HUMAN FACTORS ENGINEERING DESIGN OF AMMUNITION PRODUCTION LINE ROCKEYE MK20

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Naval Ammunition Depot
Crane, Indiana

31 March 1973

RDTR No. 239
31 March 1973

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Statement A: Approval for public release; distribution unlimited.

PREPARED BY

RESEARCH AND DEVELOPMENT DEPARTMENT

NAVAL AMMUNITION DEPOT, CRANE, INDIANA

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Naval Ammunition Depot Crane, Indiana	UNCLASSIFIED
	2b. GROUP

3. REPORT TITLE

HUMAN FACTORS ENGINEERING DESIGN OF AMMUNITION PRODUCTION LINE ROCKEYE MK 20

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

JANKOVICH, JOHN P.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
31 MARCH 1973	118	10

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	RDTR No. 239
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Details of illustrations in this document may be better studied on microfiche.	

13. ABSTRACT

The man-machine interfaces are redesigned on an ammunition production assembly line to provide the best possible human factors configuration of each work station. Machinery was to be redesigned to achieve integration of the human and machines with emphasis on the abilities, capacities, and limitations of the human body. Areas of human factors engineering considered: personnel work space (equipment arrangement, seating, layout of panels, etc.), materials handling (lifting, carrying, reaching, tools, etc.), physical environment of personnel (illumination, ventilation, noise, vibration), design of controls (information input and output devices, location, size, spacing of switches, push buttons, cranks, levers, handwheels, etc.), and industrial safety. Recommendations are based on evaluation of the human factors aspects of each work station, studied by the method of a comprehensive checklist, production observation, and operator interviews.

DD FORM 1 NOV 68 1473 (PAGE 1)

S/N 0101-807-6801

UNCLASSIFIED
Security Classification

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

DD FORM 1 NOV 68 1473 (BACK)
(PAGE 8)

1-8

Security Classification

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INTRODUCTION

Human factors engineering is the field of science aimed at creating the optimal relationship between man and his working environment. The term environment in this sense involves not only the ambient atmosphere, but tools and materials, methods and organization of work, which are all related to the man himself, to his abilities, capacities and limitations.

The objective of this study was to redesign, according to the principles of human factors engineering, the man-machine interfaces at the work stations of an ammunition production line, assembling Rockeye Mk 20 bombs. The report intends to provide recommendations to supervisors in charge of the operation. The data are given in a condensed form of listed suggestions, applicable for immediate implementation. Consequently, the theoretical aspects of the involved problem areas are covered less extensively.

Good human factors design in an industrial process affects two important aspects of production. First, stresses to which the human body is unwittingly subjected over a long period may cause loss of efficiency or create unnecessary safety hazards in the short term and disability later in life. Secondly, failure to match requirements of a task with the capabilities of the operator may cause reduced output and, in the extreme case, disaster.

A large body of information is available on human factors engineering design of work places. To put these data to work, translation is needed into the facts of industrial life. Therefore, this report presents primarily

recommendations only in a readily implementable form. The study intends to provide suggestions for immediate use on the existing assembly line without introducing drastic changes in technology of the established manufacturing process. However, reasons for the recommendations are given in condensed form to explain the underlying theoretical background. Thus the first part of each recommendation describes the changes necessary for fitting the task requirements to human capabilities. The second part of most of the suggestions presents some insight into the scientific bases which underlie them. Additional data are available in a number of handbooks which contain human factors information in a form suitable for applied implementation (References 1, 3, 9, 10). Relevant military standards are also available on human factors design of equipment (References 2, 4, 5). In the development of the human factors checklist of work stations, pertinent military test procedures were utilized (References 6, 7, 8).

The recommendations were derived from the combined findings of (1) production observation by human factors engineers, (2) evaluation of a human factors checklist and (3) interviews with production line personnel and supervisors. In this multiple method of data collection, each technique concentrated on the following aspects of man-machine interface design: personnel work space (work space arrangement, seating, layout of controls, control panels, etc.), materials handling (lifting, carrying, reaching tools, etc.), physical environment of personnel (illumination, ventilation, noise, vibration), design of controls (information input and output devices, location, size, spacing of swtiches, push buttons, cranks, levers, handwheels, etc.) and industrial safety. The Appendix of this report

contains the checklist which was used to evaluate every work station of the assembly line.

This study was supported by the Resources and Planning Department, Naval Ammunition Depot, Crane, Indiana. In compilation of the data, the assistance given by Mr. S. Armstrong, Program Manager of Rockeye Production, and Mr. R. Moody, General Foreman, Ordnance Department, is gratefully acknowledged and appreciated.

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HUMAN FACTORS ANALYSIS OF WORK STATIONS

Recommendations to improve human factors design of individual work stations are listed in this chapter. The suggestions are obtained by critically reviewing the checklist (enclosed in the Appendix) for each operation and scrutinizing findings of work station observations and interviews with workers and management. Recommendations are listed in increasing order of importance. Overlapping areas are discussed under one heading.

Work Station: A-5

Turn Bomblets and Tray Assembly

a. Provide more positive stop on turning motion of turn table. Many operators have difficulty in stopping turn table lined up with conveyor. As a result, with trial and error they move table back and forth until right position is found.

b. Provide recessed hand grips on turn table. Presently, only a few holes are cut along wheel circumference for the fingers to grip the turntables firmly, Figure 1. Grip holes should be placed all around the circumference of the end plates on each side or a contoured rim should be used.

Ideal design of handwheels is shown in Figure 2. Contour molding is strongly recommended on the handwheel rim to aid in holding it. A wheel diameter between 12 and 21 inches is suggested, rim diameter can vary between 0.75 and 2 inches, resistance between 5 and 30 lbs.

Figure 1. Work Station A-5: Turning Bomblets and tray assembly. Handwheel does not have good gripping surfaces. The other operator must bend excessively because bolt bin is 6" too low.

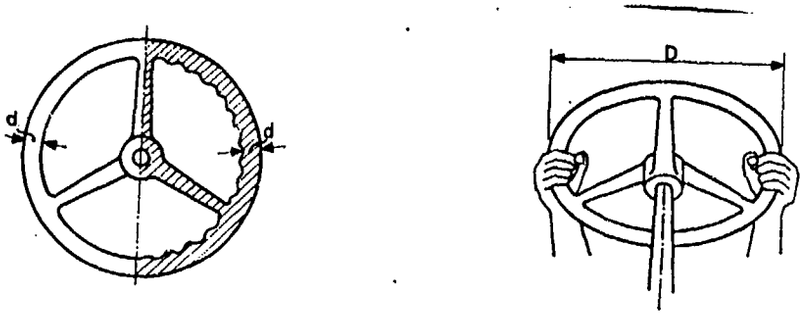


Figure 2. Design of Handwheels

d: 0.75-2 Inches

D: 12-21 Inches

Force: 5-30 Pounds

c. Provide a quick release stop in front of turn table in order to prevent tray assemblies from sliding onto the turn table when they pile up on conveyor. The operator frequently must push several tray assemblies back on conveyor to be able to rotate turn table.

d. To ease operation, sliding surface on turn table should be replaced with rollers, resembling a roller conveyor. The upper photograph in Figure 1 shows the operator spraying the sliding surface with lubricant to reduce friction. Force requirement will be greatly reduced with the application of rollers and time will be reduced to complete the task.

Work Station: A-6

Secure Bomblets and Tray Assembly

a. The lower photograph in Figure 1 shows that operator has to both bend and twist to the left in order to reach clamp bolts. Bolt container should be raised 6 inches higher above its present level to eliminate unnecessary bending motion.

Work Station: A-7

Grease Pouring Heads

a. To protect eyes from light of preheater, place a protective shield over conveyor in front of preheater entrance. Size of the opening on shield should be just large enough for tray assemblies to pass.

b. Mark hot surfaces on preheater with warning labels to prevent accidents.

NOTE: Figure 3 shows how the above recommendations had been implemented by the time this report was finished. Rubber flaps around entrance shield shade heater light completely and warning signs show hot surfaces.

Work Station: A-9

Bomblet and Tray Assembly Removed from Preheater

a. Raise legs of receiving bin for pouring covers 8" higher in order to avoid unnecessary bending when operator brushes them clean.

NOTE: Figure 4 shows how the above recommendation had been implemented by the time this report was finished. The operator's bending motion is greatly reduced.

Work Station: A-10

Pouring

a. The operator constantly adjusts six push-pull valves to regulate proper flow of explosive. Five valves increase flow when pushed, the sixth valve operates conversely, which is unacceptable. Furthermore, the steel valve shafts tend to bind to the aluminum bushings as used presently, which makes continuous regulation of flow extremely difficult, and results in stepwise jerks of adjustment. The operator has to remove the protective gloves 4-5 times a minute in order to adjust the flow.

Recommendation for immediate action:

(1) All valves must operate in the same direction.

(2) Decrease friction by using bronze bushings.

Recommendations for long-range planning: convert the linear regulating action to circular motion using a gear assembly. In such a configuration

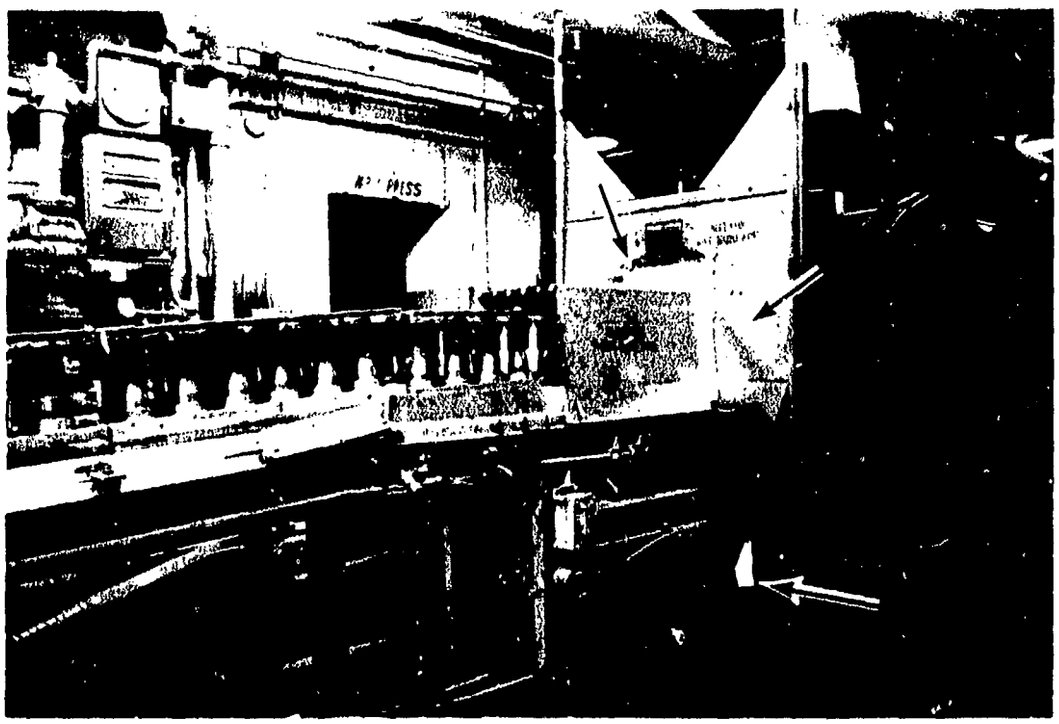


Figure 3. Protective shield has been mounted around preheater entrance to eliminate glare. Hot surfaces have been marked. The lowest arrow indicates improper method of identifying control valves with a loose paper label.

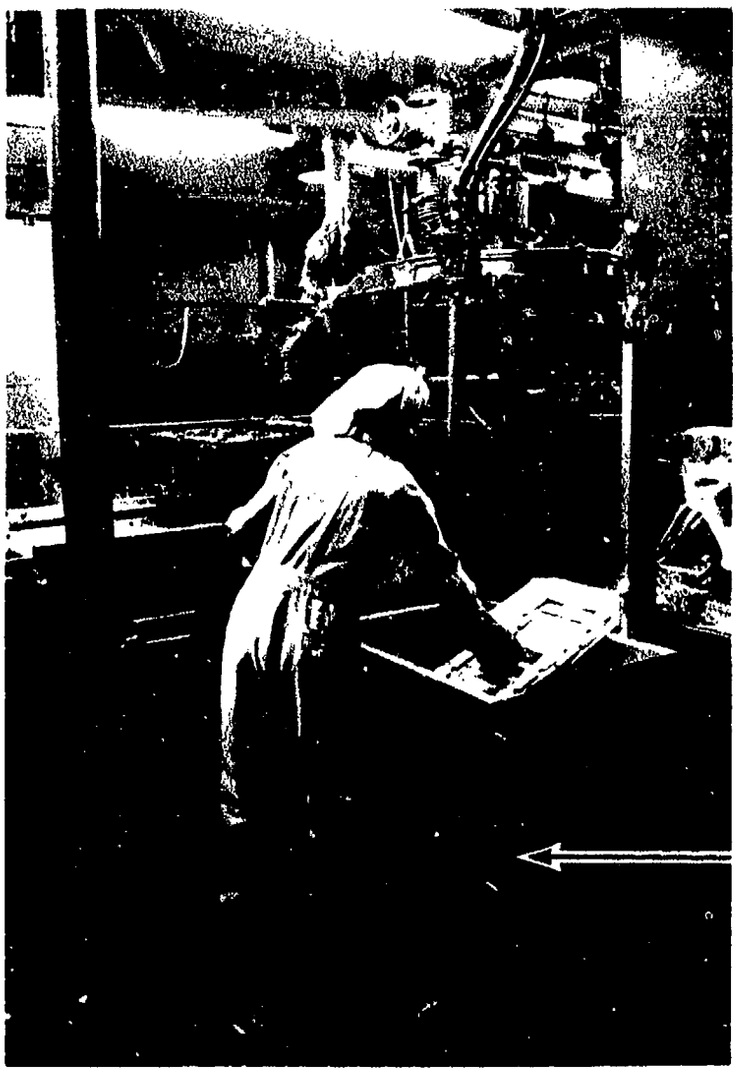


Figure 4. Work Station A-9: Bomblet and tray assembly removed from preheater. Height of receiving bin has been raised and bending of the operator's back reduced.

the flow should increase by turning regulating wheels in clockwise direction, with the wheels facing the operator. A less preferable but still good solution could be achieved by placing the regulating wheels in the center plane of the operator and increasing the flow when the top of the wheel is moved away from the worker.

b. Auxiliary light sources are needed to provide proper illumination under the kettle and in cabinet where proper height of explosive level is adjusted (and pouring cover is removed). The lights should be mounted on the side wall to provide adequate illumination under the equipment. Presently, operators complain that they cannot see well.

c. Height of work platform should be lowered 8-10", because presently the operator has to bend to be able to see the pouring level, located only 18" above the walking surface, see Figure 5. Work place arrangement with the recommended lower level walking surface is shown in Figure 6. Height of receiving bin at Work Station A-9 should be equal to height of this work surface, as illustrated.

d. Provide a good seat for the operator. A swivel seat is needed which should have cushioning, backrest, and height adjustment between 12-24". Presently, a 10" backless steel stool is used on which the workers themselves taped some foam rubber for comfort. Requirements for good work chair design are described later, for work station: Tray Repair. Figure 41 shows recommended chair dimensions and necessary adjustments to accommodate anthropometric differences. Roller casters should not be used on elevated work surfaces.

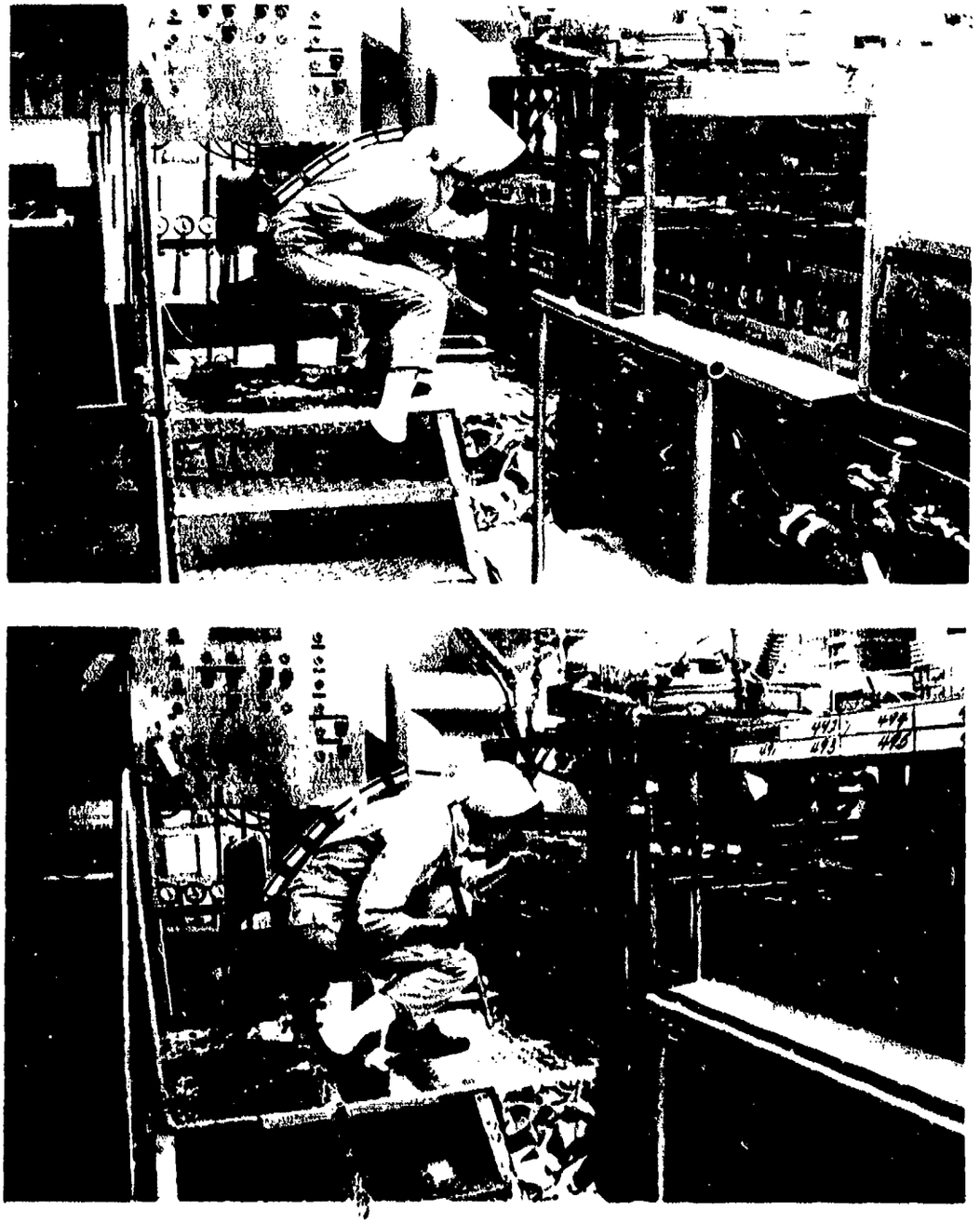
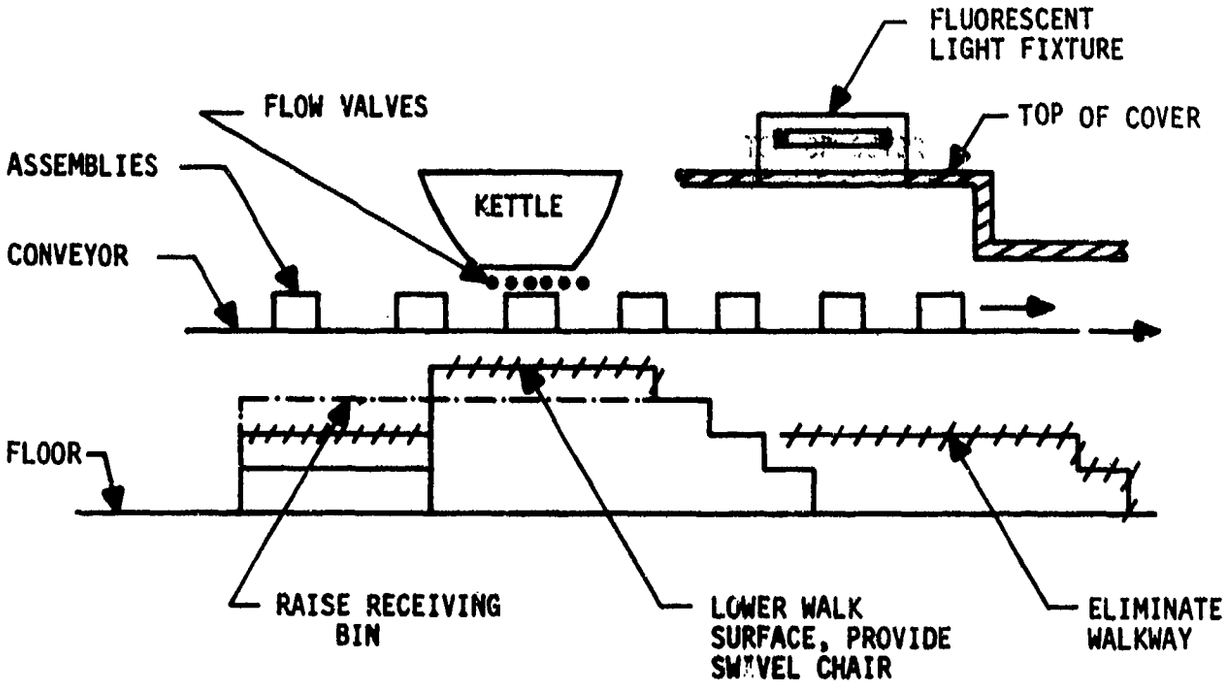


Figure 5. Work Station A-5: Pouring of Explosive. Work platform is elevated too high, the operator has to bend excessively in order to be able to observe the work process. Platform surface should be lowered 8-10".



