surgeon's knives and strap-down type patient tables. The development of anesthesia was considered a real technological breakthrough and allowed the surgeon to concentrate a larger portion of his attention directly on his work. He then began to improve the operating room environment and thus commenced the battle for maximum cleanliness. The turn of the century was made with new hospitals put into operation which stressed cleanliness of not only the operating room, but of the surgeon and patient as well. Conditions prevalent in World War I forced additional improvements in operating room equipment, and during World War II advances were made in electronic equipment and air conditioning equipment. Thus the development of operating rooms is linked to wars, and modern science continues to advance technologically in providing the cleanest operating rooms possible.

The clean room story reveals development events which parallel the operating room history. Just as World War I had its influence on operating rooms, the necessity for cleanliness was felt in manufacturing activities as well. In those days extreme difficulty was encountered in building small bearings and gears, such as used in aircraft instruments, which

could function reliably over prolonged periods. It became necessary to build these components within controlled environmental conditions. Though these rooms did not have the generic name "clean room" they nonetheless served a similar function. Thus the two types of clean rooms have developed from necessity; necessity within the operating room to prevent bacterial contamination during surgery, and necessity within the manufacturing clean room to eliminate particle-caused equipment failure. Within the operating room environment, a sterilized particle is not "dirty" - within the clean room confines any particle (in excess of allowable limits) is contamination. The cleanest clean rooms of ten years ago would hardly qualify as clean rooms by today's rigid standards. There are at least seven levels within the aerospace industry which are well defined and strictly adhered to. Environmentally controlled factors include particle counts, temperature, relative humidity, static pressure, and even illumination. Government contracts also specify the type of activity to be performed within each class of room.

III

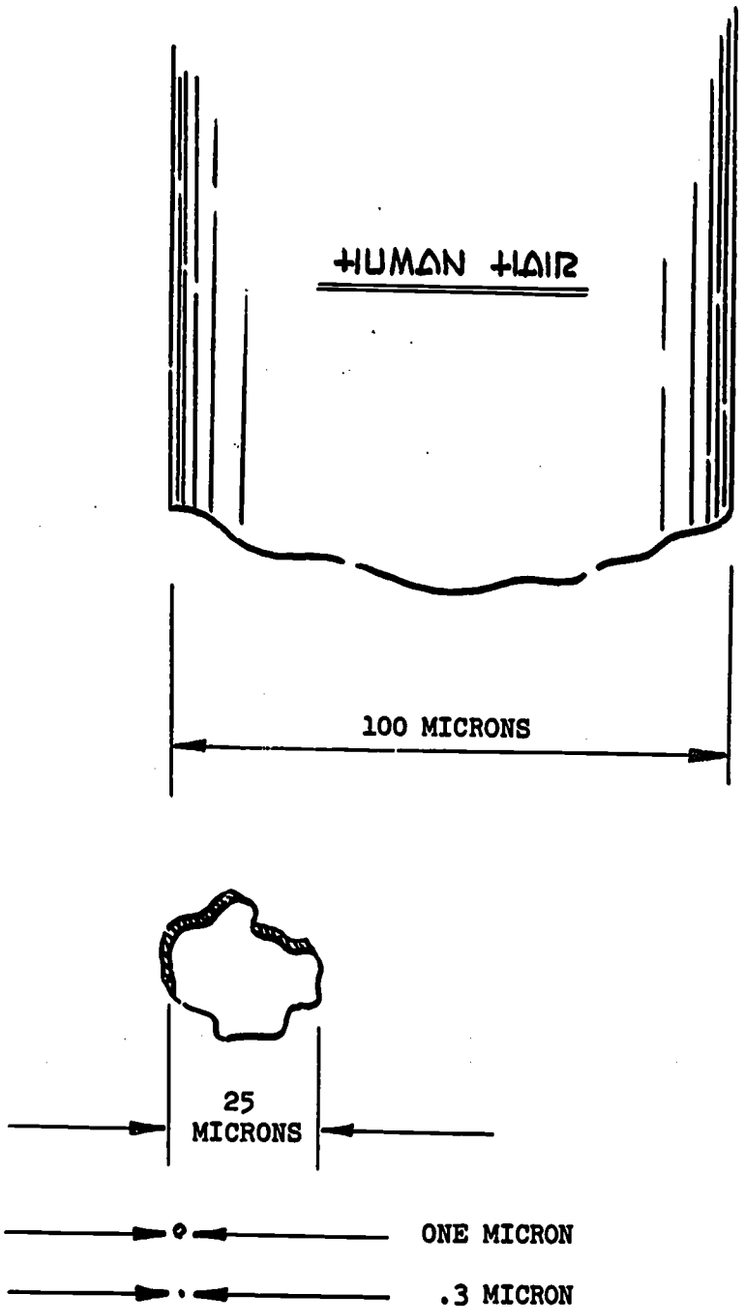
DEFINITION

There are degrees of clean in clean room installations. The degree is determined by the particle count within the air, and by the actual task techniques employed. In other words, a combination of factors must be present to have and use a clean room which will meet or surpass certification requirements of agencies such as the National Aeronautics and Space Administration.

human hair is approximately 100 microns wide. Therefore the critical size of particles may be smaller than 1/100 of the width of that hair. For some very critical work activities, the specified count may not exceed 20 particles per cubic foot of air, wherein the maximum particle may not exceed .3 micron in size. This will typically be found only at laminar flow benches which are located in clean rooms. The benches provide a self-contained atmosphere for individual work stations and are rapidly becoming the most advanced clean room facility possible in industry. Laminar flow benches will also permit more than the usual eight persons within the basic clean room environment. The flow benches are usually built into a wall and only the work area, which has side and top shields, is exposed within the room. The use of flow benches does not impose restrictions on the worker that do not already exist, it merely decreases the particle flow at isolation locations.

