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CHECKLIST OF GOOD CONTAMINATION CONTROL PRACTICES FROM A MANUFACTURING VIEWPOINT

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ABSTRACT

Contamination control problems continue to plague manufacturing facilities engaged in the production of high-reliability precision components and assemblies. While the designer bears some responsibility for these problems, many of the problems can be attributed to poorly planned and executed manufacturing practices. This paper highlights good contamination control practices in nine critical manufacturing areas. The checklists, based on years of trouble-shooting experience, contain 131 recommendations that have proven effective in minimizing contamination problems.

KEY WORDS: Contamination control, recommended practices, trouble-shooting checklists, manufacturing viewpoint.

*The major portion of this work was performed while the author was in Contamination Control and Process Acceptance Division (5425).

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CHECKLIST OF GOOD CONTAMINATION CONTROL PRACTICES FROM A MANUFACTURING VIEWPOINT

I. Introduction

The contamination control program at a given manufacturing or assembly plant is almost always less effective than required or desired. There are a number of reasons for this condition, some of which are the following:

- Inadequate product design
- Inability to measure cleanliness
- Poor choice of processing operations
- Fixturing and tooling deficiencies
- Inadequate operator training

Inadequate product design from a contamination prevention viewpoint has been covered in previous reports.[1, 2, 3] Therefore, this document will concentrate on production conditions that experience has shown can greatly degrade a contamination control program. One of the above deficiencies of special interest is our inability to reliably measure total part cleanliness. Not only does adequate equipment or instrumentation not exist, but, to the best of our knowledge, no sound approach to cleanliness assessment exists even from a theoretical viewpoint. So, for the purpose of this paper, we must forget about direct methods of measuring what we are most interested in, namely, the relative cleanliness of piece parts and assemblies.

It is important that we have a common understanding of what is meant by "clean." Our first thought might be that clean means "free from contaminants," but this definition involves another word with some ambiguity - "contaminants." Someone has defined a contaminant as being anything on the part that is not called out on the drawing. If we accept this definition, then a clean part (free of contaminants) is indeed a rarity. However, as used in this paper, clean is defined as "sufficiently low in amounts of contaminants on the part surfaces to assure that the product will function per the design intent for the expected life of the product." Our products will never be absolutely clean, but they must be clean enough so that their function will not be impaired.

Since we will not be able to measure part/product cleanliness, and, yet, our product must be cleaned to a degree that is more or less undefined, the question arises: How can we be sure that our products are cleaned sufficiently? One answer is to use an empirical approach by following practices and guidelines that have resulted from years of contamination control experience.[4, 5] The remaining sections of this paper will consist of checklists in the form of recommended manufacturing procedures or good practices that have proved useful in establishing and monitoring some of the critical handling, cleaning, and assembly steps in a production facility. These guidelines cover the following nine major areas of concern from a contamination control viewpoint.

A. Clean room and clean bench operations
B. Ultrasonic cleaning
C. Vacuum bakeout
D. Solvent spraying
E. Vapor degreasing
F. Abrasive spray cleaning
G. Combination vapor degreasers and ultrasonic cleaners
H. Storage of cleaned parts
I. Personnel selection and training

The checklists or guidelines have been designed as positive statements or recommendations. Reasons for the 131 specific recommendations are also included. The checklist can be used to verify that the current procedures at your facility are in accordance with the recommended practices.

II. Contamination Control Checklists

A. CLEAN ROOM AND CLEAN BENCH OPERATIONS[6]

	Recommended Procedure	Reason
1.	All personnel wear proper protective clothing, i.e., smocks and hair coverings, while in the clean room.	This lessens the shedding of body and/or street clothes particles which may impact on the surfaces of parts.
2.	Clean the floor of the room regularly.	This precludes the buildup of particles on the floor which could be stirred up by normal room activity and settle on the surfaces of parts.
3.	Maintain personnel activity in the clean room at a normal pace.	Abnormally fast movements of personnel do have a tendency to stir up previously settled-out dust particles and also increase the shedding of particulates from the body and clothing.
4.	Encourage personnel to refrain from wearing excessive face powder, rouge, fingernail polish, or any other cosmetics.	These cosmetics do flake off in the form of particles which could settle on the parts surfaces.
5.	Prohibit smoking in the clean room at all times.	Tobacco smoke is made up of many particles--thus, smoking is a super generator of particles.
6.	Forbid unauthorized personnel from being in the vicinity of critical areas (absolute filter and laminar flow clean benches) at all times.	People are sources of contamination; if unauthorized personnel are kept away from the operation, the chance of parts becoming contaminated is lessened.
7.	Exclude personnel that perspire excessively, that have excessive flaking of skin surfaces from employment in critical areas.	The less shedding, the less the chance of the parts becoming contaminated.
8.	Exclude sulphur-containing materials, such as rubber goods of	The amount of these materials in the clean room should be maintained at