SIDE VIEW

Figure 6. Recommended new work place arrangement for pouring of explosives with raised receiving bin, lowered walk surface, eliminated walkway, built-in fluorescent light for Work Stations 9, 10, and 11.

NOTE: Good seats had been acquired by completion time of this report, as shown in Figure 5.

e. Control Panel. Separate the controls belonging to kettles A and B by color coding on the control panel, and on the regulating handwheels. Presently, a single letter mark, as indicated in Figure 7, differentiates one control function from the other. It is suggested that color be used to code functions: one side of the panel and all corresponding valves, handwheels, etc., could be painted one color, while the other half and its valves and handwheels be identified with another color.

Use higher intensity bulbs in control panel indicators, because they are hardly visible. Use engraved plates to identify controls on panel instead of tapes. Label both emergency stop and conveyor speed regulator (their location and design is satisfactory). Speed regulator arm and housing should be painted with the warning yellow color. Label vibrator pressure gauges, cover plastic air pipes to protect them from damage (operators step on them sometimes when climbing on top of vibrator). Mark normal operating range on pressure gauges. Some electric cords are loose on back of control panel, they should be concealed. Eliminate the two unconnected signal lights mounted on the panel.

f. Label hot surfaces on vibrator. Label emergency stop switch.

g. One pipe on ceiling is sweating in cold weather, dripping condensed water on workers and walkway. Proper insulation is needed.

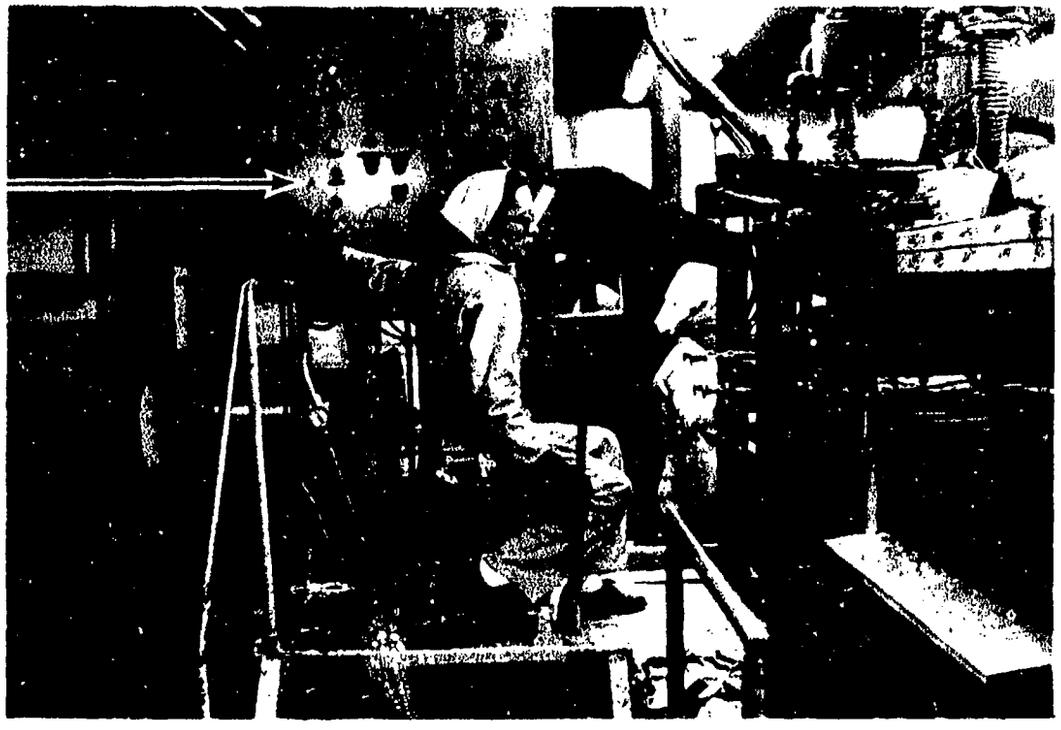


Figure 7. Work Station A-10: Pouring of Explosive. Inadequate identification of control functions A and B should be improved by color coding them on the control panel and by similarly color marking their corresponding controls.

Work Station: A-11

Cooling

a. Eliminate elevated walkway used for correcting explosive levels. Presently a two-step high platform is used providing a work surface 36" above the walking surface. This is low; the operator has to bend in order to be able to reach under the protective cover of the machine, Figure 8. Elimination of the walkway and lowering the platform of A-10 will provide a similar workplace arrangement to the present configuration but with the assurance of proper height of the work areas. Outline of this new lowered work space arrangement is shown in Figure 6, where both Work Station A-10 and A-11 are illustrated as related to each other.

b. To provide adequate illumination over tray conveyor under heat protective cover, fluorescent lights should be mounted on top of machine. An opening of the size of the light fixture could be cut in the cover plate and the fixture mounted directly on the cover plate. Figures 6 and 8 illustrate where light fixture is suggested to be installed. Tight seals between the edges of the cover plate opening and the light fixture will prevent heat escape and installation of the luminaire will not influence the present heat balance.

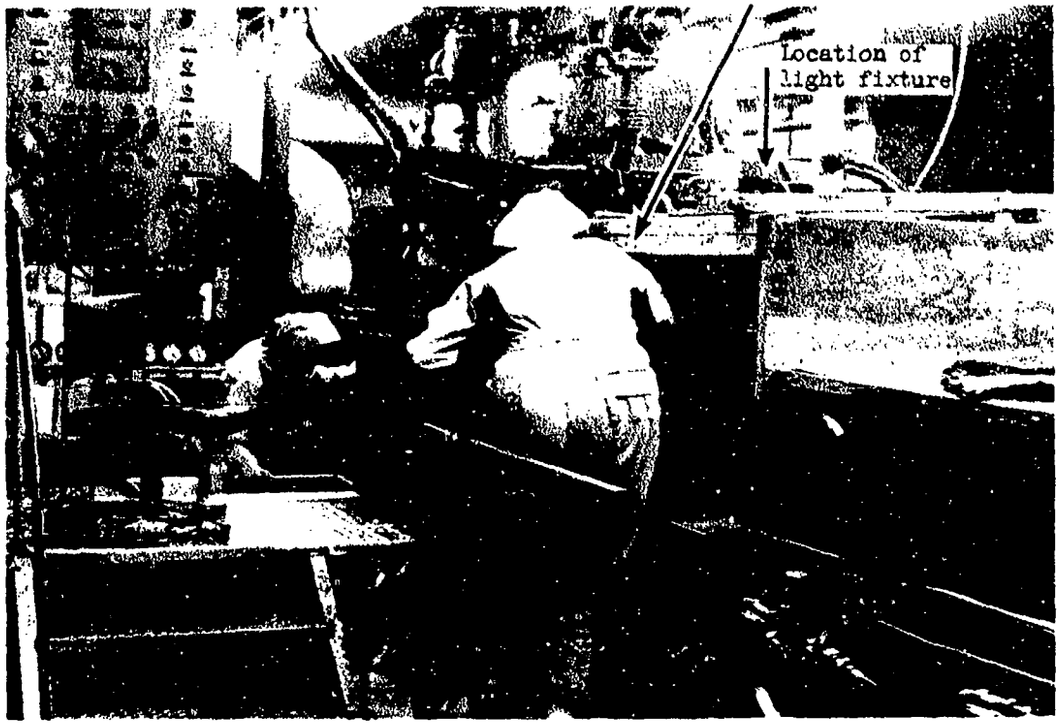


Figure 8. Work Station A-II: Cooling of explosive. Undesirably high walkway forces operator to bend excessively when attending machine. Walkway should be lowered. A fluorescent fixture should be mounted directly on cover plate to provide adequate illumination under machine top.

Work Station: A-12

Remove Bolts From Tray Assembly

a. Assembly trays should be stopped at end of conveyor II, not 4" behind as done presently, The operator has to push each tray back to position them on conveyor II. See Figure 9.

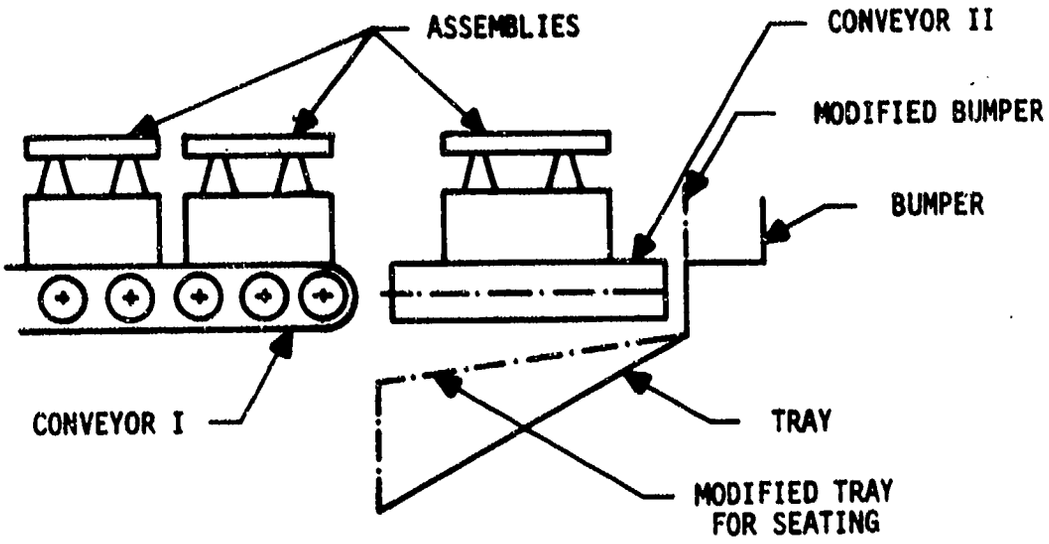
b. This work station could be easily converted into seated operation. The necessary knee space could be provided by changing only the tray under conveyor II. See Figure 9.

c. Operator complains about vibration pain in right hand and wrist due to use of impact wrench. Figure 11 illustrates work position of the operator. The right hand is unevenly overloaded with respect to the left hand. Recommendation: modify wrench suspension to make left hand operation possible so that the worker could alternately use either right or left hand. Use a wrench with larger mass, to take advantage of the larger inertia of a heavier tool to reduce vibration intensity.

d. Work level is high. Even though an elevated platform is provided for the operator, its height is still not sufficient. Figure 11 shows how operator is forced to work with raised arms and shoulders well above optimal (and normal) position. Height of work surface should be 36 to 40" above standing surface. Use of higher work platform is recommended.

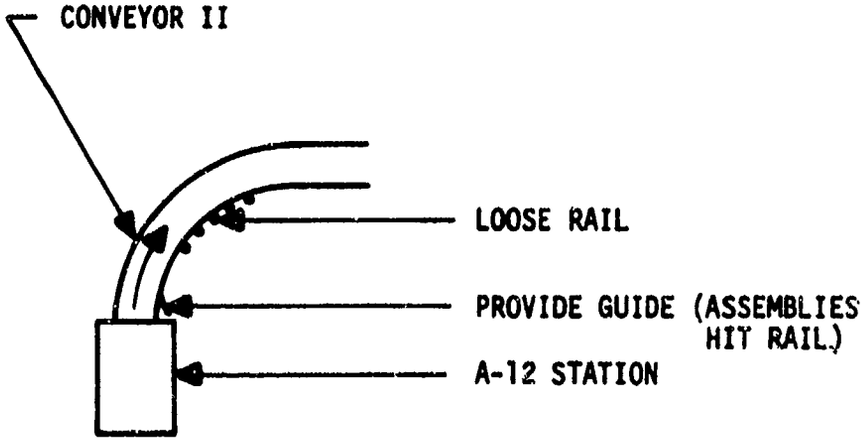
e. Provide solid side rail and guide plate on conveyor II, as indicated in Figure 10 (the present rail is broken, and trays often get stuck during rolling).

f. Use a power-driven conveyor instead of the present roller conveyor II. Major effort is needed by A-12 to push trays over to next work station.



SIDE VIEW

Figure 9. Work Station for Removing Bolts from Tray Assembly, A-12



TOP VIEW

Figure 10. Location Where Guides are Needed on Tray Assembly Conveyor, Work Station A-12

Figure II. Work Station A-12: Removing Bolts from Tray Assembly. Right hand of operator is overloaded. Air wrench should be modified for possible left hand operation. Work level is excessively high: elbows and arms are kept raised. Operator should be standing at a higher level.

Work Station: A-13

Pouring-Tray Removal

a. Conveyor between work stations A-13 and A-16 (the next stop) should be power-driven. The operator presently spends 25-30% of his time pushing and forwarding tray assemblies on the conveyor and lubricates rollers frequently to reduce the necessary physical effort. Both photographs in Figure 12 show the operators transporting tray assemblies to next work station on roller conveyor.

b. Passageway between work stations A-13 and conveyor leading to A-14 is 11 inches wide, providing inadequate clearance. Figure 12 shows the difficulty which operators experience when they try to squeeze into the passageway in order to be able to forward tray assemblies to next work station. Five more inches could be added to this space by removing protruding ends and the first unused roller from conveyor.

c. Operator lifts and removes pouring trays from press at a height of 54 1/2". This is too high for most operators, Figure 12. An elevated platform is recommended in front of the machine height 10-14". An 8" high platform is available and used, but is still not sufficient anthropometrically. The working surface must optimally be 36" above standing level. Note, however, that location of activating switches will be too low when such an elevated platform is used. Therefore, switches must also be raised proportionally to a higher level.

d. Label air valves and use shape coding on valve handles for ease of identification. Shape coding improves visual and tactile identification

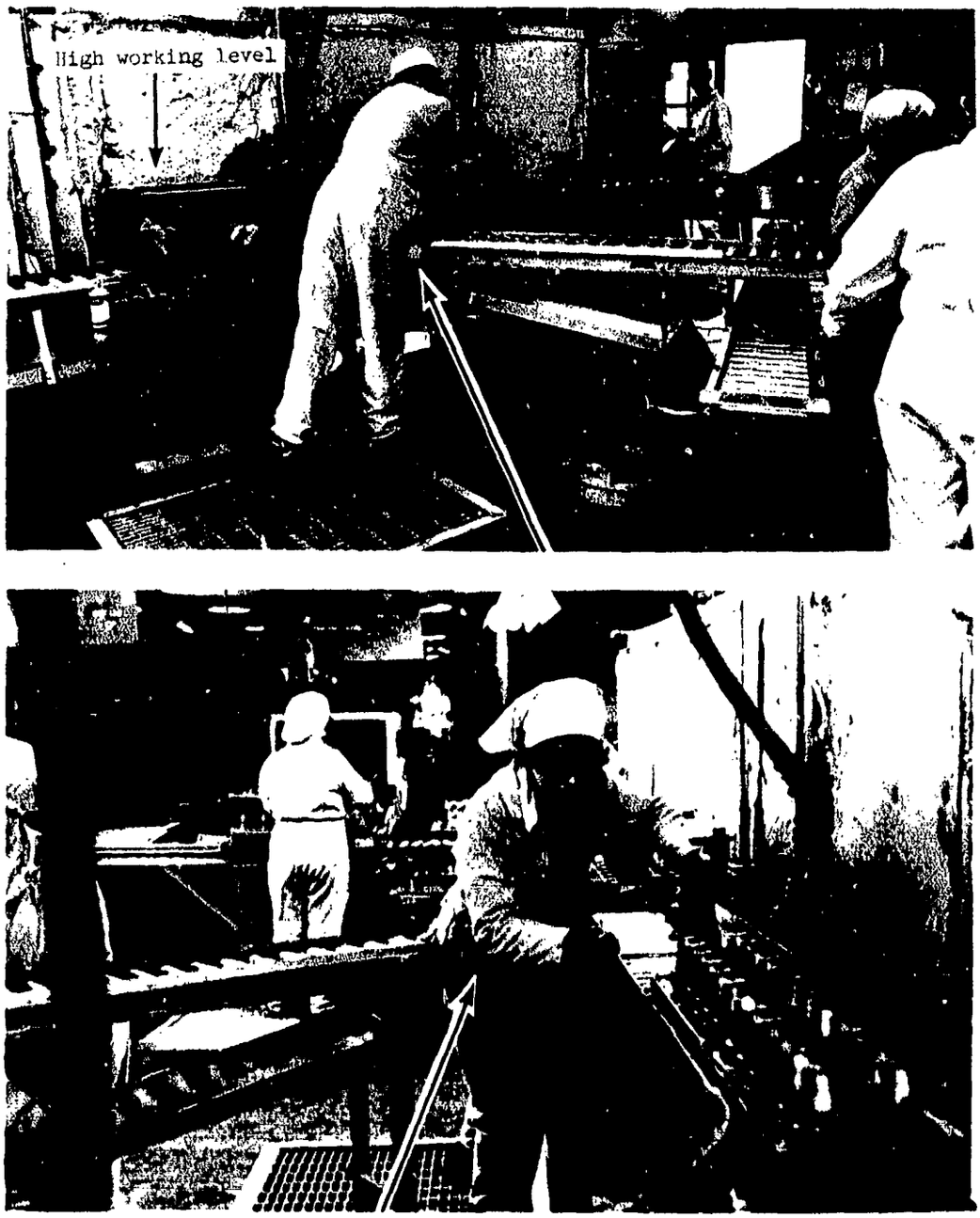


Figure 12: Work Station A-13: Pouring-Tray Removal. Operators have to squeeze through 11" wide passageway in order to be able to forward trays to next station. High working level can be improved with higher standing platform.

of controls. When feasible, it is desirable to select functional shapes that suggest the purpose of the control. Design of the shapes must be highly discriminable.

Shape coding is recommended for this work station, because operator activates machine without really looking at control levers. Presently, the only feedback information which he uses to identify the right control is the spatial location. If knobs of different shapes are used, the operator is provided with an additional channel of information for correct identification of functions. Figure 13 shows recommended knob shapes. The vertical block is intended to indicate vertical lifting action, while the spherical shape should differentiate all-directional grasping from lifting.

e. Renew worn-off paint on moving surfaces: both on grabbing heads and on lifting heads.

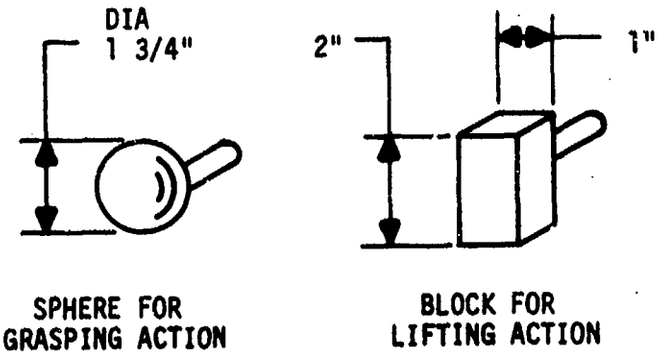


Figure 13. Recommended shape-coding of press activating levers. Shape-coding improves visual and tactile identification of functions for Work Station A-13.