Following are typical allowable particle counts adhered to by most industries in which clean rooms are vital. It must be noted that all such industries are continually upgrading all clean room factors, i.e. number of people, clothing (fiber) content, and assembly methods.

AREA		PARTICLE COUNT (per cubic foot)
ASSEMBLY - NON-CRITICAL	:	130,000
SEMI-CRITICAL ASSEMBLY	:	20,000
CRITICAL ASSEMBLY	:	2,000 to 10,000
INDIVIDUAL WORK STATION (Laminar Flow Bench)	:	20
AVERAGE LIVING ROOM	:	1-2 million



ENLARGED APPROXIMATELY 750 TIMES

Ref: 25,400 microns per inch

ILLUSTRATION #1

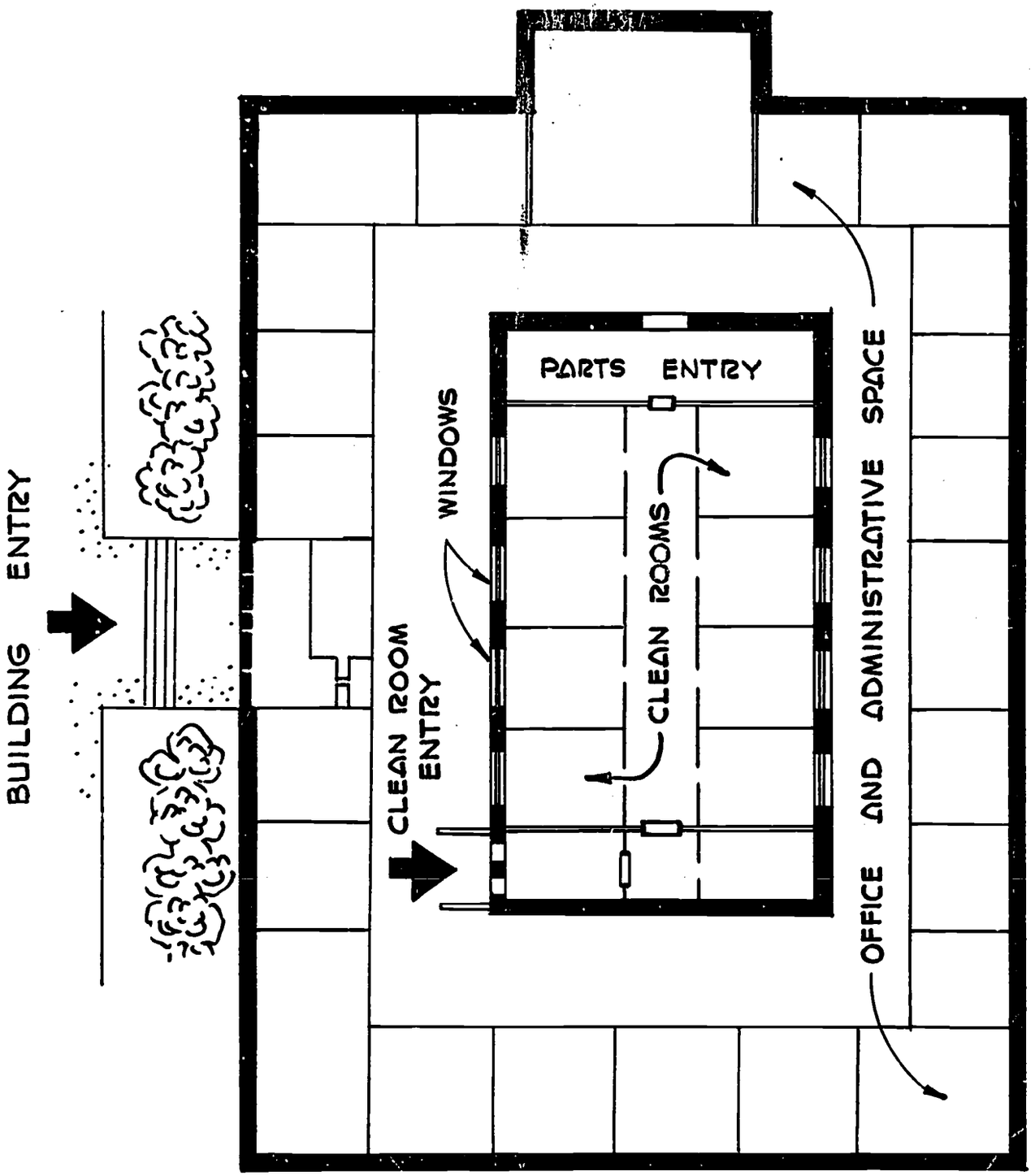
It is not feasible to attempt having an entire building conform to such critical cleanliness standards. On the other hand, one room is rarely large enough. The result is usually a complex of connected rooms, all with the clean room environment, but completely separate from the remaining building. In effect, we have a building within a building, as the sketch on the following page shows.

Illustration #2 shows the fluctuation in particle count through a typical work day. From 10:00 P.M., following cleaning, the level remains fairly constant until the start of shift occurs which raises the count fivefold. During the cleaning period the count peaks to its highest level. As illustrated, movement alone is enough to cause a dramatic increase in the clean room particle count. This is why, in many cases, employees must not enter and leave the clean areas except at prescribed times or in emergencies. Particles which are at rest on floors, chairs, and tables are designated potential contamination and when such particles are set into motion they become actual contamination.