A. CLEAN ROOM AND CLEAN BENCH OPERATIONS

	Recommended Procedure	Reason
8.	any kind, horsehair, masking tape, pencils, paper, rags, etc., from the clean bench work area.	the lowest possible level; they should never be allowed in the clean bench work area since they possess a high potential for contamination of parts.
9.	Require personnel who are either working on or inspecting parts in the clean benches to wear approved PVC (polyvinyl chloride) gloves or finger-cots while performing these operations or inspections.	This prevents the shedding of skin flakes and hair from the hands and fingers onto the parts, and prevents fingerprints (one of the most difficult contaminants to remove because of chemical complexity) from getting on the parts.
10.	Put on clean gloves whenever the gloved hands are withdrawn from the clean-bench dust-controlled area. In certain cases, such as moving piece parts into the clean air area, gloved hands may be withdrawn and reinserted without changing gloves; however, gloves must be changed prior to starting the next operation. When gloves are removed in the final assembly area for any reason, they must be replaced with clean gloves. Try to prevent a person from scratching himself. Much of the time this is an unconscious act and sometimes may be a habit. Nevertheless, this is one of the more prevalent malpractices observed over the years and perhaps one of the most difficult to prevent.	When the gloved hands are withdrawn from the clean air area, or a person scratches himself, there is a very good possibility that the gloves will become contaminated to some degree before they are put back into the area.

A. CLEAN ROOM AND CLEAN BENCH OPERATIONS

	Recommended Procedure	Reason
11.	Wipe the clean bench work surfaces clean at the start of the shift and after any operation that could leave abnormal amounts of particulates on the bench work surfaces.	When the benches are turned off at night, some particles do settle on the work surfaces, also settle out even while running. Some of these settled-out particles have a very good chance of being transferred later to parts being worked on.
12.	At the beginning of each day, or more frequently when necessary, ultra-sonically clean in isopropyl alcohol all adjusting tools and handling equipment utilized in clean benches.	Since these tools and handling equipment do come in contact with the product's surfaces, it is imperative that they be kept clean. Direct transfer of any contaminants on these tools to the product surface is very likely to occur.
13.	Require production and inspection personnel working on or inspecting the product or its piece parts in a clean bench to keep the product directly exposed to the HEPA filter face, whenever this is possible. In other words, keep the product up-stream (air flow-wise) from the hands, equipment, etc.	We can never be sure that the gloves, clothing, and equipment are absolutely free of particulates which may shed and ultimately end up on the part.
14.	Place equipment on the clean bench so that a minimum of air turbulence results and the item does not block the clean air emitting from the filter face. It is realized that the nature of some operations, especially a welding, may make it virtually impossible to locate the equipment ideally.	

A. CLEAN ROOM AND CLEAN BENCH OPERATIONS

	Recommended Procedure	Reason
15.	In cases where the nature of the operation makes it necessary to have equipment, tools, or portions of the body upstream from the product, exert extreme care to maintain cleanliness of the upstream surface.	This precludes particles from shedding on the surface of the product.
16.	Keep clean parts, subassemblies, and/or assemblies that are on the clean bench surface but not being processed in covered glass containers.	This precludes their becoming contaminated by particles generated by the work being performed at the bench (generation of particles is unfortunately one of the easiest operations known; almost any work or activity generates particles). It also lessens the possibility of someone picking up one of these parts with his bare fingers. The fact that parts are in a covered glass container, not only protects the parts, but also serves to signify that these parts are clean and care should be taken not to contaminate them.
17.	Exclude operations that would generate considerable amounts of vapors.	These gas molecules are less than 0.01 micron in diameter and are not filtered out by the HEPA filters in the clean bench. They may or may not be degrading to the product depending on the type of vapors and the material in the product. However, in order to be on the safe side, do not permit operations, such as large-scale soldering operations with resin flux,