Work Station: A-16

Remove Bomblet from Tray

a. Use a power-driven conveyor to bring trays in front of worker. Height of conveyor should be designed so that top of bomblets is 36-40" above floor level. A height of 36" is the ideal working height for standing operation. The fact that the top of the bomblets is vacuum cleaned on a very tight time schedule at this work station calls for design of optimal work space arrangement.

b. The other conveyor, which carries trays into washer, should be at the same level as the incoming conveyor. Thus, the present way of lifting trays from a lower conveyor to a higher one can be eliminated to speed and ease work load. The worker would just slide trays from incoming conveyor to forward them into washer. See Figure 14. Observe also the long leverage between center of gravity of tray at end of extended arms and torso. It calls for great muscular energy expenditure and slows work process unnecessarily.

c. Mount automatic door return spring on hallway door next to this work station. During winter, outside cold air comes in, and door cannot be kept closed.

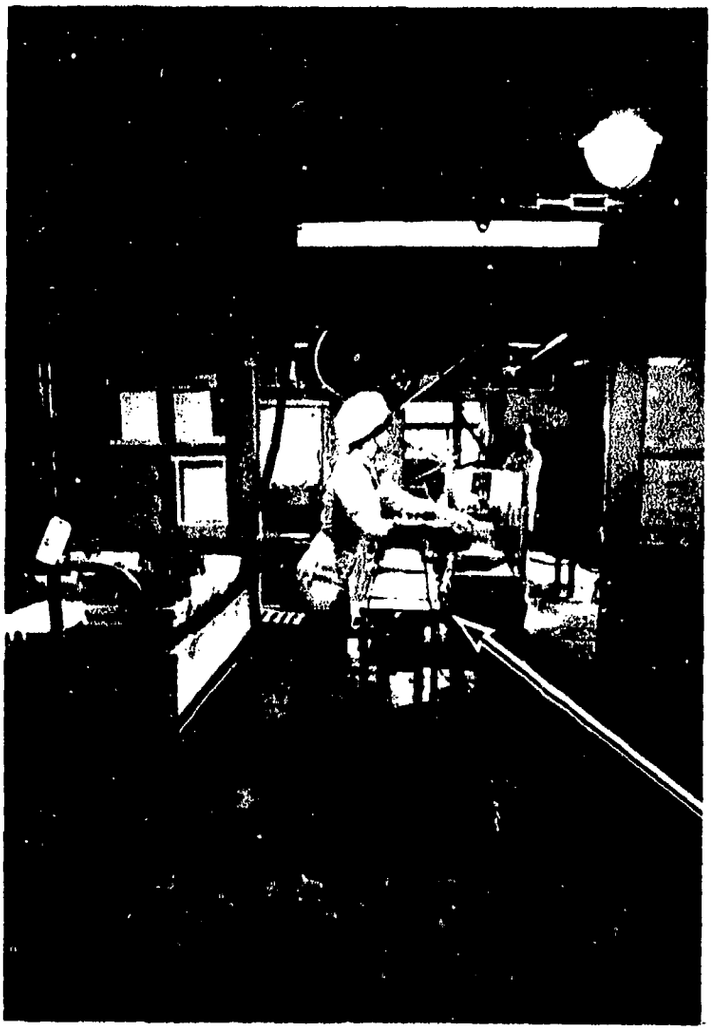


Figure 14. Work Station A-16: Removing bomblets from tray. Both conveyors should be at equal level so that operator could transfer trays from one conveyor to another by pushing them sideways. Observe undesirable large leverage between tray in the extended arms and torso. This arrangement calls for excessive muscular force exertion.

Work Station: A-17

Place Tray Assembly in Wash

a. The two emergency switches should be labelled and specified by function, such as:

(1) "Stop Steam" or "Steam Off" and

(2) "Stop Conveyor". Plane of switches and labels should face operator.

Work Station: A-18

Remove Tray Assembly from Wash

a. Cover return conveyor with protective plate under level of top surface. Label emergency switch on return conveyor.

b. Label emergency switches of washer conveyor on each side so that it is visible from all working positions.

Work Station: A-21

Bomblet Cleaning

a. Two operators transfer bomblets from cart into washer. The available workspace is cramped. One of the operators has to stand on one foot placed on the edge of the drain trough, see Figure 15. There is no proper surface provided to support other foot. Edge of the trough should be extended to provide adequate support for both feet. Such work arrangement is unacceptable from the human factors point of view. It should be corrected soon.

b. The operators do not have adequate illumination to place bomblets on steam cabinet conveyor. Figure 16 shows work area. Exposure of the photograph does not illustrate insufficient lighting conditions. Position of conveyor receptacles is not clearly visible under such conditions. Recommendation: two lights mounted on side wall or above machine to shine on front side of machine.

c. Some receptacles are inoperational, as the one indicated with arrow in Figure 16. Faulty receptacles should be replaced, because they interrupt regular periodicity and spatial arrangement of work flow. If replacement cannot be implemented, removal of faulty receptacles is recommended. Presently, they are plugged and not readily distinguishable from operational units.

d. Steam regulating handwheels on machine should be labelled, indicating function and operating direction. Presently, a loose paper slip is hanging on the hand valve, marked: "Pull for Steam and Water".

e. Place protective cover on lower half of conveyor.

Figure 15. Work Station A-21: Bomblet cleaning. Operator stands on one foot. Other foot is unsupported, an unacceptably tiresome work position.

Figure 16. Work Station A-21: Bomblet cleaning. Bomblet receptacles are not illuminated properly (exposure of photographs compensated this). Some receptacles are inoperational and plugged as the one shown with arrow, but not readily distinguishable from the others. Such arrangement interrupts periodicity and regular spatial arrangement of work flow.

f. Label emergency switch on output end of washer conveyor.

g. For long-range planning, it is recommended to transform A-21 work stations at the receiving end into seated operations. The trays carrying the bomblets could come on a conveyor, which would carry trays or individual bomblets right to the top of the feeding conveyor of the washer.

Work Station A-24

Drill Booster Assembly

a. Mount a leaning plate in front of operator to support body above conveyor. Presently, the operators support their body by leaning with their thighs against the side of the conveyor frame and stiffening their muscles, as shown in Figure 17. The supporting surface could be extended by mounting a plate on the frame of conveyor stand. The plate should be padded. Maximum height of upper edge of the leaning plate is suggested to be 33.5" above floor level. Such a height accommodates anthropometric elbow height of 95% of the female population.

b. Label hydraulic switch. A position switch with labelled on-off positions is preferable to the present push button of the air switch. The worker cannot identify on-off conditions of the machine by looking at a push button. Label emergency switch also such as "Emergency Stop".

Figure 17. Work Station A-24: Drilling Booster Assembly. Supports her body by leaning against conveyor and stiffening abdominal muscles. Provide a padded leaning plate in front of operator to support weight of torso above conveyor.

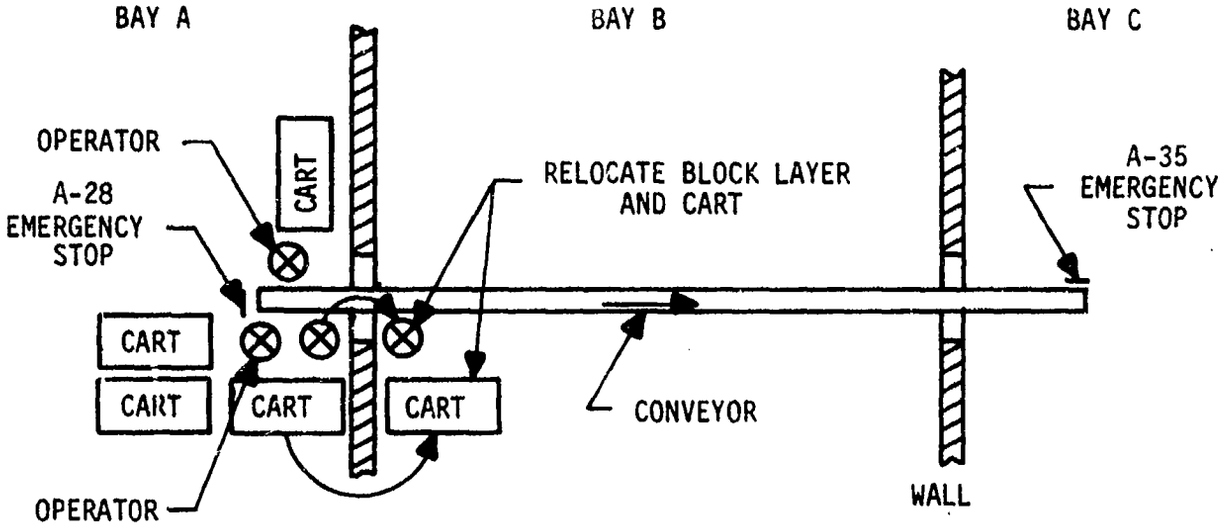
Work Station: A-28

Place Loaded Bomblet on Assembly Conveyor

a. One of the three workers performing this function puts separating wooden blocks between bomblets on conveyor. This work station is located in Bay A, Line 1, where already two other workers are positioned. The work space is crowded, free and easy emergency exit for the three workers is blocked with delivery carts. Recommendation: wooden blocks should be put on conveyor in Bay B, Line 1 that is right at the other side of the wall separating the two bays. The cart supplying the wooden blocks should be in Bay B also. No changes on conveyor or in other work stations are required. See Figure 18.

b. The three workers have one emergency switch only. It is a flip-flop type switch with the "on" position downwards. Label switch, use several switches if possible, with the "on" position up. By completion time of this report, correct labeling has been executed, as shown in Figure 19.

c. LOCATION OF EMERGENCY STOP SWITCHES ON ASSEMBLY CONVEYORS 1 & 2. This comment concerns the whole operation of the two assembly lines. Presently, there are emergency turn-off switches at stations A-28 and A-35 only on the whole assembly line, as shown in Figure 18. Frequently, however, the line has to be stopped for reasons originated at the other work stations in-between. Voice communication is being used, transmitted from one worker to the other in the extremely noisy environment of three bays where a large number of crimping machines are working. Similarly, the line is restarted with voice communication from work station A-35. There are even separating walls between the bays with openings for the conveyor only. Recommendation:



TOP VIEW OF LINE 1

Figure 18. Assignment of operators and location of emergency switches on bomblet assembly conveyor.

Figure 19. Work Station A-28: Placing bomblets on conveyor. Inadequate seating accommodations: no back rest, no height adjustment, no foot rest are provided. Adjustable, padded swivel chairs should be used, as shown in Figure 42.

each work station must be supplied with an emergency stop from A-28 through A-35, because voice communication is slow and unreliable in the high ambient noise environment. Restart should take place from one work station, A-35 only, as presently done, in order to ensure that all workers are safe for start and conveyor is not started carelessly or accidentally.

d. Seating accommodation is inadequate. Operators sit on edge of chair, or raise foot up to seating surface in trying to find a somewhat more comfortable position as illustrated in Figure 19. Good chairs are very important for good posture control. Proper support of the back prevents fatigue over extended periods of time spent in the chair during a normal shift. Chair height and back rest should be adjustable, provide swivel motion in the seat pan, and have sufficient padding in the seat shown in Figure 42. When purchasing a seat, order a more pleasing color than black.

Work Station: A-30

Seal Booster Assembly

a. Use professional sealant dispensers instead of ketchup bottles. Such dispensers do not require constant, high pressure static muscular contraction force to operate and provide even, unclogged flow. See Figure 20.

b. Seating is inadequate, Figure 20. See comments on seating for Work Station A-28, Recommendation (d).

Figure 20. Work Station A-30: Sealing Booster Assembly. Sealant dispenser requires continuous static muscular contraction, which is undesirable. Seating is inadequate: no padding, no height adjustment, no swivel action.

Work Station: A-33

Crimp Tail Fin and Base Fuze Assembly to Bomblet

a. Crimp activating switch is located in the 12 o'clock position on the face of the machine. This location complicates the operator's arm movements on Line 1 unnecessarily, Figure 21. Positioning the switch in the 9 o'clock position would simplify arm movements, eliminate twisting of the wrist, and reduce the distance needed by operator to reach for bomblet by 18 inches. Technically, changing location of switch is simple, requiring bending of one pressure line only.

b. The crimp release switch should be grouped together with the activator switch. Presently, the release switch is completely ineffective because it takes longer to move the hand from the activator to the release switch than for the duration of the whole crimping process. Therefore, the release switch should be 3-4" above the activator (which should be in the 9 o'clock position, as explained above). See Figure 22. Label release switch.

c. Label air pressure shut off valve.

Figure 21. Work Station A-33: Crimping tail fin on bomblet. Start button is positioned improperly: operator has to lift the left hand high, out of smooth sequence of other hand motions. The start button should be in the 9 o'clock position.

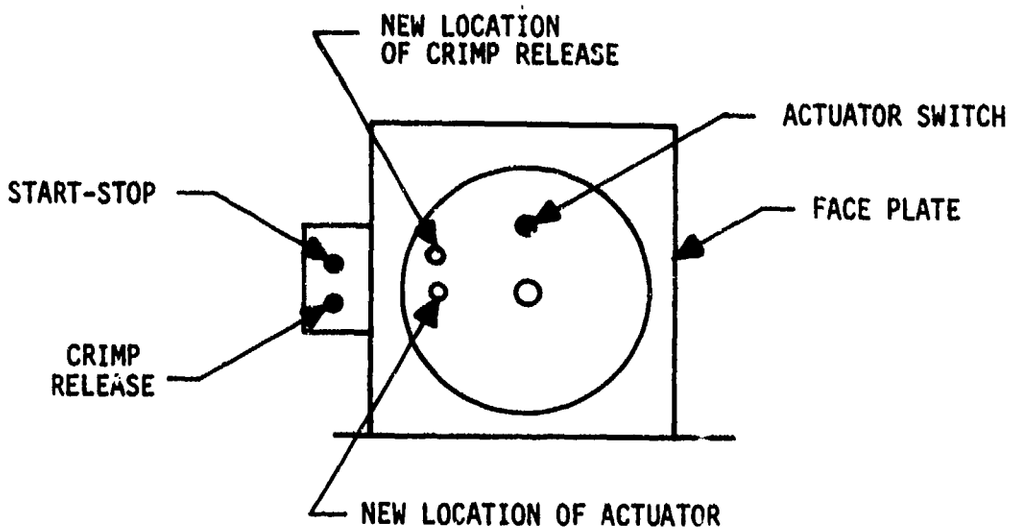


Figure 22. Recommended new location of actuator and crimp release switches on face plate of tail crimping machine, Work Station A-33

Work Station: A-34

Install and Crimp Sensing Element

a. Sensing element crimper is mounted at a 45^{o} angle to the direction of motion of the conveyor. It is extremely inconvenient to operate the machine in this position, Figure 23. The operator has to twist the lower arm to reach the bomblet, when feeding it into crimper. Most operators pull the activating lever with lower arm turned outside and with the thumb pointing down. The angle between machine front plate and direction of assembly line should be reduced to 30^{o}, exactly like the fin crimping machines. Definite simplification of hand movements can be expected. It is recommended to implement this suggestion first, and after observing operation, proceed to recommendation "b", below. It is possible that recommendation "b" might not be needed after the machines have been mounted at 30^{o}.

b. A 5-inch lever is used to operate the machine. It is in a vertically downward position. Some operators use left hand, others use right hand to activate the machine. The vertical position of the lever on Line 1, however, is awkward in either case. Therefore, it is recommended to position the lever 30^{o} off vertical to the left, as shown in Figure 24. Such a position would simplify hand movements for either left or right hand operation. Vertical position of the lever is satisfactory on Line 2.

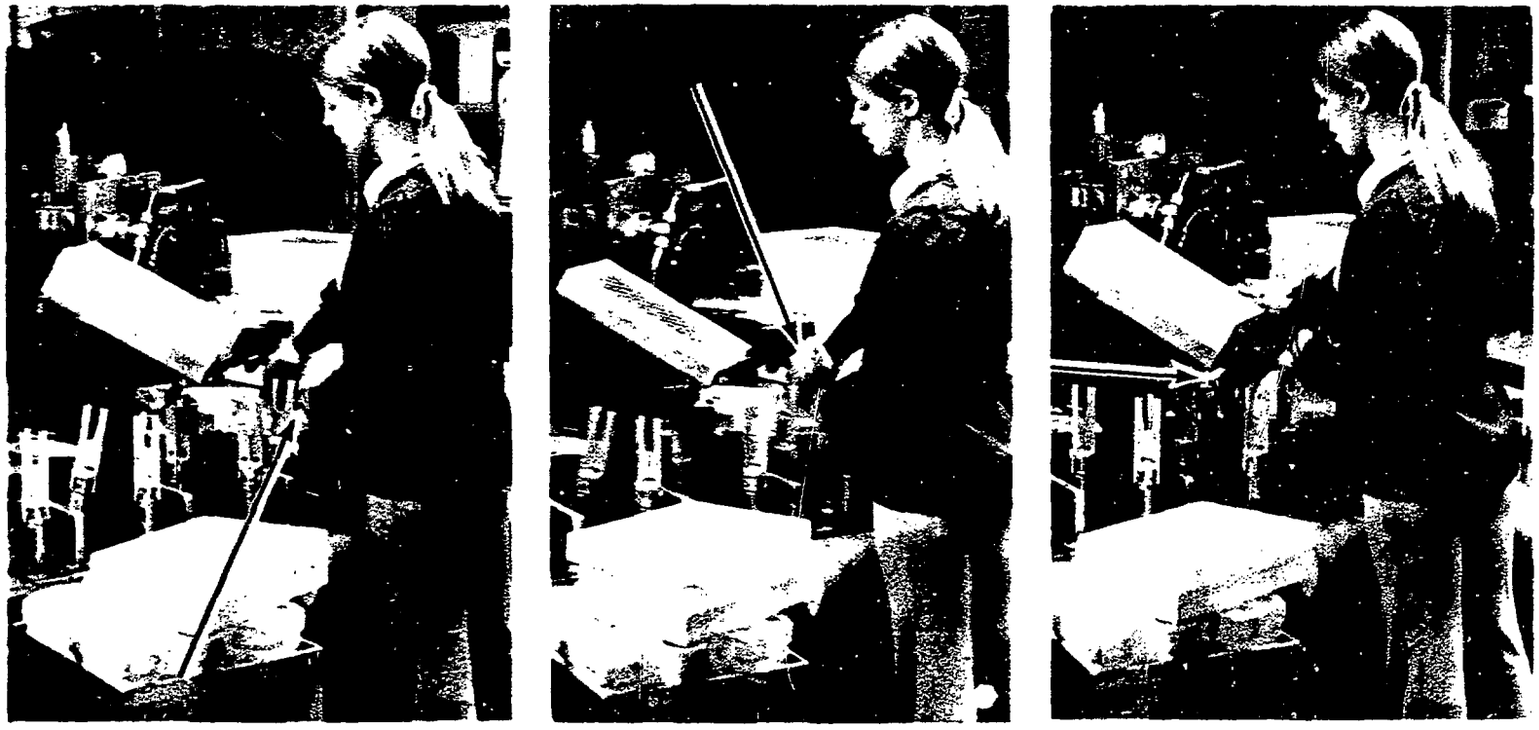


Figure 23. Work Station A-34: Crimping Sensing Element

a. Observe twisted left wrist when reaching for bomblet.

b. Right hand is twisted unnaturally outward with thumb down to activate starting lever.

c. Right hand too close to tray holder when returning bomblet to conveyor.