IV

INDUSTRY APPLICATION

As noted in Chapter II, the clean room is found in several manufacturing industries. The use of this type facility is increasing across product lines just as the quality is improving within given situations. A large diesel engine fuel injection system manufacturer is using clean rooms for assembly purposes. Prior to clean room assembly, an alarmingly



TYPICAL CLEAN ROOM BUILDING

CLEAN ROOM PARTICLE ACTIVITY

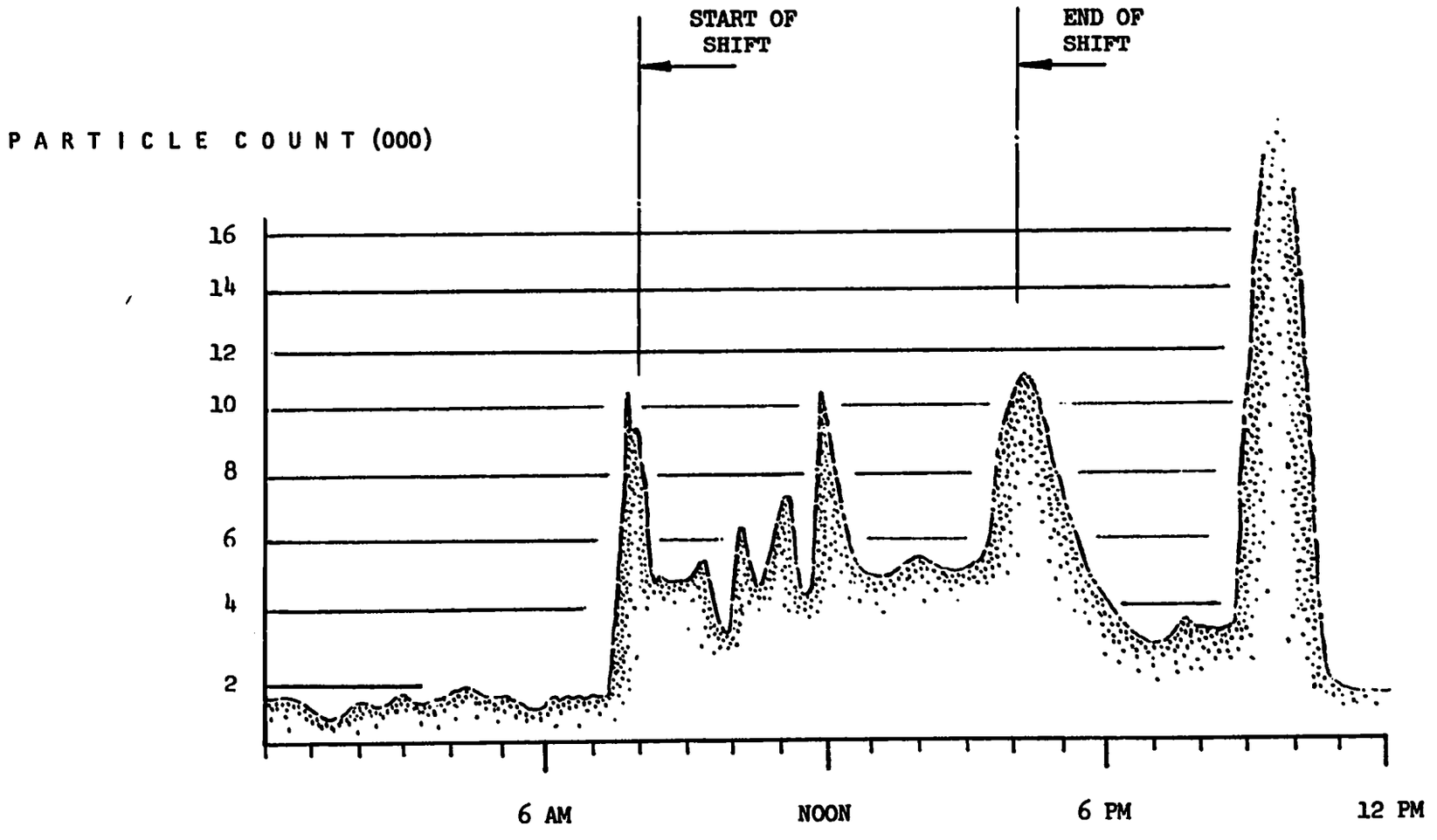


ILLUSTRATION #2

high failure and rejection rate was causing significant marketing problems for the otherwise high-quality engines. The fuel injection system is the heart of a diesel engine and must perform within extremely close tolerances. The problem was nothing more than tiny dirt particles which eventually work their way to block very small fuel passages within the fuel system. The obvious, and costly, solution was to build such units within rooms as particle clean as possible. Additional inspection and test stations were set up to insure quality control. Units are numbered, recorded, and shipped in sealed containers. A history is maintained on each system so that rejections can be analyzed and improvements made to the assembly system.

Manufacturers of medical apparatus also use clean rooms. Items such as implantable pacemakers must be made as cleanly as possible to provide the longest possible use of such equipment. Since implantable devices require an operation, two types of "clean" are involved - bacteria and particle. Such devices are surgically cleaned and sterilized in addition to the particle cleanliness of the clean room.

As previously noted, the Aerospace Industry is a leading user of clean rooms. Within this industry an ever-increasing number of products are being designated for "clean room assembly only." Certain metals, noted as exotic, are somewhat toxic and the floating particles must be promptly removed during machining. Therefore, complete processing and machining of such raw materials is accomplished in clean rooms.

We have outlined a variety of industrial uses of clean rooms but

from use to use the clean room itself remains essentially unchanged. It is an enclosure within a building, in which is maintained a closely regulated atmosphere. The air is conditioned to desired temperature and humidity levels, and the air is filtered to provide and maintain allowable particle count levels.

V

GENERAL WORKING CONDITIONS

The photographs on the following pages show typical clean rooms of manufacturers within several industries.