A. CLEAN ROOM AND CLEAN BENCH OPERATIONS

	Recommended Procedure	Reason
17.		which would generate great amounts of fumes or vapors.
18.	Exclude vacuum pumps, vacuum cleaners, and air compressors.	Almost all air-pumping devices are generators of particles, and, therefore, are undesirable in clean rooms
19.	Discourage storage atop the clean bench. This does not refer to the work surface top but rather to the topmost part (above the bench lights).	Particles will settle on the surface of stored objects, and it often happens that a stored object is brought into the bench work area and some new particles are likely to end upon the surface of the product.
20.	Establish and follow a schedule for change of prefilters in the clean benches.	This keeps these prefilters from becoming overloaded and causing either an undue load on the blower motor or a reduced flow of air through the absolute filter, or both.
21.	Make periodic measurements of the air velocity coming from the HEPA filters in the clean benches. These measurements are made with a velometer. The velocity should be 90 to 100 feet per minute (FPM) with 70 FPM as an action point.	When the air flow velocity is low, the cause is usually one of or a combination of the following: clogged prefilter, defective blower motor assembly, clogged HEPA filter, or plenum leakage. (The plenum is the enclosed space behind the HEPA filter which under operating conditions is at a higher pressure than the room it occupies.)
22.	Insure that clean room/clean bench production and inspection personnel are briefed regarding the fragility of the HEPA filters.	The media in the filters are made of asbestos and fiber glass. No sharply pointed objects, or any other objects, should be permitted to contact the HEPA

A. CLEAN ROOM AND CLEAN BENCH OPERATIONS

	Recommended Procedure	Reason
22.		filter; holes made in the filter will lesson the efficiency of the filters.
23.	Leak-test the clean benches after relocation if questionable handling was involved.	Handling such as shipping, building-to-building transfer, or severe handling in relocating within the same building may cause leaks in the HEPA filter or gasket seal. Therefore, the bench must be tested and repaired if required.

B. ULTRASONIC CLEANING

	Recommended Procedure	Reason
1.	Perform ultrasonic cleaning in a vented hood or recirculating work bench of the absolute filter or sterishield type.	This is to prevent the escape of solvent into the work area while allowing only clean air to come into contact with the parts following cleaning.
2.	Require the ultrasonic cleaners to have a minimum power density of 3.0 watts per square inch.	This level or greater of power density is required to assure sufficient cavitation to adequately clean the parts in the specified time.
3.	Maintain the coupling fluid in the ultrasonic cleaners at the proper level. The proper level should be to the bottom of the overflow opening in the tank when the beakers are inserted (provided there is an overflow opening in the tank). If there is no overflow opening in the tank, then the proper level is 3/4 to 1 inch below the top of the tank when the beakers are inserted.	This level of coupling fluid as compared to lesser amounts is to provide an optimum load for transfer of ultrasonic energy from transducer through tank bottom, coupling fluid, and beaker bottom to the parts being ultrasonically cleaned.
4.	Require the coupling fluid to contain approximately 1/4 cc of liquid detergent to each liter of water.	The reason for adding this liquid detergent is to lower the surface tension of the water and cause it to cavitate more freely.
5.	Keep the liquid level of the solvent in the beaker equal to or slightly below the level of the coupling fluid.	Experience has shown that this results in a greater amount of ultrasonic energy in the beaker because the liquid levels are balanced.
6.	Require the cleaning containers (beakers) to be made from either glass or stainless steel.	There are several good reasons for specifying either glass or stainless steel. These materials will not be attacked by the solvents used in the

B. ULTRASONIC CLEANING

	Recommended Procedure	Reason
6.		cleaning operations, thus reducing the possibility of the solvent becoming contaminated by its container. They are capable of being cleaned to a degree that the probability of surface contaminants on the interior surfaces of these containers contaminating the solvent is almost nil. The hardness of the glass and stainless steel keeps the absorption of the ultrasonic energy quite low.
7.	Use holding fixtures to support the beakers in the ultrasonic cleaning tank.	Setting beakers on the bottom of the tank, as compared to supporting them in a fixture, is undesirable for at least three reasons. It is impossible to set them on the bottom of the tank if the proper level of water is maintained per item 3 of this section. It is impossible to achieve optimum efficiency of the ultrasonic cleaner with beakers set on the bottom since the distance is not great enough for the area of greatest cavitation to occur in the beaker solvent where it is needed. Setting a beaker or any other object with any appreciable mass on the bottom of the ultrasonic cleaning tank distorts and greatly attenuates the ultrasonic signal.
8.	Keep the cleaning containers (beakers) when placed in the ultrasonic cleaning tank at least	Because of the wavelengths of the ultrasonic energy, this 1 1/2-inch distance is the minimum of coupling fluid depth