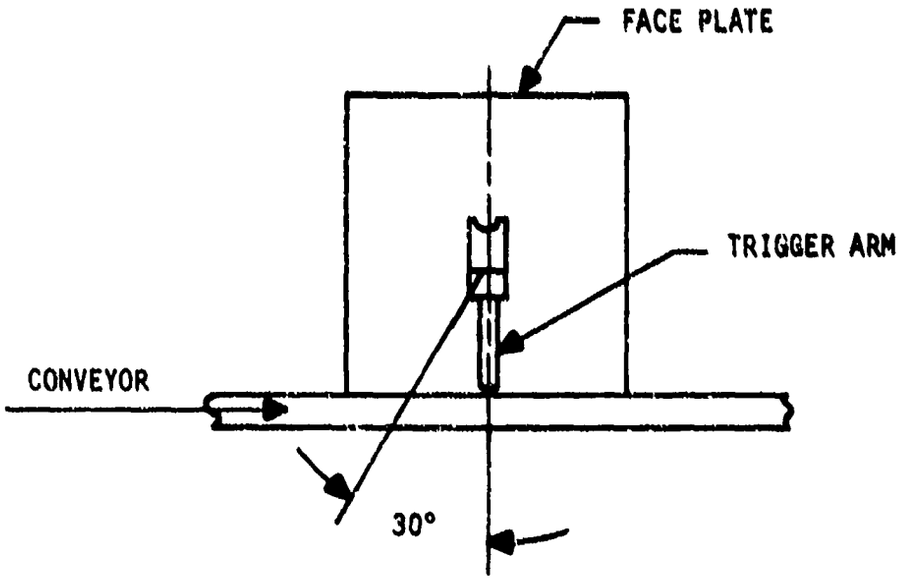


Figure 24. Activating trigger arm should be mounted 30° off vertical for ease of operation on crimping machine, Work Station A-34

Work Station: A-35

Receive and Stack Bomblets

a. Limit switch is labelled with a paper slip only. Prepare permanent label.

b. Emergency switch of stencil machine can be operated by another worker, A-35 only, because the switch is located at the other side of the machine. If A-36 wants to stop the stencil machine, the limit switch, designed for overload use only, must be kept pushed down. Release of the switch starts machine anew. Such a feature is undesirable for stops, therefore, application of another shut-off switch is recommended.

Work Station: A-37

Move Stack to Pressing Machine

a. Wheels of the assembly carts occasionally have been lubricated, and thus pushing the carts takes considerably more effort than necessary and hinders maneuverability significantly. Safety and smoothness of the operation are affected. It should be somebody's responsibility to lubricate cart wheels periodically.

Work Station: A-38

Prepare Cargo Section

a. Use of flashlights to illuminate inside of cargo section assembly is most inadequate and time consuming. The worker has to hold and direct flashlight with one hand and work with the other. See Figure 25. Recommendation: use adjustable garage lights hanging from the ceiling. The lights should stop at any height above the floor, as required. With a clip mechanism, the lights could easily be mounted on the cargo section and disconnected from it. Four or more lights are recommended to be installed.

b. General illumination is inadequate in this area. Two or more overhead fluorescent lighting fixtures should be suspended above the work station.

c. Packing strip installation tool is complicated to use, it releases frequently. A new design is recommended which achieves pressure with screw-and-cranking action. The worker would insert a cranking arm into a rectangular receptacle and screw the pressing heads tight. An outline of the concept is presented in Figure 26.

d. Provide a tool shelf along wall for storage of handtools, 36" above floor level. Presently, the operator does not have space to store tools while moving cargo sections and assembly cart from one station to another. A discarded cardboard box is being used as a storage shelf.

Figure 25. Work Station A-38: Preparation of cargo section. Illuminating inside of bombshell with flashlight is inadequate, use adjustable ceiling lights, like in garages. Installation tool, held by other hand, releases easily; use a different design.

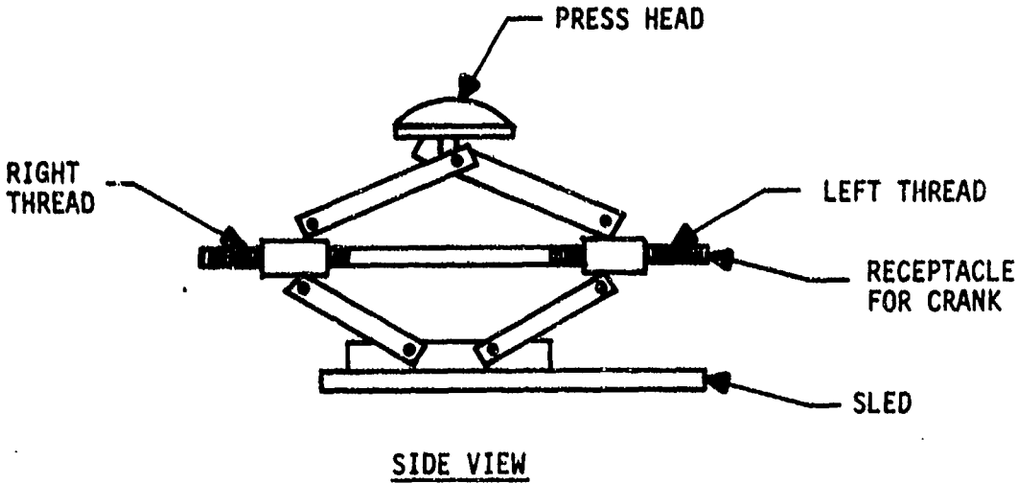


Figure 26. Concept of a packing strip installation tool to be used on cargo sections, Work Station A-38.

e. Provide tool shelf on assembly cart frame. Shelf size: 10" x 15". Presently, the operator puts one tool on the floor, while another is being used.

f. Provide a solid container for collecting valve cap screws. Mark container.

Work Station: A-42

Install nitrogen, fuze cover, nose, fairing covers, ring assemblies, and stencil

a. The operator turns nitrogen on and off with a handwheel. The operation is time consuming and the worker does not have immediate feedback on the on-off status of the system. A toggle switch should be used which turns on nitrogen in the upward position and shuts it off in the downward position. A toggle switch can be activated quickly and control setting (position) is identifiably visible.

Use a resistance force of 10 to 40 ounces. This elastic resistance should build-up, then decrease as the desired position approaches, so that the control "snaps" into place and cannot stop between positions. Recommended dimensions are shown in Figure 27.

Two indicator lights could also be used advantageously: when nitrogen is on, a red light is on beside the toggle switch; when nitrogen is off, a green light comes on, located under the red one (corresponding to the up-down position of the switch). The lights should be labelled red - "Nitrogen On"; green - "Nitrogen Off". The switch and indicator light assembly should be located on the control panel, beside the pressure gauge, in the location where the present handwheel is.

b. As another solution, a push button switch could also be used, if a toggle switch assembly cannot be obtained. Preferably a push-on-push-off type switch should be used which turns on nitrogen with one push, and shuts it off with the next push. Use of the indicator lights is important, in order

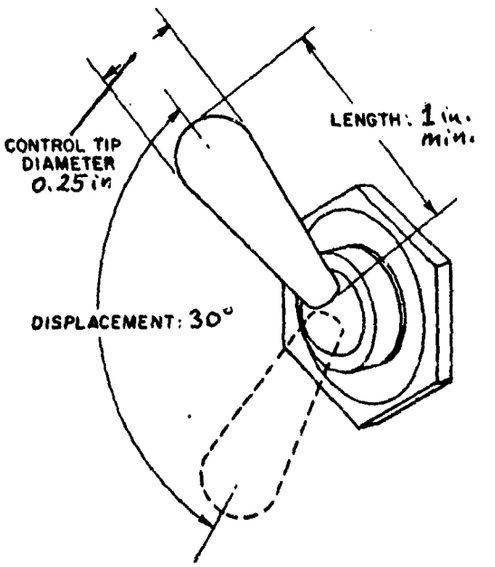


Figure 27. Design of Toggle Switch

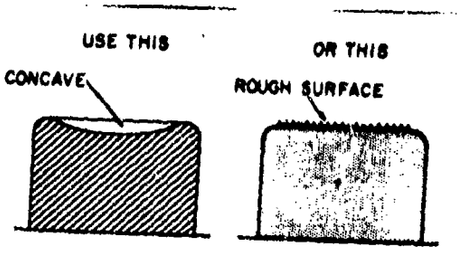


Figure 28. Activation Surface of Push Buttons

to provide feedback information to the operator on the status of the system.

A push-button switch can be operated quickly. Its action should be positive: elastic resistance, aided by a slight amount of sliding friction, starting slow, building rapidly with a final sudden drop to indicate activation. The "snap action" should not be too heavy, the recommended force is about 10-20 ounces. Displacement of the push-button is 0.125" (maximum 0.250"). A concave top is suggested to aid in centering the finger on the button, Figure 28. When this is impractical, it should have a rough surface to prevent slipping.

c. A lever-action valve is acceptable only if its movement does not exceed 90^{o} and is moving symmetrically around the 12 o'clock or 3 o'clock position. Optimal displacement is 60^{o}, with a resistance of 2 lbs. Dimensions of correct lever design are shown in Figure 29. Each lever position should be clearly labelled: "Nitrogen On" and "Nitrogen Off".

d. Two pressure hoses are provided to test bombs with nitrogen. These recoil-type hoses cross each other frequently during the operation and consequently a confusing array results, see Figure 30. It is recommended that color coding be used: one hose should be red, the other must have another color for ease of identification. The two control panels, regulating each of the hoses, should be similarly identified by color: paint the panel around the pressure gauges with the colors of the corresponding hoses.

e. Provide a bracket for the pressure valve located at the end of the nitrogen hose. Presently, the operators do not have any means to store the hose, while

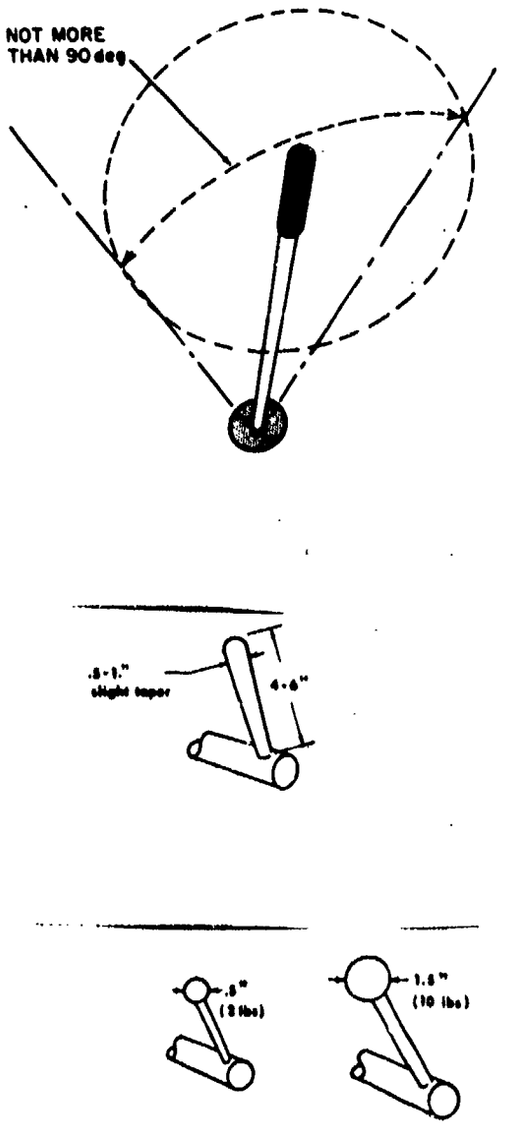


Figure 29. Design of Control Levers

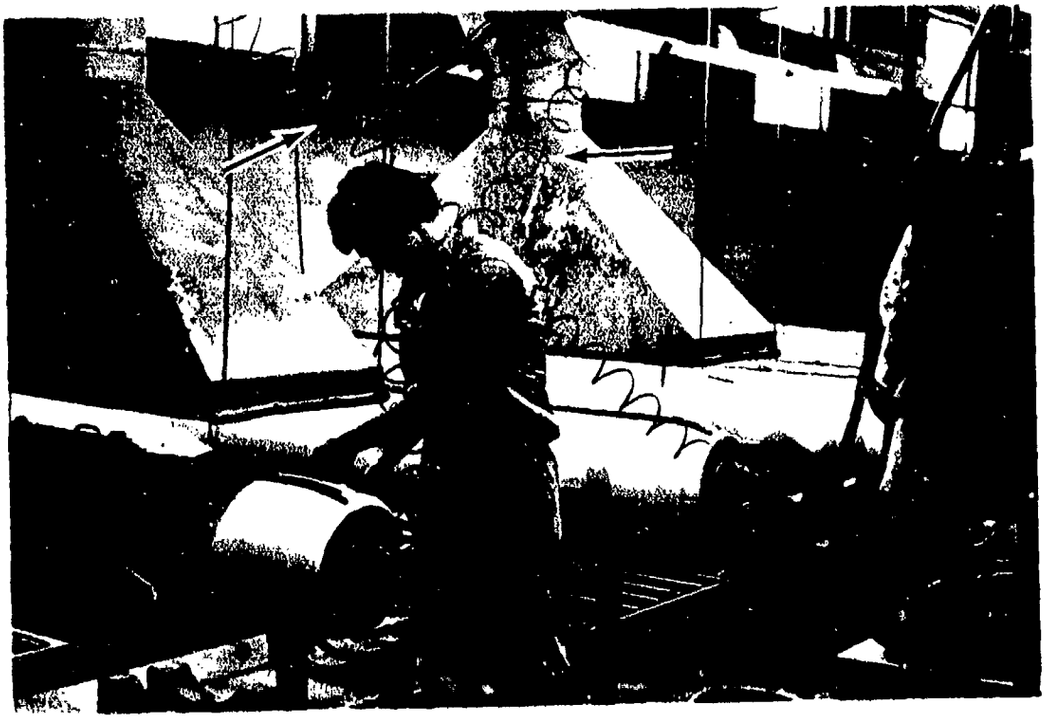


Figure 30. Work Station A-42: Pressure testing of bomb assemblies. The recoil type pressure hoses get tangled and are difficult to differentiate. The hoses should be of different color with identical colors to mark corresponding control panels.

switching from one bomb unit to another or during waiting periods. Therefore, they tie it around the exhaust hood, as shown in Figure 31. A quick release holder, resembling the microphone bracket used on radio transmitters, should be used to simplify storage and reduce operation time .

f. Mount tape holder permanently on work bench. Presently, the operator has to use both hands to cut adhesive tape to length: he keeps the holder on the bench with one hand, while he pulls the activating lever with the other. The tape holder should be bolted to table.

g. Use two clocks to provide time for pressure testing. From certain work positions along the assembly line, the exhaust hoods cover the clock and the operator has to move to another location in order to be able to mark the time for beginning and ending pressure test. A larger than present clock face is recommended. If two clocks are used, they should be set to each other and each should have identical face.

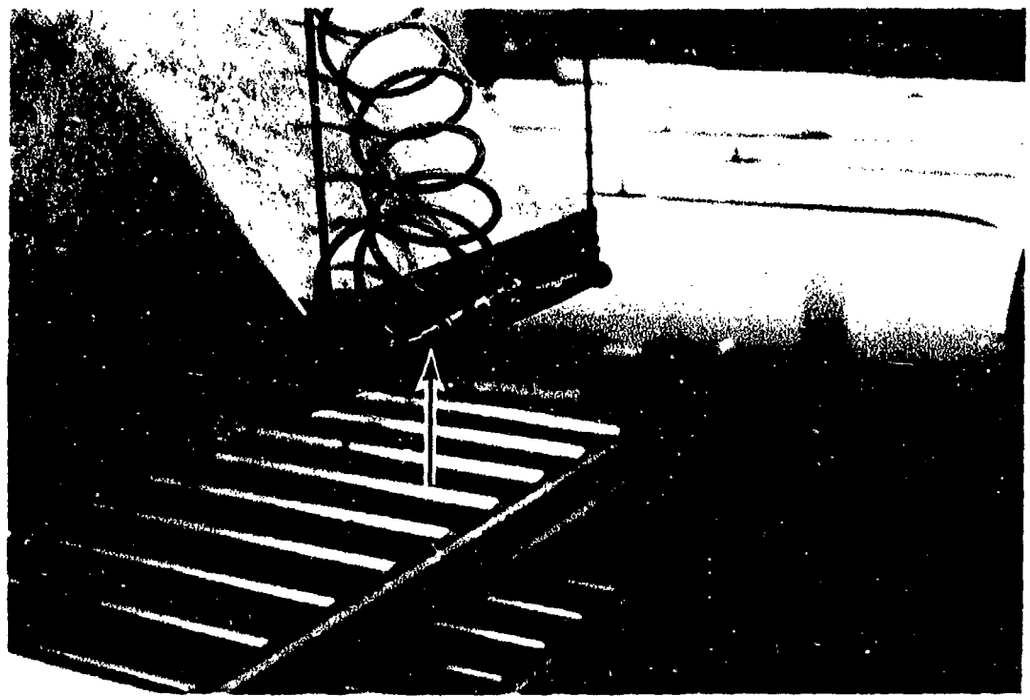


Figure 31. Work Station A-42: Bracket is needed to hold pressure hose.

Work Station: A-43

Install Bomb Into Shipping Container

a. Operator activity requires considerable energy expenditure, necessary movements to accomplish work elements call for great force exertion by large muscle groups of the back. Unfortunately, in the present work space arrangement, the operators have to perform most of the tasks in a stooped unnatural body position. Figure 32 illustrates the most stressful task: lifting and closing container cover with the back bent. When lifting loads both working efficiency and prevention of damage to the spine should be considered. In work postures like this, disease of the intervertebral discs in the spine frequently occurs due to abnormally high local pressures which develop between the vertebrae, Figure 33. Disc related diseases are fairly common in the 20-30 age group. Those in certain occupations (heavy manual work, agriculture, dock workers, nurses, etc.) suffer from disc lesions most frequently. Two solutions are suggested to ease the work situation:

1. Raise height of wooden braces 8" above present level (13 + 8" to a total of 21" above floor level). It will raise the centerline of the container to 34" level and eliminate much of the bending necessary. (NOTE: The recommended work height for standing operations is 36" above the floor level for the national average which nearly coincides with 34" level).

Figure 32. Work Station A-43: Closing bomb shipping container. Working level is improperly low because of inadequate height of support braces. Braces should be raised 8" to provide working level near to the anthropometricly optimal height of 36".

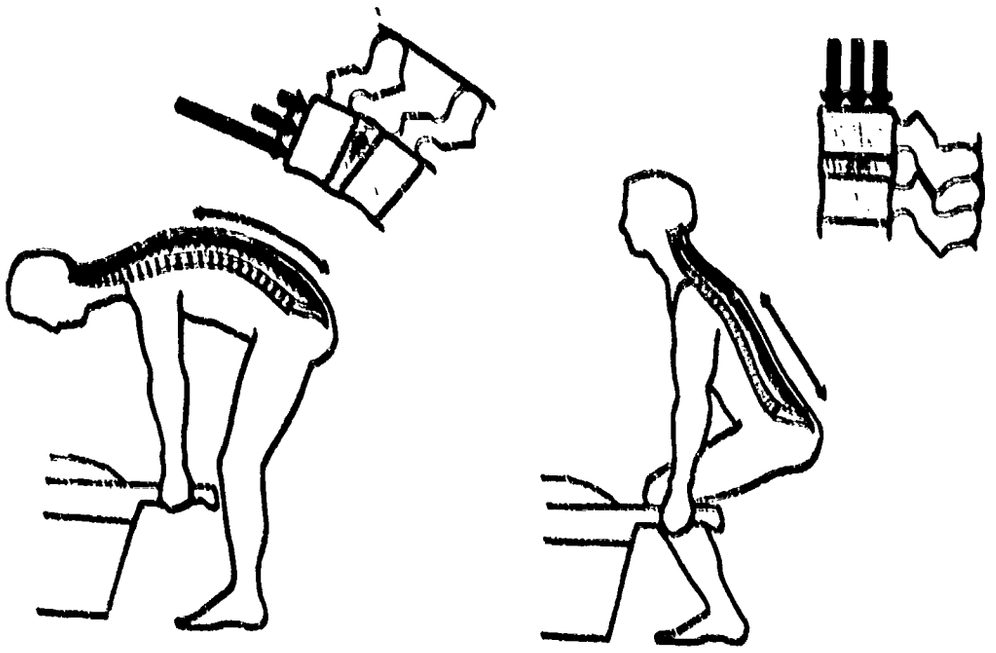


Figure 33. The undesirable effect of a rounded back on the lumbar intervertebral discs when lifting: Round back, left: high pressure develops on the periphery of the disc and increases the risk of rupture. Straight back, right: Pressure is equally distributed and the danger of accidents is reduced.