For purposes of illustration, photo #1 will be discussed. This photo was not taken within the room; it was made through the glass observation window which most clean rooms have. The purpose of the window is to allow observation of product progress as well as job problems. The "audience" is typically engineers and technicians who are responsible for various stages of manufacture. Ideally, those entering the clean room remain for a minimum of four hours. This is to keep contamination from freely entering through the opening and closing of the entrance door. Therefore, there are few visitors in the super clean room and the complex of rooms is even equipped with its own restroom facilities so that workers need not leave the regulated atmosphere. It is common procedure, as illustrated in photo #4, to move parts into clean room areas by use of air chambers which restrict the amount of outside air which would otherwise enter.

C L E A N R O O M

V I E W E D F R O M

O U T S I D E

PHOTO NO. 1

Courtesy Medtronic, Inc.
Minneapolis, Minnesota

CLEAN ROOM

WORK ACTIVITIES

PHOTO NO. 2

T Y P I C A L

C L E A N R O O M

C L O T H I N G

PHOTO NO.3

Courtesy Medtronic, Inc.
Minneapolis, Minnesota

PARTS ENTRY

TO

CLEAN ROOM

PHOTO NO. 4

Courtesy Medtronic, Inc.
Minneapolis, Minnesota

Entry into the clean room is somewhat complicated but not difficult. Because contamination consists generally of particles of matter, normal clothing is extremely contaminated. Special outer garments must be worn, including caps, shoe covers, and in some cases rubber gloves. Thus, a dressing room is necessary in which to don and remove the special lint-free and pocketless garments. Prior to entry shoes are cleaned by use of a revolving brush-vacuum cleaner machine into which the foot is positioned. Items of a personal nature, e.g., cigarettes, candy, etc., are not permitted in the work areas. Photo #3 shows a worker ready for clean room duty.

Following the dressing room routine and passage through an air shower, entry is gained into a common corridor from which individual room access is possible. The worker has now passed into the rigidly controlled atmosphere of the clean room and may become aware of the low humidity and temperature, relative to exterior conditions. This can cause minor discomfort for a very few persons, but for a majority the clean room climate constitutes a benefit. Ample evidence, in terms of sick leave records, supports this contention.

Activity within the clean room is kept to a minimum in order to prevent movement or disturbance of contamination. Ideally, each room will contain no more than eight persons, and except for actual job duties, minimum movement from work stations is made. The type worker who must move around frequently for any reason is not well suited to this occupational group. As previously noted, restroom facilities are provided within the complex, but in the actual workrooms there is no smoking or eating.

Some persons who have previously smoked rather heavily found little difficulty in conforming. This, in part, may be due to the nature of the work wherein complete dedication to cleanliness becomes a matter of self-discipline. Use of cosmetics is severely restricted and women must wear caps that cover and actually contain the hair; however, this poses no apparent problem. The caps, as with all the special outer garments worn, are very light in weight and would not disturb various hair fashion creations. All such clothing, including shoe covers, are sized.

In general, the clean room employee is unique only by virtue of the fact that his work must be performed within an area in which standards of cleanliness are very strictly adhered to. As a work world, it is very pleasant and the transition apparently is beneficial to those involved. It is a world into which recorded music is piped to help combat the starkness of uninterrupted quiet. Quite often, clean room jobs are related to products such as spaceships, wherein pride through association of a successful and widely publicized project instills a high degree of dedication in all workers. A true holiday spirit prevails in an aerospace plant following a successful space flight using the firm's particular component. As explained by one plant official, a rocket in flight becomes a personal achievement to each project worker and this is especially pronounced within clean room groups. Competition, between clean rooms and between projects, actually exists in a world where all appears near perfect. The consequence of carelessness, or less than best effort, is everlastingly a matter of record.

them. The employed housewife with children returning from school to an empty house will not be likely to devote full effort to her job in a clean room. On the other hand, housewives free of such pressing daily problems are among the best clean room workers.

As noted, the job requirements are not what make these occupations unique. Basically, clean room assembly jobs are no different from other assembly jobs so far as tools are concerned. Regular sized tools, such as screwdrivers, pliers, and drivers, are used on products such as irons, toasters, and automobiles. However, many clean room products, such as gyroscopes, contain very small parts which normal size tools will not fit. Small tools, such as those used by jewelers and dentists, are used by many clean room assemblers, and except for size, there is no difference from other assembly handtools. It is, rather, the method by which the tools are used and techniques of assembly that differ. It is true that most clean room products are small and may contain complex moving parts, and that microscopes to aid in assembly are in abundant use. A microscope merely magnifies the parts, however, and does not add to the task complexity. By the same token, smaller tools are used to handle smaller parts, but -- again, the actual job complexity does not necessarily change. In essence, the basic job is to build a unit, component, or system. The difference is in the cleanliness surrounding the assembly. The importance of a low contamination count has already been discussed and the ramifications to the job will now be presented.

Because tiny unseen particles carried in the air can cause destruction of an otherwise perfectly functioning system, it is necessary to filter the

air within the assembly area. Just as important, it is necessary to work with clean tools and parts. The air filtration system will not completely perform this task and it is here that the clean room job becomes different. First, it should be noted that within the field of engineering there are contamination engineers. These individuals prescribe the methods of assembly which insure that the product is as clean as possible. Each task within the clean room is therefore a function of cleaning as well as fabrication of the product.