B. ULTRASONIC CLEANING

	Recommended Procedure	Reason
8.	1 1/2 inches from the bottom of the tank to the bottom of the beaker and not touching the sides of the tank.	required to achieve optimum transfer of energy into the actual cleaning container. All ultrasonic cleaning systems show a decay or decrease of cavitation intensity as measured from the center of the tank to the inside wall of the tank.
9.	Use simple, lightweight fixtures whenever possible to suspend the parts in the beaker.	Fixtures negate the attenuation effect that is caused when parts are placed on the beaker bottom and provide both an easier way of inserting and removing the parts from the solvent and an efficient drainage of solvents. Fixtures or baskets offer a convenient handling facility for the dry nitrogen blow-off which usually follows immersion in solvents.
10.	Limit the number of parts per cleaning container to one layer.	From prior discussions of attenuation of energies and the effects thereof, the reason is quite clear for the one-layer limitation. The upper layers of parts will not be cleaned as thoroughly as the bottom layer.
11.	Keep the parts being cleaned completely covered with at least 3/4 inch and preferably 1 inch of the specified solvent during ultrasonic cleaning.	There are two reasons for this requirement. The scrubbing action of the ultrasonic cleaner sharply decreases in the uppermost portion of the solvent. This extra amount of solvent provides greater dilution of the contaminants removed.

B. ULTRASONIC CLEANING

Recommended Procedure	Reason
12. Keep the volume of the parts being cleaned less than one-fifth of the volume of the solvent being used.	A certain minimum amount of solvent is needed to achieve optimum cavitation and adequately disperse the contaminants removed. Remember that contaminants are being removed from the part surfaces and when the part is removed from the solvent, some solvent and some contaminants are still on it.
13. Properly orient the products or parts being cleaned.	In cleaning subassemblies or assemblies containing more than one large plane surface, the large plane surfaces should be oriented vertically. With subassemblies, or assemblies containing only one large plane surface, the most critical surface (contamination-wise) can be placed downward so that it receives the maximum available energy. Parts or subassemblies may touch each other, but care must be exercised that overlapping and shielding do not occur.
14. Require that cavitation be occurring when parts are added to and removed from the cleaning solution.	There is less possibility that air bubbles will be entrapped in crevices and blind holes than when there is no cavitation occurring. A more effective rinsing action is obtained and fewer particles are left on the part surface than would be otherwise.
15. Minimize the possibility of the cleaning solvents being mixed when beakers containing different solvents are mounted in the same ultrasonic cleaner.	This practice lessens the possibility of different solvents becoming mixed by drippage from parts and fixtures. Where smaller amounts of cleaning are done, a cleaner for each solvent

B. ULTRASONIC CLEANING

	Recommended Procedure	Reaso:
15.		is not economically feasible. Extra precautionary measures are required in this type of operation to keep the solvents from being mixed or an improper sequence from being used.
16.	Degas the ultrasonic cleaner prior to the start of each cleaning day and whenever the coupling water is changed.	The water contains a certain amount of air and this air in the water causes undue attenuation.
17.	Rinse the beakers with approximately 10% of beaker volume of the cleaning solvent to be used immediately before using the beaker.	This will remove almost all of the soluble contaminants and a large percentage of the insoluble contaminants that may be on the inside of the "clean" beaker. Extreme care should be exercised that beakers in which one type of cleaning solvent has been used shall not be used for a different type of cleaning solvent before all residue of the first cleaning solvent has been removed.
18.	Change the solvents in the beakers after each load of parts has been cleaned.	You cannot clean a part in contaminated solvent, and after a load of parts has been cleaned in solvent, that volume of solvent is not clean.
19.	Monitor the ultrasonic cleaners for cavitation intensity. The cleaning specifications define how and when this monitoring shall be performed.	Cavitation is the actual cleaning mechanism of ultrasonic cleaners. This specified monitoring test should be performed at least once a week and any other time that the function ability of the ultrasonic cleaner is in doubt.