3. The operators have to be explained the technique of correct lifting, and importance of keeping back straight when lifting loads. When a man stoops to lift with the torso horizontal, a large pressure is exerted on the lower spine as a result of lever action. To prevent build-up of this damaging stress, some good principles of work physiology should be adopted:

- the load to be lifted should be kept as close to the body as possible;
- the back should be held straight; with a rounded back, danger of "slipped" discs is much greater;
- initially the knees should be bent and the trunk kept as u t as possible, with the back straight, Figure 33

NOTE: The above principles are taught to school children in Sweden to develop correct work posture for a lifetime.

b. Illumination level is inadequate. Use of the fluorescent lighting fixtures (with two 40 watt bulbs each) is recommended.

c. Task accomplishment requires much walking around containers and braces. Therefore use of good quality rubber walking mats is recommended. Mats should be laid everywhere around the braces, on both sides of roller conveyor, between wall and braces; except at areas where fork lift operates: within the braces. When selecting mats, the color should not necessarily be black, a more pleasing color could be purchased.

d. For summer ventilation, provide two portable frame fans with three speeds and with adjustable blow direction. If fans will be mounted high on the wall in front of the windows, the speed selector switches should be located at a height which can be reached from the floor.

e. Paint the brace structure yellow with yellow/black warning stripes on the corners.

Work Station: A-44

Banding

a. Adequate work space is not primarily a convenience, it is a requirement to insure acceptable level of operating efficiency. In laying out a work space, consideration must be given to methods by which the units will be assembled. Presently, the bomb containers are too low, the operator has to kneel in order to be able to perform his function, Figure 34. The worker wears rubber knee caps under his slacks. Furthermore, the clearance between the containers and the wall is 30 inches wide only. Note in Figure 35 that 30" clearance is recommended for standing operations and that 45" minimum width is needed for kneeling. The dimensions given in Figure 35 are the minimum clearances. They should be unobstructed spaces, measured from the working surface to the nearest opposing surface. Two recommendations are suggested:

1. Raise height of wooden braces 8" above present level (13 + 8" to a total of 21" above floor level). It will raise the centerline of the container to 34" and eliminate much of the bending necessary.

2. Increase the distance between braces and the wall 18" wider than presently available, as shown in Figure 36. Such a wider clearance, combined with the increased work height will result in sufficient accommodation.

b. Palletizing is done on the floor. Tools and bands are laid on the floor, and the worker either kneels or stoops heavily, Figure 37. Construction of a palletizing brace is suggested which is 12" high, 110" wide for the banding operation. Depth of 48" is needed for holding the containers and an additional 16"

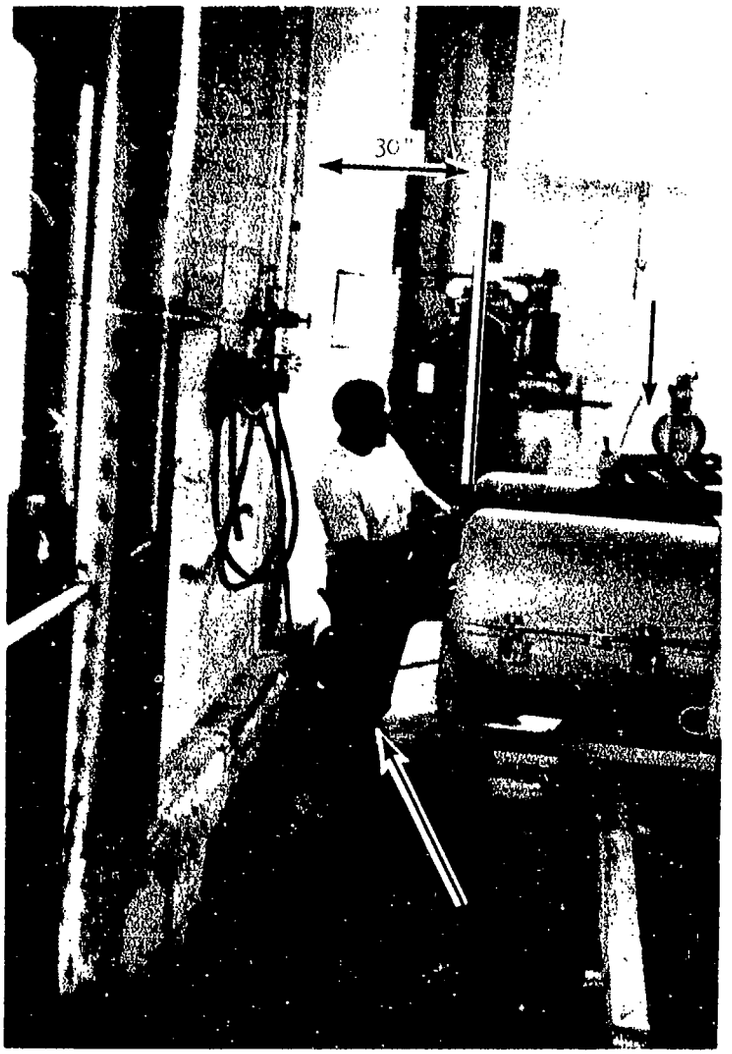


Figure 34. Work Station A-44: Banding of shipping containers. Clearance between wall and container should be a minimum of 45". The low working level should be raised by increasing height of support braces 8". NOTE: Improvised tool box.

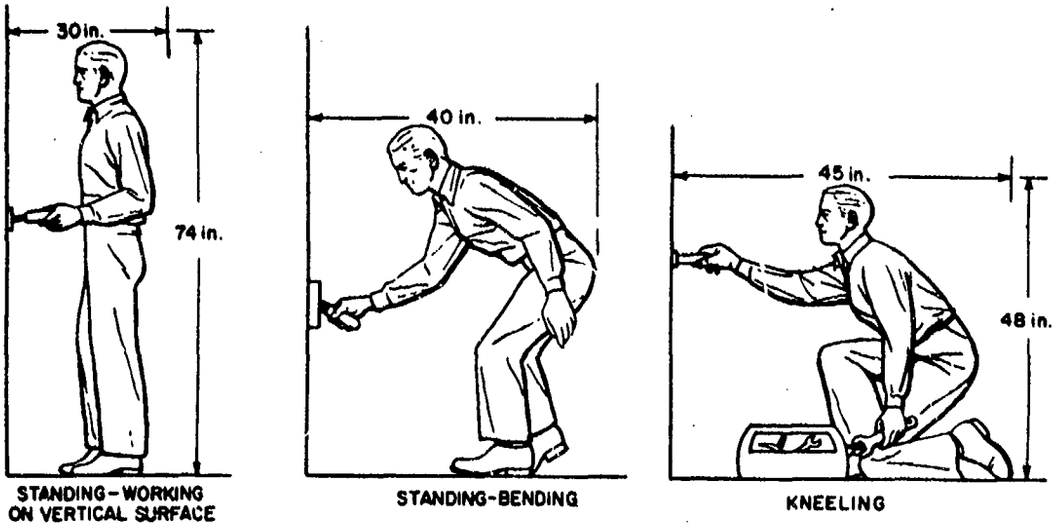


Figure 35. Minimum clearance to be provided for various body positions assumed by the worker while performing his tasks.

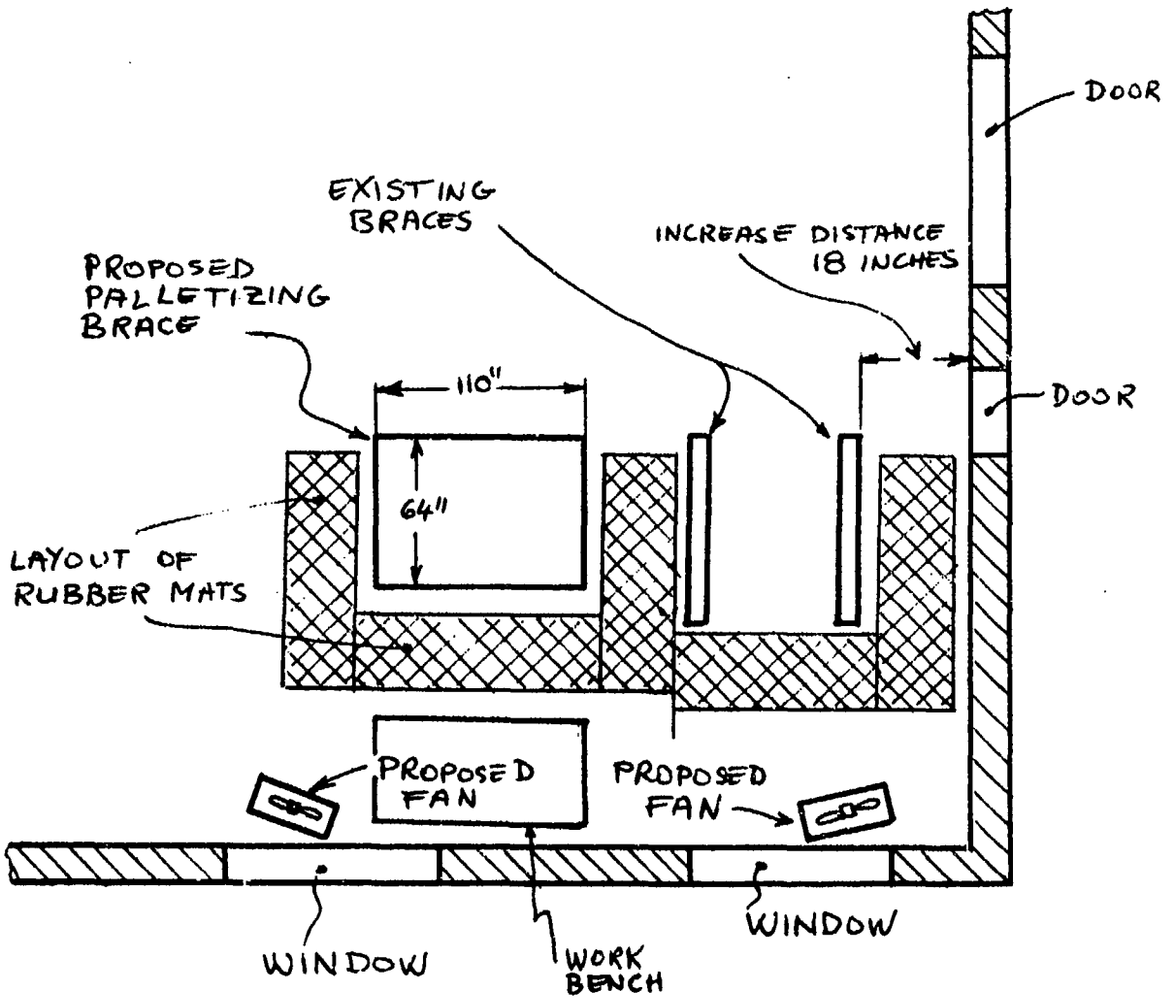


Figure 36. Proposed work space arrangement of Work Station, A-44:

-raise brace height to 21"

-increase clearance by wall

-provide palletizing brace

-provide fans

-provide rubber walking mats

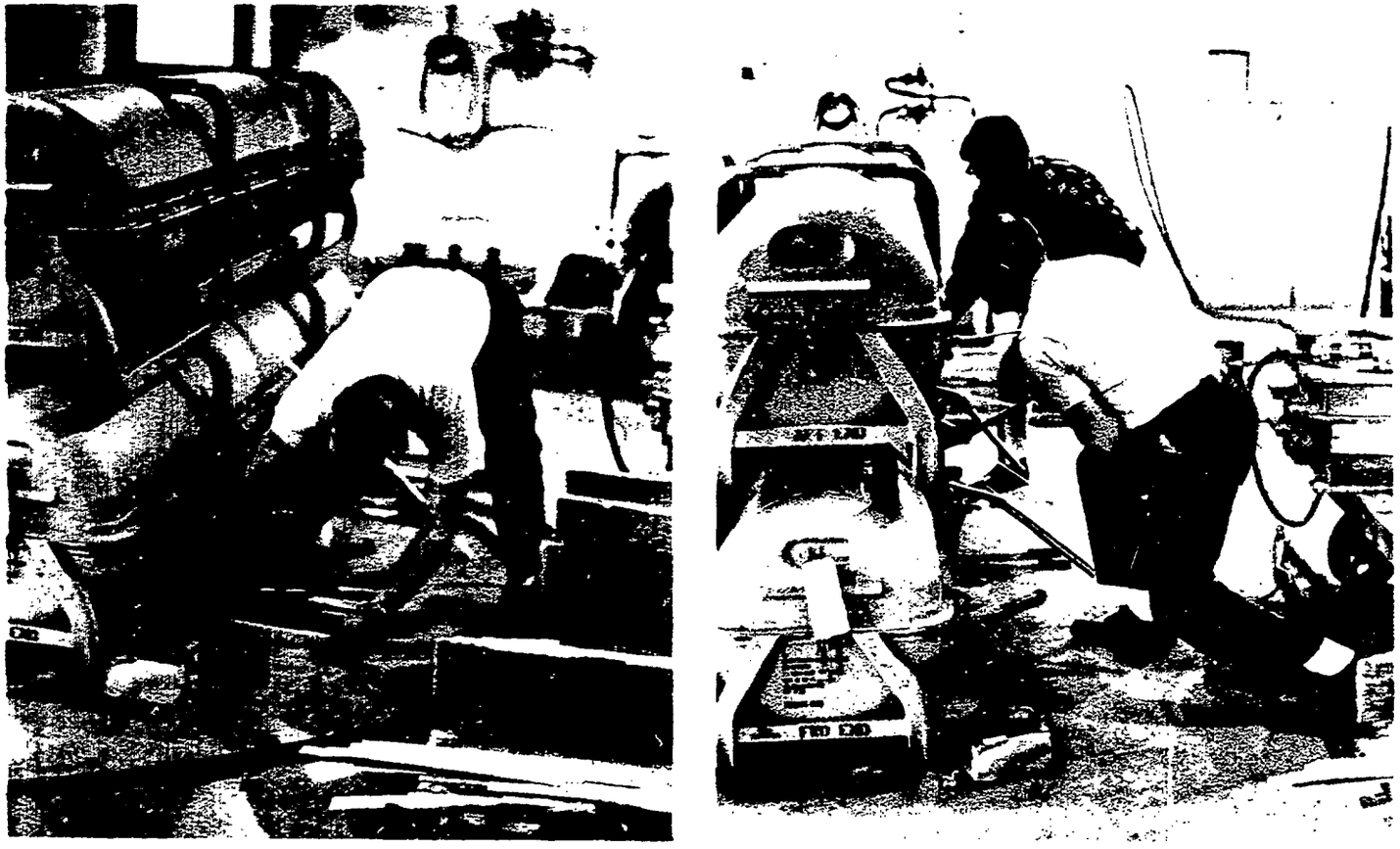


Figure 37. Work Station A-44: Palletizing operation showing excessive, undesirable bending. Working level should be raised by providing braces under containers.

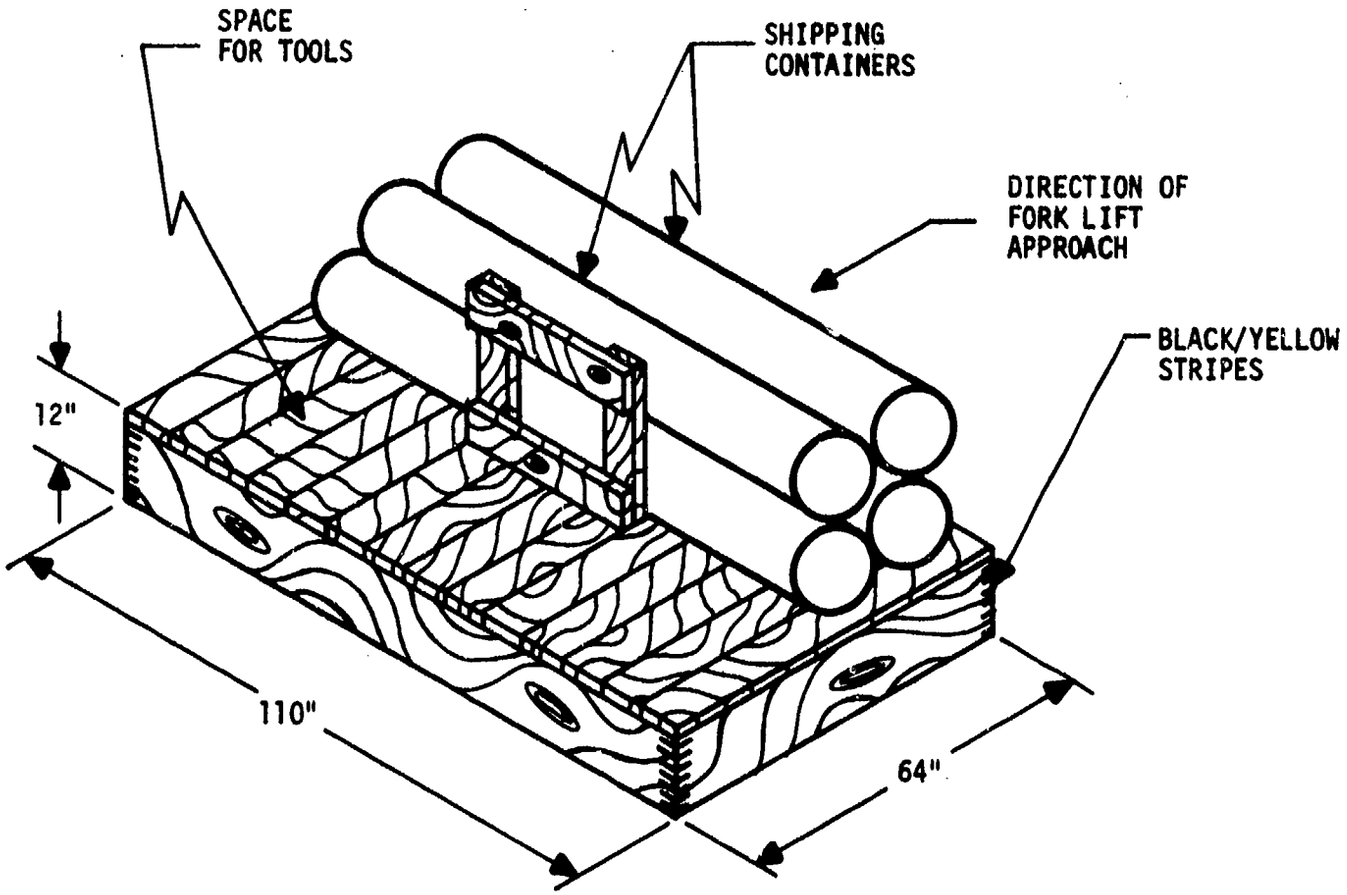


Figure 38. Suggested configuration of palletizing brace for Work Station A-44.

should be provided for holding tools: a total of 64" minimum. Note that top of the brace should be covered, like a table top, because palletizing bands must be placed under containers for fastening, Figure 38. Paint the brace structure yellow, with yellow/black warning stripes on the corners.

c. Acquire air-powered bander for 1¼" steel band used in palletizing. Muscular force requirement is unnecessarily large for this task. An air operated bander is used for the 3/4" band, a similar unit is recommend for the wider band.

d. For summer ventilation, mount two fans in front of windows, Figure 36. Use three speed fans so that air volume could be regulated according to needs. A fan is located above the operator on the ceiling, but it blows over to Work Station A-42 and does not relieve stalled summer heat at this location.

e. Two sets of fluorescent light fixtures (with a pair of 40 watt tubes each) are needed to provide adequate illumination. Light is not sufficient for lacing seal wire into pressure valve hole.

f. Provide comfortable rubber walking mats around work station, as shown in Figure 36. Mats could be used anywhere around brace structures, where fork lift does not operate. When selecting mats, the color should not necessarily be black, a more pleasing color could be purchased.

g. Build a light wooden tool box for operator. Presently the worker uses an old cardboard box with a taped on handle to carry his tools around bomb containers, as indicated in Figure 34.

h. A work bench (or table) is recommended for use in palletizing area, for storage of tools and supplies. Its location is shown in Figure 36, table height is 36".