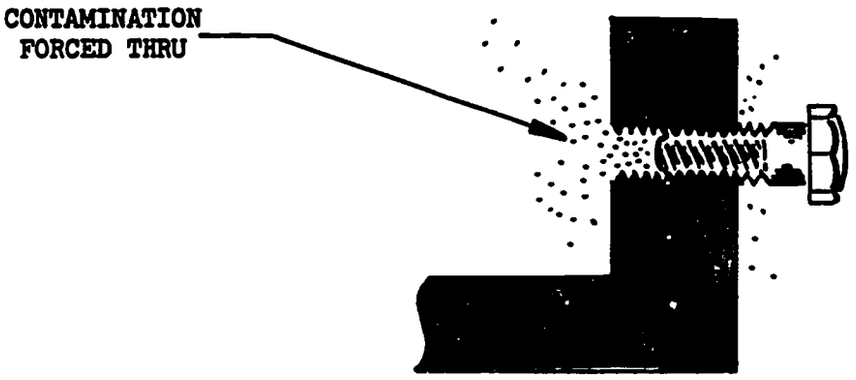
Many techniques are used to insure cleanliness. Lint-free wiping cloths are extensively used on parts and tools; parts are brushed, dipped, and sprayed in solvents such as liquid freon; special work areas are constructed with individual "pressurized" air pockets to prevent contamination from entering. A typical job could include all of this and a hypothetical job might be as follows:

....Attaches heater to unit bracket with wrench. Wipes wrench with cloth and drops cloth into covered can (using foot control lever to operate top). Secures switch to unit, using screwdriver. Wipes screwdriver with cloth and drops cloth into covered can, etc.

In general, the assembly job in this example involves using standard hand-tools to build the unit. Following each tool use, the tool is wiped from the top down, and the cloth dropped into a hinged-top can. The reason for this almost continual cleaning is that every time parts are joined together small particles of metal are rubbed off. Some float away, others adhere to the unit, while the remainder stick to the tool. This is the reason for wiping and disposing of the cloth following each usage. The contam-

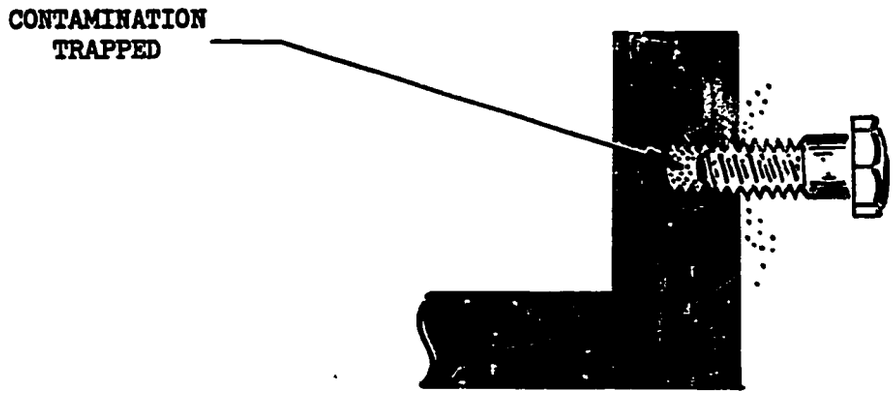
ination caused by the friction of metal to metal comes under close scrutiny by the contamination engineer. An instruction to join two parts together may read "...tighten holding screw slowly..". Although holes are pre-tapped, much metal dust is created when tightening down a bolt. This dust must not become a part of the finished item and must be disposed of. It is imperative therefore to know when such contamination is being created and where it goes. An example appears on the following page which shows why it is sometimes necessary to tighten a bolt slowly. As shown in section "A", contamination is being created by running the bolt through an open hole. This dust is forced through as the bolt is turned in. Section "B", on the other hand, shows that the dust is being trapped when the bolt is turned into a closed hole. Provided the bolt is turned slowly, most contamination is trapped and cannot escape. If the bolt is turned rapidly, the dust is forced out past the threads and allowed to spread. Thus, each task of assembly is so designed as to minimize the creation and distribution of contamination. Thus, cleaning tasks are designed accordingly. For example, following the turning of the bolt in section "A", the entire unit would doubtless receive a freon bath to eliminate the dust. Liquid freon is used extensively in clean rooms because it leaves no residue. A single unit may be cleansed with it more than two dozen times in the above described manner.

The clean room "state of the art" today is such that if a cleaning device or method appears to have merit, it will be utilized "to be on the safe side." Obviously, this is not intended to reflect that a haphazard



SECTION 'A'

OPEN



SECTION 'B'

CLOSED

method is used to insure cleanliness, but it is true that some rather exotic devices are employed. One such unit uses freon in both liquid and near gaseous states. In any case, there is no doubt that the methods of control and disposition of contamination will continue to improve as performance quality demands increase.

Higher particle count clean rooms, though serving the same general purpose, are not as restrictive concerning employee activities within the clean rooms. Many permit smoking and workers are free to leave the room at will. Less protective clothing is necessary and cleaning of tools is not required following each usage. There is no scrub down or vacuum cleaner procedure and a coverall, with pockets, is donned and removed within the work area. Most such rooms are air-conditioned and are cleaned more thoroughly than remaining shop areas. The floors are enameled or treated with some other equally cleanable surface. This is in sharp contrast to the usual bare concrete floor found in adjacent plant areas.

Just as the particle count varies from site to site, the amount of cleaning effort varies from product to product. Aside from the special outer-garments worn, the main job difference is the amount of cleaning necessary to the product. Within the highest clean levels, it is possible that 50% of a person's work day could be spent cleaning the parts and tools with which he works. To the other extreme, as little as 5% may be spent in such activities and this may be the final assembly step, opposed to the almost continual operation at the above extremity.

In general then, workers in clean rooms have two jobs - 1), to build or assemble a unit, and 2), to clean parts, tools, and completed units. The assembly function remains the same while the amount and method of cleaning change as the demand for cleanliness increases. In addition, other significant factors arise which affect the prospective employee's suitability for acceptance into the clean room work force. Because of the extremely high costs of constructing and maintaining a clean room complex, firms consider clean room employees as an investment. Training is essential, yet because of the necessary restrictive measures, such training is at best difficult to administer. Certain training is best given outside the clean room, such as soldering and the use of epoxies. Furthermore, agencies such as N.A.S.A., in addition to specifying the clean room conditions, also require solderer and in some cases epoxy certification for employees performing these tasks. Because of ever-changing technological conditions, these two skills are becoming increasingly critical. At least one firm, for its super clean rooms, requires that a person successfully complete certification training for these two activities. Prior experience is not required, and in some cases, experienced persons fail the training course and are not eligible for clean room positions. The reason for requiring all workers to satisfactorily complete the training is to maintain a uniformly qualified labor force. Failure to pass the training course may merely indicate that a person does not possess the necessary degree of a particular aptitude for which performance in clean rooms is critical. The course is not difficult, and to a large degree could be considered a qualifica-

tion test for which training is given. Experience has proven that course repetition does not increase the necessary aptitude and repeats are therefore not given.

VII

EMPLOYEE SELECTION

As stated previously in this text, the actual jobs within clean rooms are quite similar to related jobs in the "outside" world. It is true that as the level of cleanliness increases, the jobs involved are such that mistakes or careless work may jeopardize lives and systems costing millions of dollars. However, assuming that every working person is capable of continually doing his best work, then the actual job requirements are identical. Job conditions, however, are far from even being similar. The important factor is how well a person can adapt to these conditions.

Specific knowledge is easily measured through testing, trial, sampling, and numerous other methods. To this extent, jobs in clean rooms would be easily filled, especially since most entry positions do not demand previous experience. The important element for measurement is a person's adaptability to clean room conditions. This determination is especially difficult and, unlike experience, there are no perfect tests designed for this purpose. Studies have been conducted to gain data which would help develop such aids, but the results have been almost valueless. In one case, at least, a successful clean room worker was used as the basis for a very detailed questionnaire to be used for

placement purposes. The results of placement using this criterion was very poor. As noted before, this procedure is very costly and time-consuming. More importantly, the misplaced worker is far from satisfied and will not perform adequately. Two placements are then necessary - the unhappy worker and the job he is unable or unwilling to fill.

Another method, though somewhat unscientific, is to rely entirely on interview. This obviously requires that the interviewer be thoroughly familiar with the clean room environment and will doubtless be a person with responsibility for clean room production standards. It must be realized, however, that this method is totally dependent upon the interviewer's ability to draw out from the applicant enough background data with which to form judgments. To this extent the interviewer may cover a wide variety of subject matter in order to form as broad a base as possible on which to make decisions. A particular hobby, for example, may represent the precise interest factor being sought in an individual. This does not by any means reflect that a person without hobbies would not have even a higher potential in any given category. It does mean, however, that the interviewer must open another subject for discussion in order to gain the desired information. For this reason, such interviews do not follow a prescribed course, nor is there a prescribed length of time for such discussions. Many judgmental measurements must be made by the interviewer, including the following:

1) INTERESTS - Interest has been defined as "...a tendency to become absorbed in an experience and to continue it..." Numerous studies have confirmed that a significant relationship exists

between job stability and satisfaction, and positive interest in the type of work. Sufficient evidence further shows that interest categories are bipolar in nature to the extent that certain likes can reliably predict opposite dislikes. For example, persons who show a preference for activities dealing with things and objects will normally dislike activities concerned with people and communication of ideas. The interviewer, guided by generally known successful clean room interest factors, must attempt to determine if similar interest factors are present in the interviewee. As stated earlier, a hobby preference may expose this factor; previous employment may confirm the finding; or, there may be no available evidence that the interest factor exists, in which case judgment alone may be necessary. Not only must final judgment be made on the presence of this factor, but in most cases it is essential to determine the degree to which it may exist.

2) TEMPERAMENTS - An occupational definition for the term temperaments may not coincide with the everyday dictionary version, but it is a valuable placement tool when used to indicate "...the personality qualities which remain fairly constant and reveal a person's intrinsic nature." Various basic temperament factors exist from which judgments may be assigned to an endless variety of job duties. As with the preceding interest factors, careful consideration must be given in determining actual job requirements relative to these elements. This is strictly a matter of judging those jobs in terms of the elements possessed by those successfully employed.

3) APTITUDES - Aptitudes are the specific capacities or abilities required of an individual in order to facilitate the learning of some task or job duty. In general, testing provides adequate knowledge of a person's aptitudes. However, the uniqueness of some clean room occupations can invalidate the usual placement process with regard to aptitudes. Again, the interviewer must make such final judgments but at the same time be cognizant of the allowable tolerance within job requirements.

There are many additional job elements which must be considered for placement purposes, even in less critical situations. For most occupations the penalty of a trial period is not so severe as within clean rooms. Logically, the higher particle count rooms are easier to effect placements in, as they present more typical work conditions. In any case, selection of persons for certain clean room jobs is very difficult and is complicated by the requirements imposed due to the unique conditions. It is of prime importance that such workers be properly placed, both to insure the highest quality control standards and obtain maximum employee satisfaction.

RELATED EXPERIENCE

A high particle count clean room does not represent too severe a change over typical manufacturing shop conditions. Consideration for employment is based largely on the job requirements with only minor concern for the conditions under which the employee works. Clean room activities in such plants are usually a small percentage of the total

tasks involved and therefore require relatively few people. The rooms are clean, well-lit, and in many cases are air-conditioned regardless of the remainder of the building.

The products requiring these assembly conditions are generally small in size and the jobs require only minor physical exertion. Such clean rooms are considered by many of the other employees as choice jobs and are therefore much sought after. Selection methods can, in these cases, rely almost entirely on related experience because the "clean" conditions have not been increased to a level which becomes part of the job duties for the individual workers. Except for routine assembly cleaning, these are clean rooms by virtue of the mechanical air filtration system and not by worker participation to any noticeable degree. As the particle count is decreased, the worker participation increases to the level previously defined for super clean rooms. As this process occurs, the importance of previous "non-clean" experience diminishes.