Work Station:

Tray Repair and Maintenance

a. Work station should be arranged so that it corresponds to the type of operation: seated work station, with one work table and one work bench. A possible floor plan arrangement is suggested in Figure 39. The work table is presently small (36" x 48"). A minimum of 36 x 72" table size is recommended. Partitions should separate the work station from the rest of the room. Large enough space should be created with the partitions to store an adequate supply of trays and equipment for several hours. Openings should be wide enough for delivery carts. Even GSA office partitions could be used, but higher than 66" walls are preferable.

b. Workers should be seated whenever possible as a principle of human factors engineering. Seating position decreases stress on the leg, unnatural postures can be avoided, energy consumption is reduced, and there is less demand on blood circulation. The most important dimensions for the work table to be used are shown in Figure 40. For the tray repair operation, height of the work table can even be 4" lower than the recommended 36" for general operation. One reason for this change is that the work pieces are 8-10" high, and when these units are placed on the table, the operators will be working at a level higher than usual.

Use of high work benches is not recommended, even though it is frequently assumed that the worker could stand or sit at will. It has been shown that reason for standing is poor seating arrangement in most cases.

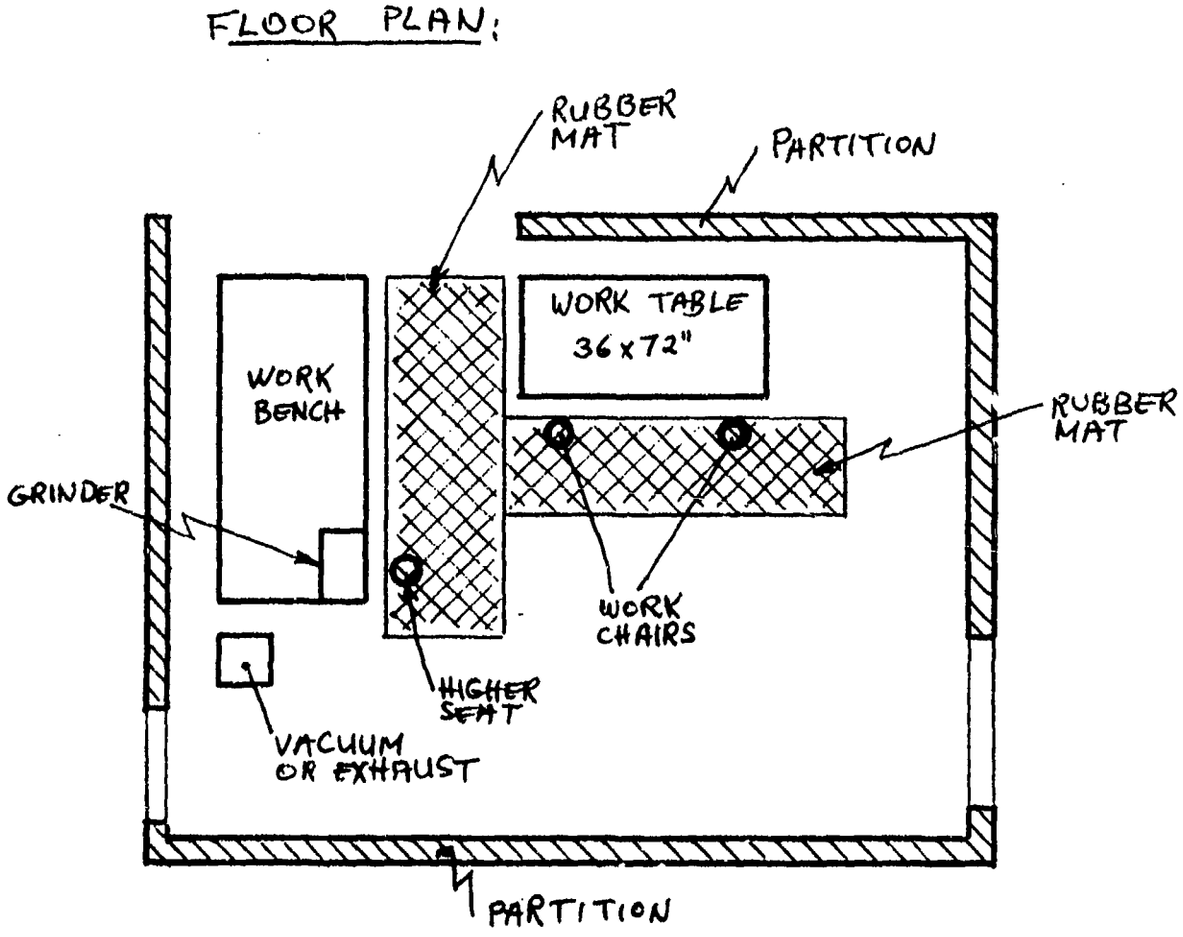


Figure 39. Work place arrangement for tray repair and maintenance.

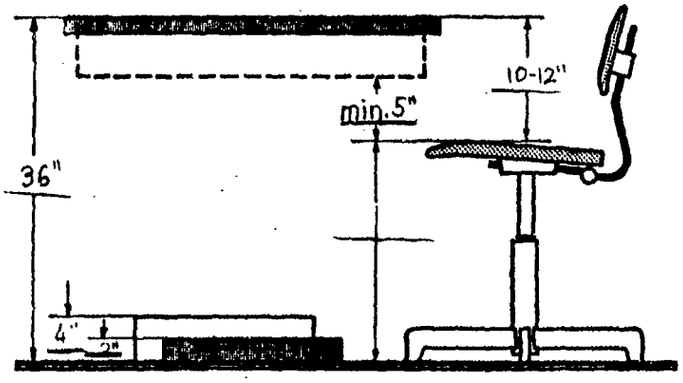


Figure 40. Recommended dimensions for work tables.

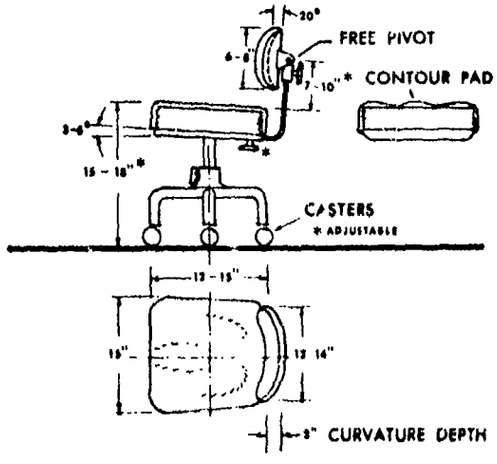


Figure 41. Dimensions of a good chair for seated operations.

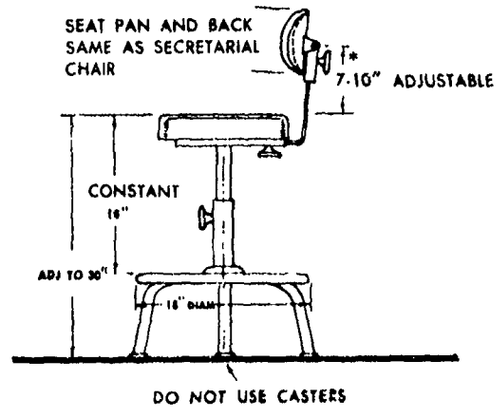


Figure 42. Dimensions of a good chair for alternating seated and standing operations.

However, when seating is the best that can be provided, the operators never stand. A floor level production line is considered to be the most recommended. Standard chairs should be used and low benches (36") which suit the chair height. For women, due to shorter stature, foot stools can be provided as necessary.

c. Provide good work seats for the operators. Outline of a recommended seat is shown in Figure 41. The basic consideration for this type of chair is the providing of good posture control. Proper support to the small of the back is very important to prevent fatigue over extended lengths of time spent in the chair during a normal workday. The chair should be adjustable and mobile, provide swivel motion in the seat pan, and have sufficient padding in the seat and back rest. The upholstery should provide ventilation to prevent sweating during hot, humid weather. When selecting a chair, a more pleasing color than black could be purchased. Adjustment knobs or handles should be designed so that they are easy to manipulate. Remember that the chair is used most often by women who do not have as much strength in their hands as men.

For the grinding operation, a different type of seat is recommended, because the work surface is higher. The chair must resemble a good drafting chair. It is shown in Figure 42. The upper part of the chair should have approximately the same dimensions and features shown above for the above chair. Note that caster wheels are not recommended. Purchase a more pleasing color than black.

d. Two fluorescent fixtures (with a pair of 40 watt tubes each) should be located above both the work table and bench. The suitable positioning of

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d. Two fluorescent fixtures (with a pair of 40 watt tubes each) should be located above both the work table and bench. The suitable positioning of

the light is shown in Figure 43. Good location of luminaires will not produce absolute or relative glare. No light source should appear in the visual field of the operator; unscreened lighting units should not be used in work areas; use of polished surfaces or reflecting materials on machines, table tops, etc. should be avoided.

e. In addition to the general illumination, it is wise to consider a special supplementary light near the immediate work area, Figure 44. Care must be taken to make sure it is positioned so that it is not directed into the operator's eyes--or is not positioned so that the light reflects from the bench into his eyes. Watch for shadows which may be created by position of piecework of operator's hands. This type of additional lighting should be provided for each operator at the work table and at the grinder.

f. Use good quality rubber walking mats on the floor, as illustrated in work space arrangement, Figure 39. Use other than black color.

g. At grinder, provide an exhaust system to remove rubber grindings and to clean work surfaces. A shop vacuum cleaner might be adequate. Also study the applicability of an industrial exhaust.

h. In the summer, provide two portable fans for air circulation. The fans should have adjustable speed, should be equipped with roller casters so that the operators could set the most suitable air exchange condition, and direction of blow should be adjustable.

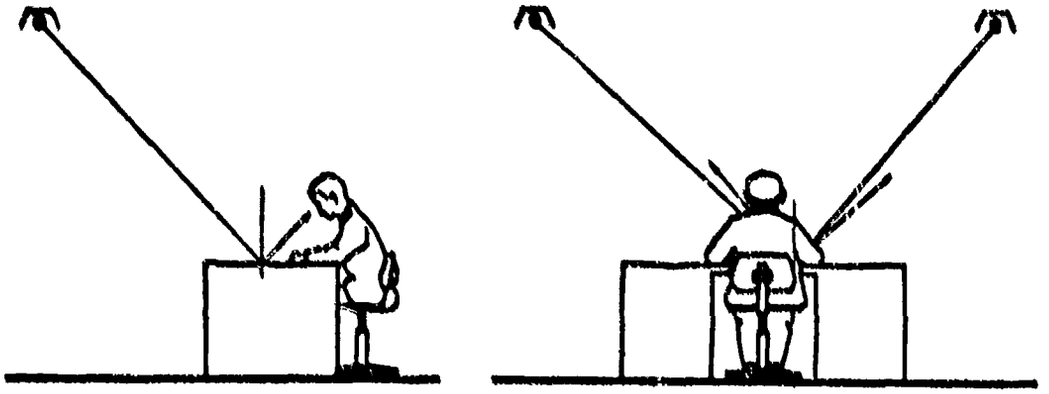

Figure 43. Arrangement of Lighting Fixtures

Unsuitable positioning of the light source in relation to the work place. Reflected light coincides with the line of sight, so that direct glare through reflection can occur.

Suitable positioning of lights. Reflected light does not hit the eye and glare through reflection is avoided.

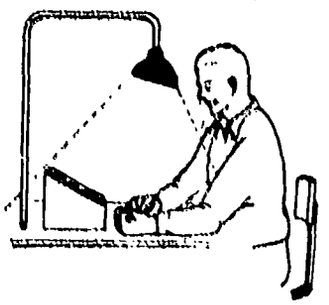

Figure 44. Supplementary light near the immediate work area.

Work Station: B-1

Octol from Conveyance to Building

a. Operator loads boxes of explosives on conveyor carts in 40-50 sec. intervals. Between each load, he moves explosives from railroad cars into building. There is no information provided fo the operator when he should be ready to place next load of explosives on conveyor. He might be outside in the railroad car, or in another part of the storeroom, when conveyor cart arrives. Therefore, he has to keep a constant watch on and guess time intervals of arrival of conveyor carts.

An auditory signal should be provided to indicate operator's next arrival. Approaching carts could activate a buzzer switch. Buzzer should sound about 10 sec. before loading time. The low background noise level of the work station makes possible the use of a low intensity sound signal.

The major advantage of auditory signals is in the fact that the operator can act upon the information he receives without physically facing the source of the signal. The human auditory-perception system is a very capable discriminator of wanted versus unwanted sound and is ideal for sorting usable signals from noise.

b. A conveyor stop switch should be located inside the storage room, on the left side of the exit door. In emergency such location seems to be the most efficient place to stop the operation. Presently, the conveyor stop is located outside in the walkway, and not in the room, where the operator is loading the conveyor. The switch must have a label.

c. In summer, use of a portable fan is recommended. The fan should be equipped with adjustable speed, adjustable direction of blow and should have rolling casters so that the operator could be able to position it according to needs.

Work Station: B-5

Receive Explosive and Screen

a. Location of shut-off switch for power conveyor is unsuitable for emergency operation. Presently, if emergency occurred, the operator would have to go under the conveyor toward the danger and would get farther from exit than his normal working location, Figure 45. It is recommended that a stop switch be located on the wall next to the emergency exit. The switch should be labelled.

b. To activate power conveyor located behind the magnetic separator, use a push button, or a lever action starting switch instead of the present handwheel. Advantages and design characteristics of these instant-action starting devices over handwheels are discussed for Work Station A-42, Recommendations a, b, and c.

The starting switch should be labelled, direction of starting and stopping action be indicated.

c. Provide a portable, variable speed adjustable fan for summer ventilation. Details of recommendations are discussed for Work Station B-1, c.

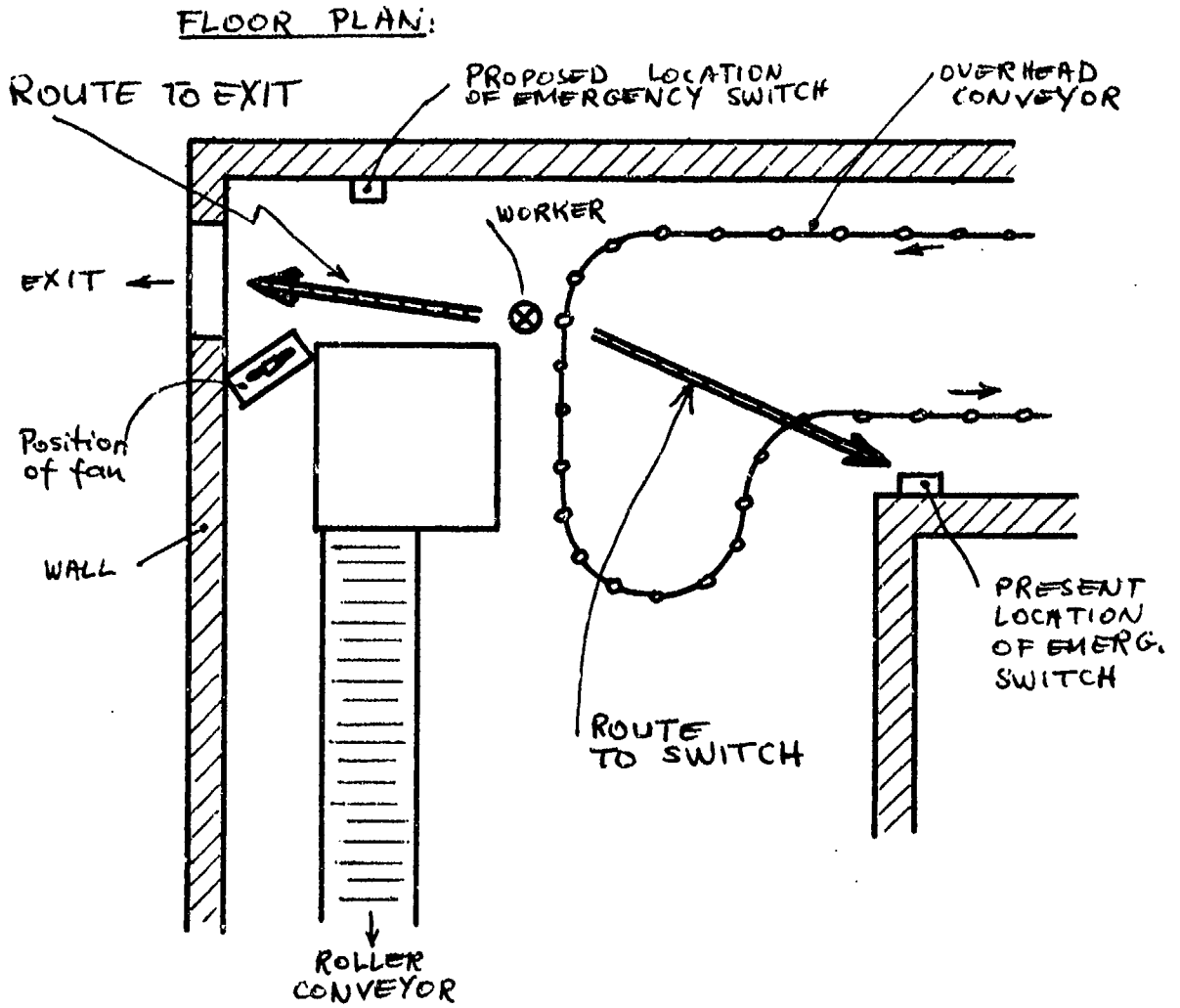

Figure 45. Work Station B-5: Unloading explosive from conveyor. In emergency, route to stop switch takes operator farther from exit than he originally was.

Work Station: B-6

Melting of Explosive

a. Conveyor starter switch is located between the two kettle stands. Its location is excessively far from each work station, the operator has to step on edge of stand and stretch out to reach it, Figure 46. Separate switches should be located adjacent to each of the two kettles within easy reach of the operator.

b. To activate power conveyor, use push button or lever action starting switches instead of the present handwheels. Advantages and design characteristics of these activating devices over handwheels are discussed for Work Station B-5, Recommendation b, and Work Station A-42, Recommendations a, b, and c.

c. Mount a stop plate at end of kettle feed conveyors. Presently a putty knife is stuck between the two last rollers of the conveyor to prevent boxes, filled with 60 lbs. of explosive, from rolling over conveyor. The stop plate should not extend to full width of the rollers in order to ease removal of boxes, Figure 46.

d. Label the following hand controls:

-pressure regulating hand wheel (function and direction of "on-off")

-agitator speed regulator

-conveyor start-stop valve (indicating "on-off" directions).

e. To facilitate mobility of the operator between the two work locations, connect the kettle stands with an elevated walkway, and locate stairs between

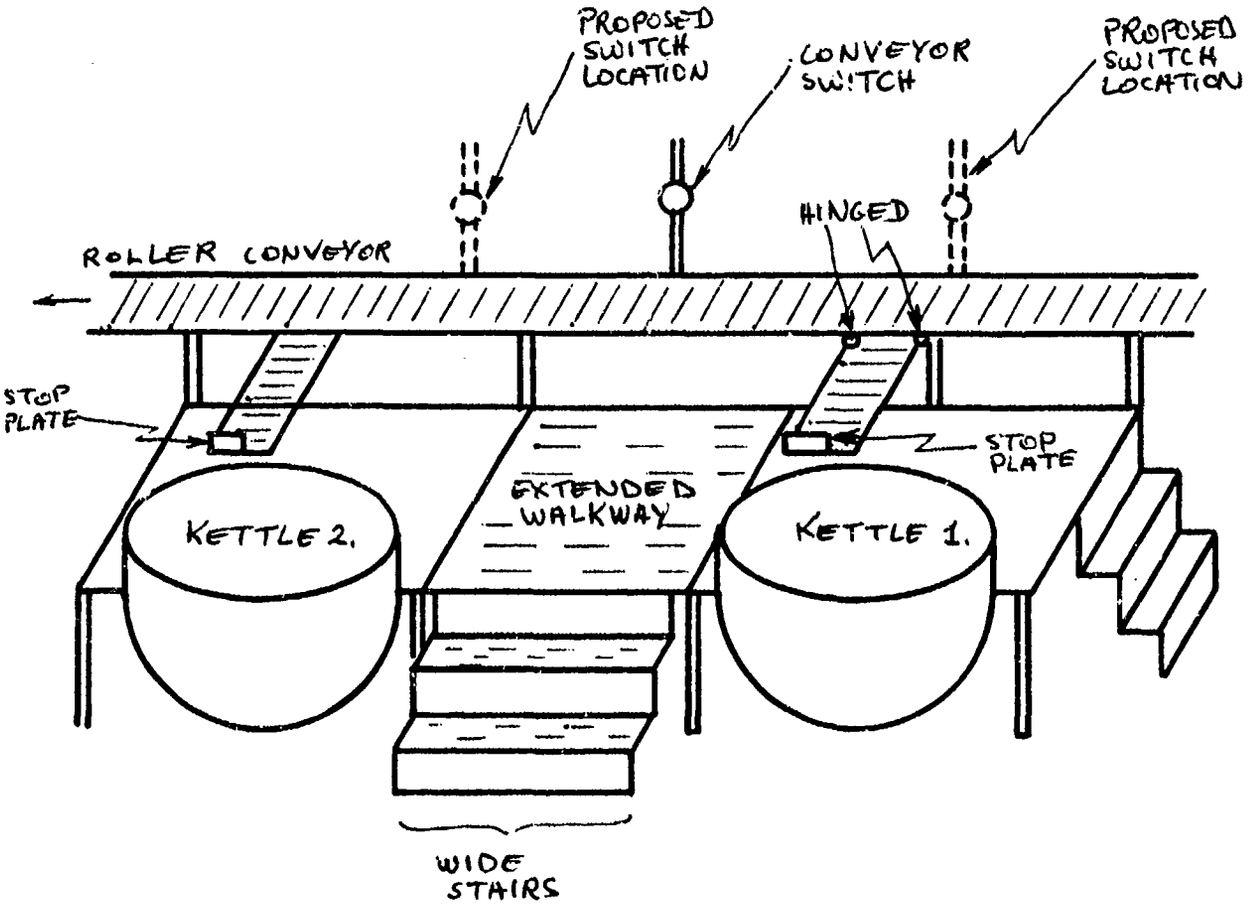

Figure 46. Suggested modifications for Work Station B-6, Melting of Explosives

the kettles, Figure 46. The conveyor leading to the first kettle must be converted for folding. Design concepts of stair construction are shown in Figures 47 and 48. Ladders are suggested for inclines which are between 50 and 90 degrees. Those ladders which range from 50 to 75 degrees should have flat treads; rungs may be used from 75 to 90 degrees. The distance between treads or rungs may vary from 7 to 16 inches, 12 inches being the most desirable. Hand grips should be provided on all ladders. Hand-rails on both sides must have non-slip surfacing and should have the dimensions shown in Figure 48. Use the maximum width available between the kettles when constructing the stairs.

f. Provide two portable variable speed fans for summer ventilation, if safety permits. Principles of fan selection are discussed for Work Station B-1, Recommendation c.