Almost all clean room jobs, especially entry level, will involve product assembly. This can mean either an assembly line, where each person does one part, or, in some cases, the entire unit is assembled by one individual. At least two factors influence the type of assembly process: product complexity and maximum allowable particle count as related to the number of persons required to man an assembly line. A low contamination count requirement dictates the maximum number of people within the room, regardless of <u>any</u> other condition. It is possible, therefore, that the product lends itself to assembly line methods, but assembly line methods would cause too high a particle count.

In any case, assembly line experience would be helpful in adapting to clean room work because most assembly lines require the worker to maintain one work position. This is in harmony with the "Is this move necessary?" philosophy of many clean rooms. The assembly tasks, exclusive of cleaning motions, are relatively simple and involve the use of standard, though small, handtools such as screwdrivers and pliers. Many clean room products are machined to very close tolerances and moving parts must perform within extremely small clearances. However, the Assembler is rarely responsible for creating or adjusting to these critical performance conditions.

Quality Controller, Inspector, and Technician are other clean room job titles, and, as with the Assembler, the lower the particle count the less similar these jobs are likely to be to their "dirty" room counterparts. Calibration is another task often performed in the clean room, as is packaging in at least several medical apparatus plants. The main determination as to which jobs are clean room, is made by the product itself. As an illustration, gyroscopes, used as a part of guidance systems, are sealed following assembly and initial testing. After sealing, the gyros may be removed from the clean rooms for calibration, test and other reasons including system assembly. Fuel injectors for diesel engines are capped to prevent dirt from entering the critical jet openings. This is not a permanent seal and caution must be exercised when handling completed units. Implantable medical apparatus, at the other extreme, must be sterilized and packaged prior to leaving the clean room. This is, of course, to prevent bacteriological contamination. In addition to Assemblers,

Testers, and Packagers, there are Injection Molding Machine Operators and Epoxy Finishers in this clean room field. All of the foregoing jobs would be closely related to those jobs not in clean rooms, except for the worker participation in combating contamination - particle or bacteria. Again, the higher the count, the closer the relationship and the more important such previous experience becomes. In some cases, such as calibration and test, previous training and experience is required, not just desired.

VIII

SELECTED OCCUPATIONAL ACTIVITIES

The job descriptions presented in this chapter are intended to represent typical jobs within selected industry clean rooms. For purposes of illustration, entry level jobs are depicted. As noted previously, more advanced positions require training, and in some cases, previous related experience. For proprietary reasons, certain detail is omitted from the descriptions, but such deletions do not materially affect the complexity or the working conditions of such jobs.

A. Aerospace Industry

Clean room occupations in this industry are perhaps the most unique because of the variety of activities found. Within this field is also found a wide range of clean room levels. The particle counts, through at least seven levels, range from 20 per cubic foot up to 130,000 per cubic foot. Exotic metals, which contain desirable properties and im-

portant advantages, must be machined in clean rooms because they are toxic. Unless used within the controlled environment, such metals could be injurious to the health of such workers. In addition to various Machinist and Machine Operator titles, other jobs include: Quality Controller, Inspector, Tester, Calibrator, and Assembler. Each of these jobs has its own labor grade structuring and the following description would apply to the entry, or lowest, Assembler grade as found in the gyroscope assembly super clean room.

1. AEROSPACE ASSEMBLER

Nature of work - Fits together, alines, and balances parts such as gimbals, spin-motors, sensors, and heaters to form gyroscopes for use in inertial guidance systems. Uses handtools, jeweler and dentist tools, static and dynamic balancing equipment, and accomplishes all work in accordance with super clean room assembly procedures.

A typical task from the above paragraph would be as follows:

Winds and balances spin motor: Places motor shaft in winding machine jig and depresses start button to activate winding mechanism. Transfers wound armature to balancing machine jig and starts machine to rotate motor. Observes indicator dials, right and left, to determine points and amounts of unbalance. Stops motor at indicated locations and depresses air-drill lever until indicated amount of metal has been removed from armature. Repeats balancing procedure until specified readings are obtained, right and left. Places motor on test rack and

attaches lead wires to begin test period. Removes motor following specified time period and repeats balancing procedure.

The above task represents what this worker would do for 20% of his workday. The remainder is used in joining parts together to form the gyroscope. Heaters, sensors, and jewel-bearings are assembled using tools such as jeweler's screwdrivers, dental probes, microscopes, handtools, and soldering irons. A large percentage of the time is spent in cleaning the tools and parts. Various cleaning methods are used such as blowing with a compressed air hose, scrubbing or rinsing with liquid freon, or immersing parts in cleaning machines. Lint-free wiping tissues are used following most actions, with the tissue being immediately disposed of.

Working Conditions - Super clean rooms are temperature and humidity controlled, providing a constant climate. The rooms are well illuminated and music is played at intervals to break the boredom often accompanying the quiet of such rooms. Rest room facilities are provided within the clean room complex and every effort is made to encourage workers to remain in the clean room environment throughout the entire work period. Personal items, such as cigarettes and snacks, are not permitted in the work areas, nor are most cosmetics allowed. Clean room dress, including shoe and head cover, is mandatory in addition to the pre-entry procedure explained earlier.

Physical Demands - Most clean room assembly positions require very minimal physical exertion. Parts and tools are small and weigh relatively little. Although assembly line techniques are used where feasible, there is no appreciable accumulation of units to cause even occasional heavy lifting.

Microscopes, all with dual eyepieces, are in common use, but are not so powerful as to cause eye strain. Perhaps the most important physical demand factor, for some, is that excess movements must be minimized in order to avoid increasing the particle count. Most jobs involve sitting in comfortable chairs while working at table heights.