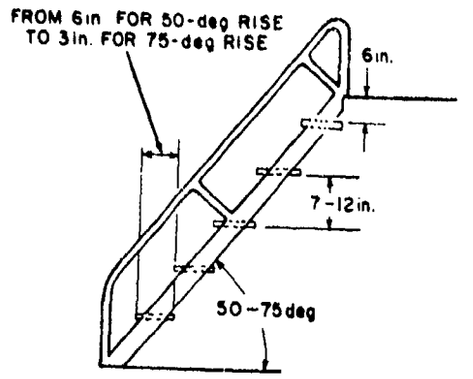

Figure 47. Recommended dimensions for ladder design

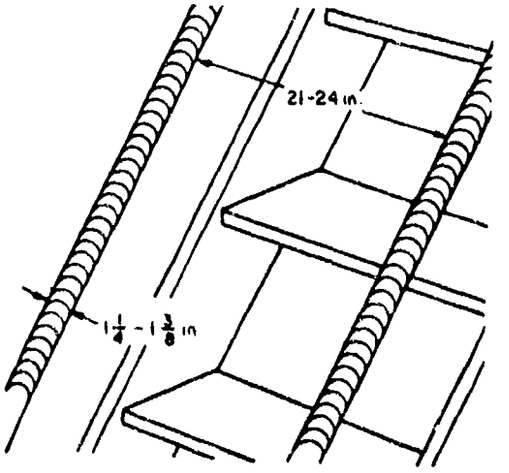

Figure 48. Handrails on both sides of ladder must have non-slip surfacing and should have the dimensions shown.

Work Station: C-2

Press CH-6 Powder Into Booster Pellets

a. Operator has to fill press in every 11 minutes. A larger powder container cannot be used for safety reasons. Presently, the operator has to monitor filling level visually through a mirror system. The procedure requires constant attention, no timing device is provided, a clock or warning signal is not available. Provide a timer, which restarts automatically every time the closing safety chain is fastened. The timer should activate a signal light which comes on 20 seconds before next filling is due. The light should stay on until chain is secured again. Signal light should be located over the inspection station outside the press chamber. Manual override of the timer must be available.

b. The present method of quality inspection is illustrated in Figure 49. The operator uses a micrometer to measure dimensional tolerances on explosive pellets. Level of illumination is most unsatisfactory, no work table is provided. A seated operation must be created with good chair and good illumination arrangements.

Design of the work table for inspection tasks is shown in Figure 50. Note that in addition to general ceiling illumination, frontal local lighting should be added; the light sources screened against direct view; luminaires be phased and have light diffusing elements (grooved or matt glass); the light source should present a large light-yielding surface.

Figure 49. Work Station G2: Present method of quality inspection for dimensional tolerances with micrometer. Figure to the right shows diagram of a good inspection station.

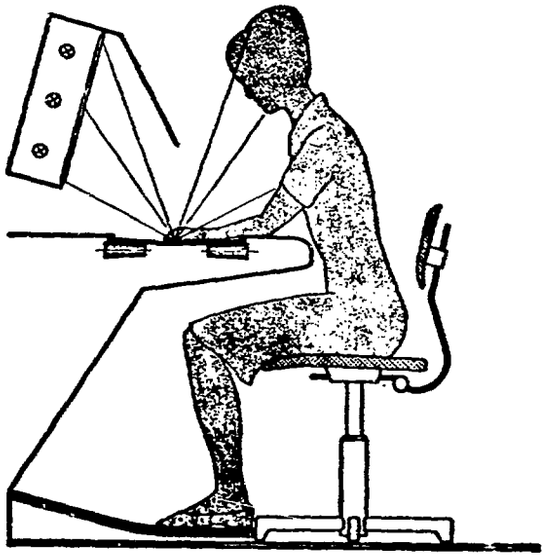

Figure 50. Layout of how an inspection station should be built. The light comes from a three phase shift fluorescent source through a light diffusing glass which forms a large illuminating surface. The light source is screened from the eyes, and provides frontal incident lighting. In this way defective parts are easily recognized. Adjustable, padded swivel chair and foot rest are provided.

It has been shown that when working with small objects like in the swiss watch industry, frontal lighting is better than side lighting. With frontal lighting, the side of the object towards the operator throws strong shadows and the object stands out against the bright background. Performance as well as subjective judgment are better with frontal lighting than with other arrangements.

Suitable positioning of general illumination sources is discussed in detail for Work Station: Tray Repair, Recommendation d, and in illustration Figure 50. The recommended seat design is shown in Figure 41, and explained for Work Station: Tray Repair, Recommendation c. Dimensions for good work table design are presented in Figure 40. The work table should be 36" high with a 4" high footrest. The seat must be adjustable between 15-18". Knee space of 5" or more should be provided under the table above the sitting surface.

Good chairs are very important for good posture control. Proper support of the back prevents fatigue over extended periods of time spent in the chair during a normal shift. Chair height and back rest should be adjustable and be mobile with roller casters, provide swivel motion in the seat pan, and have sufficient padding in the seat and back rest.

d. Noise level at this work station is excessively high. The noise is generated by two stamping machines pressing pallet cups and caps. The presses must be housed in sound absorbing chambers to reduce transmission to noise from the source to the human. For visual observation

of the operation of the presses, double insulating windows can be built in the chamber walls. Soundproofing chambers are commercially available and are extensively used in industry to comply with requirements of the Walsh-Healey Act on noise control.

Work Station: C-5

Assemble Booster Assembly

a. Area of work surface is not satisfactory as shown in Figure 51. For four C-5 operators two work tables, each 36 x 72", are needed. Table height should be 36". This is a seated operation with the most undesirable seating accommodation: table height is 30" with chair heights of 20", which is far too much. Seats have no cushioning, no back rests. Dimensions and seating arrangement for good work table design are discussed earlier for Work Station: Tray Repair, Recommendations b and c. The work table, as shown in Figure 40, should be 36" high with a 4" high foot rest. The seat, Figure 41, must be adjustable between 15-18". Knee space of 5" or more should be provided under the table above the sitting surface.

Good chairs are very important for good posture control. Proper support of the back prevents fatigue over extended periods of time spent in the chair during a normal shift. Chair height and back rest should be adjustable and be mobile with roller casters, provide swivel motion in the seat pan, and have sufficient padding in the seat and back rest.

b. Noise level excessively high. If safety permits, considering the explosive materials being handled in this enclosed area, sound absorbing panels should be attached to ceiling to reduce noise and sound reverberations from the smooth wall and ceiling surfaces.

c. A portable restroom is recommended outside the exit. Presently the workers have to climb and descend a height equivalent to six normal floors each way to the nearest restroom.

Figure 51. Work Station C-5: Assembling booster units. Work tables are small, no knee space provided. Chairs should have padded back rest and sitting surface. Use of foot rests under table is recommended.

Work Station: C-6

Crimp Booster Assembly

a. The work station should be converted to seated operation. The reason why the operator stands beside the press, as shown in Figure 52, is the fact that the supply trays are too far to reach from a seated position. To accommodate knee space, the table holding the supply trays should be moved back and a frame constructed for holding the trays above the knees. Design concept of this work space arrangement is also illustrated in Figure 52. The seat to be used is shown in Figure 42, it must have padding, swivel motion, and foot rest. Roller casters are not recommended.

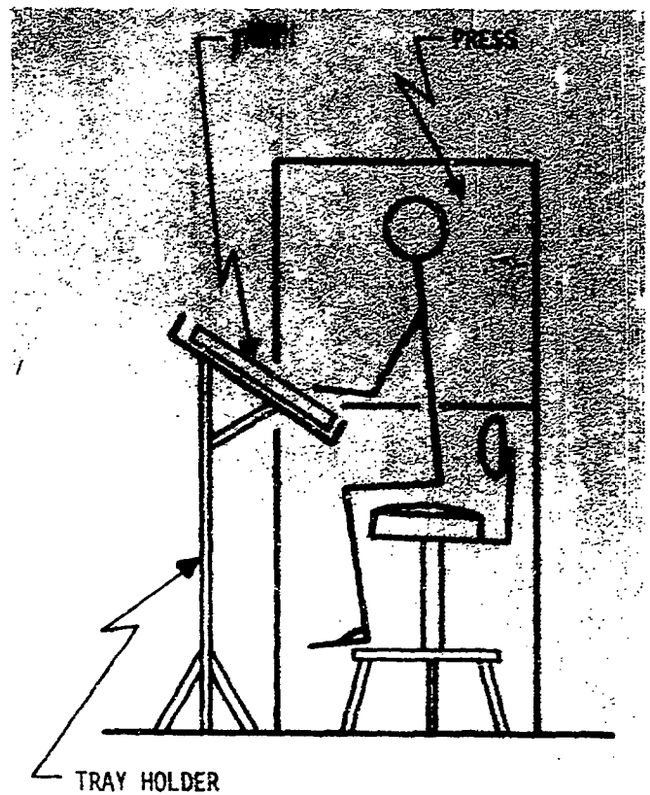

Figure 52. Work Station C-6: Operation of crimping press could be converted into seated position by providing a tray holder. On the photograph, the table occupies knee space.

APPENDIX

HUMAN FACTORS CHECKLIST OF WORK STATIONS

WORK STATION: _____

DATE: _____

HOUR: _____

OBSERVER: _____

ENVIRONMENT:

	INSIDE	OUTSIDE
A. TEMPERATURE		
B. HUMIDITY		
C. NOISE		
D. ILLUMINATION LEVELS		

APPENDIX

HUMAN FACTORS CHECKLIST OF WORK STATIONS

WORK STATION: _____

DATE: _____

HOUR: _____

OBSERVER: _____

ENVIRONMENT:

	INSIDE	OUTSIDE
A. TEMPERATURE		
B. HUMIDITY		
C. NOISE		
D. ILLUMINATION LEVELS		

CHECKLIST FOR PERSONNEL WORK SPACE AND ARRANGEMENT

	YES	NO	N.A.
Overall Workplace Layout			
1. Is the location, size, configuration and accessibility of equipment such that it is operable and maintainable by at least the 5th through the 95th percentile group of the user population including the full range of clothing which they must wear.			
2. Adequate space is provided for each operator in front of the equipment on which he must work.			
3. Each operator can leave his working position and the compartment without disturbing any other operator.			
4. Operators who must communicate directly with each other verbally are located close to each other and can see each other's faces at their operating positions.			
5. Aisle space and access aisles to operating positions are clear to allow for continuous traffic where required.			
6. From their operating positions, supervisors can observe all the personnel under their charge.			
7. Where common displays must be viewed, all of the operators requiring information from them have a clear line of sight from their operating positions.			
8. Emergency equipment is provided in easily accessible locations and clearly marked.			
Equipment Factors -- General			
9. The major display for each operator is mounted perpendicular to his normal line of sight.			
10. Other important displays are mounted as close to perpendicular to the operator's normal line of sight as feasible.			

WORK SPACE (Con't)	YES	NO	N.A.
11. Writing space is provided where tasks involve the use of books, manuals, or forms.			
12. Knee and foot room is provided beneath panel surfaces. Minimum dimensions are 25 inches high, 20 inches wide, and 18 inches deep.			
13. The height of the writing surface above the floor is 29 inches.			
14. Overall equipment height does not exceed 62 inches. If it is desirable for operator's line of sight to extend beyond his equipment, overall height does not exceed 48 inches.			
15. Are controls requiring precise or frequent operation located between 8 and 30 inches above the midpoint of the sitting surface.			
16. Visual displays on vertical panels are mounted in an area no higher than 70 inches and no lower than 40 inches above the standing surface.			
17. Precise-reading indicators and important controls are placed in an area no higher than 64 inches and no lower than 48 inches above the standing surface.			
18. Controls mounted on vertical panels are located in an area no higher than 70 inches and no lower than 30 inches above the standing surface.			
19. Precise controls or controls which are operated frequently are mounted between 40 and 55 inches above the standing surface.			
20. Are work benches and work surfaces used to support jobs, instructions manuals and worksheets provided for standing operators with work surfaces approximately 36 inches above the floor?			
21. Are writing surfaces, if required on equipment consoles, at least 16 inches deep.			

WORK SPACE (Con't)

	YES	NO	N.A.
22. Indented toe space is provided along the bottom front of each rack, at least 4 inches high at the base.			
Seating			
23. The seat itself is at least 16 inches square.			
24. A seat-height adjustment of 19 ± 2 inches (minimum) is provided.			
25. If a high chair is required, a vertically-adjustable foot rest is provided.			
26. The seat is essentially flat under no load.			
27. The seat, back, and arms are padded.			
28. Arms are provided on the seat, which are a minimum of 2 inches wide and 10 inches long.			
29. The seat back makes an angle of 90 to 110 degrees with the seat surface.			
30. The seat back is at least 15 inches square.			
Layout of Panels and Units			
31. Primary controls and displays are placed within the optimal visual and manual spaces on the equipment or unit.			
32. Emergency controls and displays are placed in readily accessible positions with critical emergency controls and displays located in optimal visual and manual areas.			
33. The emergency controls which affect the equipment extensively if operated require at least two distinct motions to operate them. That is, they are guarded or otherwise shielded from inadvertent operation.			
34. Secondary controls and displays are placed within the limiting visual and manual areas.			
35. Set-up, calibration, or test controls and displays are given lowest priority location, placed outside the operator's normal work area, or placed behind access doors.			

WORK SPACE (Cont)	YES	NO	N.A.
36. When displays are used sequentially, they are aligned horizontally from left to right as close to each other as possible.			
37. Every control and display on the panel has a descriptive legend associated with it.			
38. The operator's hand does not block the view of the display when he operates an associated control.			
39. Controls associated with use by the right hand are located below or to the right of their displays, and vice versa for controls operated by the left hand.			
40. There is an adequate separation between controls so that they can be operated easily without inadvertent operation of adjacent controls.			

CHECKLIST FOR MATERIAL HANDLING

	YES	NO	N.A.
Handles			
1. When possible, handles are provided on covers, drawers and components to facilitate handling.			
2. Recessed rather than extended handle fixtures are provided to conserve storage space or to preclude injury by accidental striking of the handles.			
3. When handles cannot be provided, hoist and lift points are clearly marked.			
4. When possible, handles are located over the center of gravity to prevent the object from tipping while being lifted or carried.			
5. Handles are positioned so that they cannot catch on other units, wiring, protrusions, or structural members.			
6. Handles are placed on any component which might be difficult to grasp, remove, or carry or wherever there is a tendency to use fragile components as hand holds.			
7. The following dimensions are minimum for handles to be used by the ungloved hand: a. Weight to be lifted or moved is under 25 lbs: Handle diameter: 1/4 - 1/2 inch Finger clear: 2 inches Handle width: 4 - 1/2 inches			
b. Weight to be lifted or moved is over 25 lbs: Handle diameter: 1/2 - 3/4 inch Finger clear: 2 inches Handle width: 4 - 1/2 inches			
Covers, Cases, and Tool Aids			
8. Hinges are used where possible to reduce the number of fasteners required.			

MATERIAL HANDLING (Con't)	YES	NO	N.A.
9. When a hinged cover is used, a space equal to the swept volume of the cover is provided (e.g., opening of the cover is not obstructed by bulkheads, brackets).			
10. Structural members, other components, do not interfere with removal of a cover.			
11. It is evident when the cover is in place but not secured.			
12. Where feasible, guides, tracks, and stops are provided to facilitate handling and to prevent damage to components.			
13. When possible, the same size and type of fasteners are used.			
14. Where compatible with stress and load considerations, fasteners for mounting components and equipment require at most one complete turn.			
15. If bolts are required, a minimum number of turns are required to tighten or loosen them.			
16. Captive nuts and bolts are used where feasible.			
17. Bolts requiring high torque are provided with hexagonal heads.			
18. Labels are accessible and, where possible, face the operator.			
Lifting and Carrying			
19. Equipment is modularized such that weight of removable components is below 20 pounds whenever possible.			
20. Materials or components to be carried short distances by one man do not exceed the values given in the following table.			
Maximum allowable weight (lbs) / Height lifted from ground (ft) 142 / 1 139 / 2 77 / 3 55 / 4 36 / 5 20 / 6			

MATERIAL HANDLING (Cont)	YES	NO	N.A.
Reaching.			
Smallest allowable openings for one-hand tasks are as follows:			
21. Inserting empty hand held flat: 2 1/2 by 4 1/2 inches.			
22. Smallest square hole through which empty hand can be inserted: 3 1/4 by 3 1/4 inches.			
23. Using 8-inch screwdriver with a 1-inch diameter handle: 4 by 4 inches.			
24. Inserting small box: diameter of the box plus 1 3/4 inches.			
Smallest allowable opening for two-hand tasks are as follows:			
25. Reaching through opening with both hands to depth of 6 to 25 inches: width, three-quarters the depth of reach; height, 4 inches.			
26. Reaching in to full arm length (to shoulders), straight ahead, with both arms: width, 20 inches; height, 4 1/4 inches.			
27. Structural members of the chassis do not prevent access to parts.			
28. Units are located so that blind adjustments are not necessary.			
29. Parts frequently are mounted on roll-out racks, slides, or hinges.			
30. Limit stops are provided on roll-out racks and drawers; override of these limit stops is easily accomplished.			
31. Guide pins or their equivalent are provided for alignment.			
32. Physically similar but non-interchangeable units are so keyed that it is impossible to insert a wrong unit.			
33. Components are laid out so that a minimum of place-to-place movement by the operator is required.			

MATERIAL HANDLING (Con't)	YES	NO	N.A.
34. Components are located and mounted so that access to them may be achieved without danger to personnel (e.g., from electrical charge, heat, sharp edges and points, moving parts, chemical contamination).			
Tools			
35. Variety of tools is held to a minimum.			
36. Metal handles are avoided on tools likely to be used in extreme cold or heat.			
37. Tools are of dull finish to avoid glare in strong light.			
38. Speed and ratchet-type tools are provided when necessary.			
39. Non-sparking tools are provided for use in an explosive atmosphere.			

CHECKLIST FOR SAFETY	YES	NO	N.A.
1. Is the equipment provided with safe handles, lifting rings and/or slings?			
2. Is the weight distribution such that the equipment is safe to handle, move, or position?			
3. Is the equipment designed so that the center of gravity and the configuration of legs and supports makes the equipment unlikely to tip over from unbalance or strong wind?			
4. Are handles recessed rather than extended where they might be hazardous?			
5. Are handles positioned so they cannot catch on other units?			
6. Have sharp or overhanging edges and corners that may cause injury to personnel been eliminated?			
7. Is it evident when a cover is in place but not secured?			
8. Are struts and latches provided to secure hinged and sliding components against accidental movement which could cause injury to personnel?			
9. Are conspicuous warning placards mounted adjacent to very hot/cold equipment?			
10. Do switches or controls which initiate hazardous operations, such as ignition, ovens on, etc., require the prior operation of a related or locking control?			
11. Are warning plates provided where mechanical assemblies, linkages, springs, etc. are under constant strain or load?			
12. Are steps and ladders, and methods of fastening and supporting them, safe?			
13. Do floor surfaces provide adequate non-slip characteristics?			
14. Can air that is used for equipment cooling be completely isolated so as to prevent contamination of air around personnel?			

SAFETY (Con't)	YES	NO	N.A.
15. Do gears, cams, levers, fans and belts have adequate safety covers?			
16. Where test item design includes the use of pressurized systems and components, are safety and/or relief valves, controls, and other safety features provided?			
17. Does equipment design include positive stops, torque limiting devices, safety links, fuze plugs, and/or quick release or disconnect features?			
18. Are provisions made for protection against eye hazards from flying particles?			
19. When glass is used, is it shatterproof?			
20. Are any components mounted such that vision is obstructed?			
21. Are potential mechanical hazards adequately treated in the draft instruction manual?			
22. Are proper tools and test equipment furnished with the test item?			
23. Are face plates and eye pieces shatterproof? Allow full vision, and cause minimal interference to hearing?			
24. Do shoes and boots have rigid safety toe?			
25. Are sole of boots and shoes slip resistant?			
26. Do heavy load items that are man carried have quick release capability for doffing in emergency (attack, falling, etc.)			
27. Is item interface designed so that heavy load can be lifted with operators back held straight?			
28. Are fire and explosion hazards properly safeguarded?			
29. Are dangerous fuels, cleaning fluids, acids, caustics, solvents, and other harmful chemicals properly marked, stored and handled?			
30. Are portable, hand-operated fire extinguishers provided where fire hazards exist or may be created, and are they of the correct type?			

SAFETY (Con't)	YES	NO	N.A.
31. Are fire extinguishers placed where they are readily accessible, but not immediately adjacent to points where fire would probably originate?			
32. Are suitable safeguards provided for detection and elimination of toxic dusts, gases, fumes, and mists?			
33. Are appropriate measures taken to protect personnel from visible and invisible high intensity light sources?			
34. Are properly marked, positioned, and unobstructed fire exits provided?			
35. Are all requirements for protective clothing explicitly noted?			
36. Are all safety limitations in equipment usage clearly defined?			
37. Are warning signs coded and colored?			

CHECKLIST FOR PHYSICAL ENVIRONMENT OF PERSONNEL

	YES	NO	N.A.
Lighting			
1. Adequate general illumination is supplied for movement of personnel without visual hindrance.			
2. Adequate illumination levels are provided on all work surfaces and panels where specific requirements for low level illumination are not present.			
3. Local light units are provided for exacting visual tasks where required, or where general illumination is inadequate.			
4. Luminaires and reflecting surfaces (like scope faces and meter cover glasses) are so arranged in relation to each other that no glare is present at the eye of the operator in his normal operating position.			
5. Work surfaces and panel faces have a non-glare finish.			
6. Panels have illumination of adequate uniformity. There should be no significant light and dark areas.			
Air Conditioning			
7. Temperature is controllable within the range of 65 to 80°F to $\pm$ 2° under ambient temperature conditions. (This range should be lower for operation requiring a great amount of activity by operators).			
8. No large surface has a surface temperature greater than 10°F different from the controlled air temp rature.			
9. Air movement is no noticeable or disturbing in the vicinity of working positions.			
10. Humidity is controlled between 30 and 70%.			
11. Provision is made to control noxious fumes and gases, dusts and odors below perceptible levels, or below levels which are likely to produce some undesirable physiological effects.			

PHYSICAL ENVIRONMENT (Cont)	YES	NO	N.A.
12. An adequate volume per unit time of clean air is provided.			
Noise and Vibration			
13. Vibration is controlled so that personnel task accomplishment is not interfered with.			
14. Maximum integrated noise level.			
15. Where frequent conversation is required between operators, maximum integrated noise level is no more than 70 db.			
16. Where exposure to high noise levels is required, operators are supplied with and required to wear ear protection.			

CHECKLIST FOR DISPLAYS

Information and Signals	YES	NO	N.A.
1. Information presented is necessary for the decisions or actions required of the operator.			
2. Information is presented in the most immediately meaningful form (i.e., no interpretation or decoding is required).			
3. Information is displayed to the accuracy required by the decisions or actions of the operator, and preferably no more accurately than required.			
4. If scale interpolation is required, it does not introduce a probability for operator errors which are greater than the operator's task permits.			
5. Information for different types of activities.			
6. Failure in the unit is clearly shown or the operator is otherwise warned.			
7. Visual signals are of sufficient size, brightness, and duration to be easily and obviously seen.			
8. Duration of visual signal is never less than 0.5 second and, where applicable, the signal lasts until the appropriate response has been made.			
9. When a task is extended in time, a flashing signal is used (rather than a steady one) because of its greater attention-getting value.			
10. Important signals are placed directly in front of the operator or as close to this position as possible.			
11. For flashing signals, the flash rate should be high (at least one cycle per second with the "on" period at 0.5 second).			

DISPLAYS (Con't)

	YES	NO	N.A.
12. Auditory signals are sufficiently different from the prevailing noise background to be easily and obviously heard.			
13. Auditory signal duration is at least 0.5 second and, where applicable, the signal lasts until the appropriate response has been made.			
General Design			
14. The display can be read easily from the expected or normal locations of all operators who require the information.			
15. Company trade names or other markings irrelevant to the display (e.g., patent numbers) do not appear on the display in a manner that is distracting.			
16. When the operator must monitor and/or perform a sequence of operations, the displays are arranged in the actual order of events.			
17. When no definite sequence of operations determines the order of events, the displays are grouped by function.			
18. The relationship between the display and its associated controls is unmistakable in terms of:			
a. The proper control to use.			
b. The direction of movement of the control.			
c. The rate and limits of movement of the control.			
19. The display is designed to minimize the problem of parallax within the normal visual axis of the operator.			

DISPLAYS (Con't)	YES	NO	N.A.
20. Are emergency controls and displays placed in readily accessible positions within 30 degrees of the operator's normal line of sight?			
21. Are emergency controls and displays located in the optimum areas in preference to primary controls and displays, when the nature of an emergency is so critical that emergency controls and displays should be given top priority in location?			
22. Are secondary controls and displays (less important than primary ones but used periodically during normal operations) placed within the optimum areas? Is their exact location determined primarily by association and proper grouping?			
Illumination			
23. Contrast between pointers, markings, and characters and the background under all expected conditions of illumination is adequate for ready reading.			
24. If the instrument has a movable pointer, the pointer is well illuminated at all positions.			
25. Brightness is uniform over the display face.			
26. Glare does not interfere with the interpretation of the display regardless of the display location in the work area.			
Coding			
27. Zone markings are employed as necessary to indicate the various zones of operating conditions (e.g., desirable operating range, danger-lower limit, danger-upper limit, caution, undesirable-inefficient).			
28. Color coding is generally as follows: red requires immediate action, yellow, caution and monitor green, proceed normally; white, combine information to determine required action; blue, command to take action.			

DISPLAYS (Con't)	YES	NO	N.A.
29. Indicator lights used for the most critical conditions are significantly different from the other indicator lights (i.e., in color, brightness, or size).			
Legends			
30. All letters are capitalized except for extended copy which is in capitals and lower case letters.			
31. All numbers are Arabic except for special identification.			
32. The use and symbols is avoided, but, if symbols are used, they are common meaningful ones.			
33. Letters, numbers or other symbols are a minimum of 1/8 inch high.			
34. Indicators are labeled according to function.			
35. Legends are uniform and standardized for ease of recognition (i.e., when indicators serving the same function appear in different places, all are labeled in the same manner).			
36. Legends are brief, but no so brief as to be ambiguous.			
37. If abbreviations are used, they conform to common usage.			
38. Legends are permanently affixed by either etching or embossing, or, if surface legends must be used, decals with a protective coating or embossed metal identification "metalcals" are used.			
39. Legends are not obscured by parts, components, moisture proofing covers.			
40. The legend is placed on, or sufficiently close to, the display (preferably above the display) which it identifies so that there is no ambiguity concerning the relationship.			

DISPLAYS (Con't)

	YES	NO	N.A.
41. Legends consist of black characters on a light background, except for black-lighted panels where illuminated characters on a dark background are used.			
Dials, Gauges, and Meters			
42. Changes in indication are easy to detect both in magnitude and direction.			
43. The relationship between a dial and other dials in its associated panel grouping is similar in terms of:			
a. Scale breakdown and numerical progression.			
b. Values on all dials increase in the same direction.			
c. Under normal operating conditions, all pointers are in the same relative position.			
44. The scale numbers increase in a regular and obvious sequence.			
45. The scale graduation interval (distance between graduation marks) is approximately equal to the degree of accuracy required in reading the indicator.			
46. All major scale divisions are numbered.			
47. The pointer extends to, but does not cover, scale graduation marks.			
48. If possible, numerals appear on the opposite side of the graduation marks from the pointer so that the pointer does not cover them in reading.			
49. The dial face is designed as simply as possible and only information which is usable by the operator appears on the display (i.e., manufacturer's name, does not appear).			

DISPLAYS (con't)

	YES	NO	N.A.
50. The circular scale numbers increase in a clockwise direction (i.e., clockwise pointer movement indicates an increase in magnitude).			
51. The pointer moves clockwise as a result of moving an associated lever on switch clockwise, upward, forward, or to the right.			
52. The circular scale zero is located near the bottom of the dial except when zero calibration or check reading is required.			
53. Except on multirevolution instruments, there is a scale break of at least 1-1/2 major divisions at the end of the scale.			
54. Numerals arranged so that they are upright in all positions.			

CHECKLIST FOR CONTROLS

General	YES	NO	N.A.
1. The control requires as few movements as possible.			
2. Successive control movements are interrelated (i.e., one movement passes easily into the next).			
3. Controls used in rapid sequence have uniform direction of motion.			
4. Control movements are consistent for all equipments which one operator uses.			
5. Are discrete-adjustment type (detent) controls used when performance requirements are such that the controlled object can be adjusted in a limited number of discrete steps?			
6. Are continuous adjustment type controls used when precise adjustments are needed along a continuum, or when a large number of settings (usually more than 24) is required?			
7. Are controls oriented to fit normal habit-pattern reflexes; e. g., does a clockwise movement of the control produce a clockwise motion to its visual display?			
8. Are controls shape coded, where possible, to improve visual and tactile identification, by the use of standardized shapes and, when feasible, functional shapes which suggest the purpose of the controls?			
9. Control movement to produce any increase in magnitude, including switching "on" is as follows:			
a. For linear controls: movement forward (i.e., away from the operator), upward or to the right; and for overhead linear controls: movement to the right.			

CONTROLS (Con't)

	YES	NO	N.A.
b. For rotary controls: movement clockwise.			
10. The control is physically designed to stand abuse, even for unexpected direction of movement (e.g., energy or panic response).			
11. Positive indication is provided that the activation of a control has resulted in equipment response.			
Location			
12. If the operator's tasks are complex, the controls are distributed so that no one limb is overburdened.			
13. Controls requiring rapid, precise settings are assigned to the hands.			
14. Controls requiring large amounts of continuous forward application of force are assigned to the feet.			
Grouping			
15. Similar controls are grouped.			
16. Relationship between the control and other controls in its associated panel group arrangement is unmistakable in terms of:			
a. All controls progress in the same direction.			
b. All control pointers are in the same relative position under normal operating conditions.			
c. Associated controls are grouped and additionally related by marked outlines if necessary.			
Coding			
17. All primary and emergency controls are easily identifiable both visually and non-visually.			

CONTROLS (Con't)	YES	NO	N.A.
18. Qualitative codes are used to code qualitative information (i.e., geometric shapes or colors).			
19. Quantitative codes are used to code quantitative information (i.e., size, brightness, length).			
Location Coding			
20. The most important and most frequently used controls are located in front of the operator in the optimum manual areas as follows:			
a. Located within comfortable reach, or			
b. Between elbow and shoulder height for hand controls.			
c. Emergency controls are quickly identified and located for maximum speed of operation.			
21. Are warning lights an integral part of, or located adjacent to, the lever, switch, or other control device by which the operator is to take action?			
Shape Coding			
22. Shapes can be discerned both visually and tactually.			
23. If the coded control presents sharp edges, a clean grasp area is provided.			
Size Coding			
24. If the operator cannot compare the sizes of all controls before selecting the proper one, only two or three different sized controls are used in any one group.			
25. Controls of the same size are used for performing similar functions.			

CONTROLS (Con't)

	YES	NO	N.A.
Color Coding			
26. Color coding is used only in white-lighted areas.			
27. Control color provides ample contrast with the background.			
Push Buttons			
Size			
28. Button size is at least 1/2 inch diameter.			
29. For the special case of thumb or heel of hand operation, the button size is at least 3/4 inch diameter.			
Spacing			
30. Spacing between edges of adjacent push button controls designed for fingertip operation (e.g., on keyboards, keysets, special purpose matrices) is at least 1/4 inch.			
31. For the special case of thumb or heel or hand operated push button, spacing between edges of adjacent controls is at least 2 inches.			
32. Push button shape is either concave inward to fit the finger or the surface is provided with a high degree of frictional resistance to prevent slipping.			
33. Unless design is such that operation of one push button will automatically activate other push buttons, there is little likelihood of accidental activation of more than one push button at a time in a group.			
34. If accidental activation of a push button will cause a critical situation the push button is well guarded by a channel or cover guard, or is recessed.			
35. Push button controls are arranged in a horizontal array rather than a vertical array whenever possible.			

CONTROLS (Con't)

	YES	NO	N.A.
36. Spacing between adjacent edges of toggle levers mounted in a row is at least 3/4 inch.			
37. The displacement of toggle lever is sufficient for visual and tactual discrimination in its particular application.			
38. For two-position switch, centerline displacement between on-off mode is at least 60 degrees.			
39. For three-position switch, centerline displacement between adjacent positions is at least 40 degrees from center.			
40. If mounted horizontally, it is so only to be consistent with orientation of the controlled function and movement forward or to the right corresponds to "on", or "increase", while motion rearward or to the left corresponds to "off", "stop", or "decrease".			
41. Rows of toggle switches are mounted in a horizontal (rather than vertical) array to prevent inadvertent activation of the wrong switch.			
42. Critical toggle switches are provided with a locking device or control guard cover so that at least two discrete operator movements are required to activate the control.			
Rotary Selector Switches			
Size			
43. For circular control, the knob diameter is from 1 to 4 inches.			
44. Pointer or knob grasp depth is at least 1/2 inch (but not more than 3 inches).			
45. Displacement between adjacent detents is at least 15 degrees or 1/4 inch, whichever is greater (i.e., for 15-degree displacement, index marks are arranged on at least a 1 3/4 inch diameter).			

CONTROLS (Con't)

	YES	NO	N.A.
46. Maximum displacement between detents is 45 degrees except where contrast size or power requirements necessitate wider spacing, in which case up to 90 degrees is acceptable.			
General			
47. The selector switch has a fixed scale with a moving pointer.			
48. The knob pointer is close to the scale index mark to minimize parallax.			
49. All knobs are black except in red-lighted areas where all knobs are gray.			
50. Pointer and index marks and characters have sufficient contrast with their backgrounds to be readily visible under all expected conditions of illumination.			
51. Where several knobs of similar appearance are grouped, control discriminability is optimized by increased physical separation, control coding, or the insertion of dissimilar controls between them.			
52. The grasp area on the control knob is provided with a rough surface finish to prevent slipping.			
53. Detents are provided at each control setting.			
54. Where a selector switch has more than 4 positions and multiturn operation is not required, start and end stops are provided (i.e., two positions in addition to the number of active mode settings).			
Knobs			
55. For fingertip grasp, knob dimensions are as follows:			
a. Knob diameter is minimum 3/8 inch, maximum 4 inches.			

	YES	NO	N.A.
b. Knob depth or grasp area is minimum 1/2 inch, maximum 1 inch.			
56. For palm grasp (or door knob type knob) dimensions are as follows: knob diameter is minimum 1 1/2 inches, maximum 3 inches.			
57. If a pointer or index mark is used on the continuous control, it is close to the scale index mark to minimize parallax.			
58. Index numbers are not obscured when hand is on the control knob.			
59. All knobs are black, except in red-lighted areas where all knobs are gray.			
60. Pointer and index marks and characters have sufficient contrast with their backgrounds to be readily visible under all expected conditions of illumination.			
61. The grasp area on the control knob is provided with a rough surface finish to prevent slipping (knobs over 1 inch diameter are serrated).			
Cranks			
62. Crank radius for light load and high rate (up to 275 rpm) is not optimum consistent with performance requirements and within the followiny recommended radius values: minimum 1/2 inch, maximum 4 1/2 inches.			
63. Crank radius for heavy loads is optimum consistent with performance requirements as follows:			
a. For under 175 rpm rate and heavy load radius is within the following recommended values: minimum 5 inches, maximum 8 inches.			
b. For extra heavy loads, maximum radius is 20 inches.			
64. Spacing between the outside edge of the crank handle and any other obstruction is at least 3 inches.			

CONTROLS (Con't)	YES	NO	N.A.
65. The crank is used for tasks requiring at least two rotations of control movement.			
66. For tasks involving large slewing movements plus small fine adjustments (less than 1/2 rotation) the crank is mounted on a knob.			
Handwheels			
67. Cross-sectional diameter of handwheel rim is at least 3/4 inch but not greater than 2 inches.			
68. Indentations are built into the rim to aid in holding it.			
69. Handwheel is located so that there is at least 3 inches between the outer edge and the nearest obstruction.			
Levers (Under 6 Inches)			
70. For fingertip grasp, knob diameter is between 1/2 inch and 1 inch.			
71. The lever does not protrude from the panel surface more than 6 inches.			
72. For one hand, random operation of a lever, at least 2 inches separation between the outer edge of the lever at maximum displacement and any obstruction is maintained.			
73. For two hands, simultaneously operating adjacent levers, at least 3 inches separation is maintained.			
74. For discrete position lever controls, either a locking slot or a detent is provided at each control position.			
75. Operator performance is not hampered by excessive control resistance.			
76. Support is provided for the body part being used in making fine adjustments with small lever type controls as follows:			

	YES	NO	N.A.
a. For finger movements, the wrist is supported.			
b. For small hand movements, the forearm is supported.			
c. For large hand movements, the elbow is supported.			
Foot Controls			
77. For foot activated push button, the effective button diameter is at least 1/2 inch.			
78. For control using a pedal, pedal size is at least 1 by 4 inches.			
79. For operator expected to wear normal or light footwear, displacement is at least 1/4 inch.			
80. For operator expected to wear heavy footwear, displacement is at least 1 inch.			
81. For control operated by ankle flexing only, maximum displacement is 2 1/2 inches.			
82. For control operated by leg movement, maximum displacement is 4 inches for push button and 7 inches for pedal.			
83. When foot does not rest on the control, resistance is at least 4 pounds.			
84. When foot may rest on the control, resistance is at least 10 pounds.			
85. For normal operation with foot resting or not resting on control, maximum resistance is under 20 pounds.			
86. Foot push button or pedal will return to the null position when force is removed.			

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