Training and Qualifications - As previously explained, the interview is usually the final qualifying factor for clean room placement. Consideration is given to interest, aptitude, and temperament factors along with a personal judgment made by the interviewer of an applicant's suitability for such employment. In some plants, minimum training is required prior to actual assignment to the clean room. For example, a three day soldering training course is given new employees which must be passed. Also, a short training course covering epoxy is required. Because clean rooms are certified by agencies such as N.A.S.A., certain types of work must be performed to N.A.S.A. specifications. Just as some persons must be registered to become electricians, certain workers must be certified to solder or work with epoxies.

These are training courses and must not be considered as tests of previous experience, since none is required. The courses must be passed, however. Average training time for Assembler positions, following appointment, is nine months.

Advancement - As experience is gained in the entry level position, advancement is gained through the higher Assembler grades. Further training, or education, will enable an individual to enter other work areas,

such as calibration or test. Additional education and training can lead to jobs such as Technician.

2. MEDICAL APPARATUS

There are numerous clean room jobs within medical apparatus manufacturing plants, but for illustrative purposes, this chapter will discuss the Assembler of implantable devices - namely the electronic pacemaker. The clean room in this instance is also a certificated super clean room.

Nature of work - a new employee will usually start as Fabricator and be given the necessary in-plant training, an average of four months, to become fully qualified. The pacemaker has no moving parts or critical tolerance/clearance specifications. It is composed of electronic parts such as resistors, capacitors, diodes, transformers, and batteries. The Fabricator works with the unit at varying stages of assembly. For example, prior to assembly certain parts are coated with silicone. The parts are then assembled into a loose unit and the Fabricator then bonds all parts together to form a rigid component. The technique is known as "potting" and is applied to the battery unit and the control group. When the various potted groups are inspected, both visually and by test, they are assembled together to become a pulse generator. Following a series of inspections, potting as a complete unit, and functional testing, the units enter the clean room preparation area. This is the final area prior to super clean room entry and here the units undergo cleaning and surgical scrubbing. Within the super clean room, the final assembly and fabrication tasks are performed. Electrodes are molded and mated to the pace-

makers and additional coating is applied. It is within this super clean room that the gas sterilization and spore tests occur, which follow packaging. Additional tests, including an x-ray check, are made prior to shipment.

The Fabricator is thus involved in several areas of manufacturing pacemakers. He must therefore be thoroughly familiar with several clean room procedures, since some tasks are not within the super classification. The Fabricator works with machines and devices such as: encapsulation machines, epoxy dispensers, vacuum systems, molds, silicone dip tanks, and at the same time must practice the cleaning techniques of clean rooms. In general terms, the Fabricator is mainly responsible for the sealing and molding of pacemakers at various stages of assembly.

Working Conditions - In general, the comments relative to aerospace super clean rooms apply equally to this industry. As noted, product sterilization also occurs but this has no influence on the room itself. In addition to the air filtration system which determines the particle count for the room, the fabrication process requires additional ventilation at certain work stations. As described earlier, the pacemaker is coated and sealed with silicone and epoxy. There are curing agents in these substances that produce fumes which, in large quantity, are decidedly unpleasant if not somewhat injurious. Separate exhaust systems are used at these immediate processing points to draw off these strong fumes and remove them entirely from the plant.

Physical Demands - In contrast to the aerospace clean room, considerable

movement is necessary in this case. However, there is still no appreciable physical exertion required beyond walking between several work stations. Rarely would anything weigh in excess of 10 pounds and the pacemaker unit only weighs several ounces. Molds for the encapsulation machine perhaps would be the heaviest weight at about five pounds each.

IX

EMPLOYMENT OUTLOOK

The employment outlook for clean room occupations is based on several conditions. First, it is safe to state that an increase in such jobs will continue for probably the next five years at a fairly high rate. It should be noted, however, that this increase will not be made up entirely of new jobs. As the level of product reliability demands increases, so must the environmental conditions be improved and, in many cases, cleaner rooms will be required.

Continued technological advance in product miniaturization will result in increased clean room facilities also. As products and components shrink in size, the smallest foreign particle becomes significantly more important. A microscopic speck of wood, for example, from an ordinary pencil is large enough to render a space vehicle guidance system useless. It will continue to be necessary, therefore, to build such components within the cleanest clean rooms possible. Just as small size and light weight are critical to the spaceship, there are examples where the opposite is true. In these cases the small microscopic particles are incapable of causing such severe, or total, malfunction of a system.

Clean rooms become obsolete through improvement. The rooms of ten years ago are no longer acceptable for meeting today's high performance demands. New or less critical products may take up the space formerly occupied by pioneering first efforts. As experience is gained, improvements are made based on necessity and desire. For the most part, clean rooms represent necessity - not just desire.

The outlook for clean room employment is therefore dependent upon these several factors: new products which will require clean rooms, established products which warrant improved clean room standards, and offspring products requiring the same or different clean room standards than the parent device. New products requiring some degree of clean room facility will not be limited to a single or even several industries. Food processing, laboratory equipment, automotive components, machining plants, and the entire family of aerospace divisions are all areas in which clean rooms will flourish.

Traditionally, the clean room appearance, with its uniquely garbed workers, has presented a world of work not often seen by other than scientists, engineers, and technicians. Only a few years past, such highly trained personnel did constitute the majority of workers in the clean room employee population. Components which were then "one-of-a-kind" are now being mass-produced due to the ability of today's machining techniques to produce near-perfect parts.

It is true that of all the problems in the manufacture of critical

goods the chief concern is the never-ending battle to eliminate contamination. It is to this purpose that the clean room employee must first be dedicated. Education to clean room policies and working procedures is essential.