B. ULTRASONIC CLEANING

	Recommended Procedure	Reason
20.	Insure that the time of insonation conforms to the callout in the cleaning specifications.	These times of insonation must conform in order for the final product to be sufficiently cleaned to function properly. Any deviation from the specified times can only lead to problems with the final product.
21.	Insure that the cleaning containers are being properly cleaned.	Previous statements referred to the slosh rinsing of the beakers; here we are referring to the actual cleaning of the beakers. The procedure for cleaning these beakers should be given in the cleaning specifications.
22.	Use clean solvents in the parts cleaning operations.	There should be references in the cleaning specifications as to what quality or grade of solvents shall be used.
23.	Perform the dry nitrogen blow-off when specified and by the proper technique.	The nitrogen blow-off removes large amounts, relatively speaking, of the solvent that is left on the parts when they are withdrawn from the solvent. If the solvent were permitted to dry on the part, entrapped contaminants would remain on the parts. Be sure that the less exposed surfaces are included in the blow-off of the solvent from the parts and also that the solvent is really blown off the part, not just relocated to some other surface on the part.

C. VACUUM BAKEOUT

	Recommended Procedure	Reason
1.	Require that the vacuum oven have a maximum temperature rating of at least 225°F ± 10°F.	This assures that the oven is capable of delivering the thermal energies required for the vacuum bakeout operation. The tolerance includes temperature differences within areas of the oven and the temperature controller operating range.
2.	Assure that the oven design is such that it is sufficiently vacuum-tight to maintain a pressure of 2 inches of mercury absolute pressure or less, using a modest pumping system.	The intent here is to be sure that the oven has the capability (vacuum-wise) of doing the vacuum bakeout job required of it.
3.	Locate the vacuum ovens reasonably close to the cleaning facilities.	The main reason for this is for convenience and to minimize contamination possibilities during a lengthy transfer.
4.	Locate the vacuum pumps outside of the clean assembly area.	The output of these pumps contains may contaminants, none of which is desirable in the clean assembly area.
5.	In addition to proper valving sequence, use a cold trap or filter to avoid contamination of clean parts by back-streaming pump oil vapors.	After all the effort to get the parts clean, we do not want to dump a load of contaminants on them and the clean interior of the oven by improper valving sequence or absence of a cold trap.
6.	Keep the ovens clean.	The principal function of the vacuum bakeout is the removal of trace amounts of solvents. Therefore, the oven should be kept clean so as not to

C. VACUUM BAKEOUT

	Recommended Procedure	Reason
6.		deposit any contaminants. It should be wiped out with isopropyl alcohol once each week or whenever it may inadvertently become contaminated.
7.	Limit the use of the vacuum oven to the vacuum bakeout operation.	If the oven is used for functions other than the vacuum bakeout it will most probably become contaminated.
8.	Assure that the vacuum seals are free from nicks, cracks, mars, and dirt accumulation.	Obviously, any of these defects can cause leaks; hence, the functional integrity of the seals must be preserved.
9.	Assure that the elastomer seals are free from adherence to their mating surfaces.	Adherence of these seals can only lead to trouble in the form of leaking ovens.
10.	Load the oven properly.	A vacuum bakeout oven can be either underloaded or overloaded. The function of the oven is not impaired because of underloading, but over-loading the ovens can lessen the effectiveness of the vacuum bakeout operation. Parts should not be stacked in a manner that surfaces of different parts overlap surfaces of other parts in a contacting fashion. Leave air gaps so that the trace amounts of solvents may escape.
11.	Assure that the time, temperature, and vacuum pressure conform to the cleaning specifications.	In order for the trace amounts of solvents to be removed to the degree that is required, the parts must be

C. VACUUM BAKEOUT

	Recommended Procedure	Reason
11.		vacuum-baked at the temperature, under the vacuum, and for the time specified.
12.	Require the vacuum pump to run continuously during the final 15 minutes of the vacuum bakeout operation.	It is not enough to remove the contaminants from the parts - they must be removed from the oven so that they are not redeposited on the parts when vacuum is released and the door is opened.
13.	Prior to their use, thoroughly clean the trays on which the parts are placed for the vacuum bakeout operation.	If the parts are placed in an unclean tray, they will become contaminated by contact. Also, there may be contaminants on the tray that will volatilize at a temperature near that of the oven.
14.	Cover the trays before removing them from the oven and place them in a laminar-flow clean bench to cool.	The trays with the parts should be covered to preclude particulates from getting on the parts during the transfer to the clean bench. The justification for a clean bench is to have the air that flows to the part surfaces as clean as possible as cooling occurs.
15.	Backfill the ovens with either nitrogen or filtered air upon completion of bakeout.	The same reasoning as given in the previous paragraph is applicable here. We do not want to dump dirty air on the clean parts.

D. SOLVENT SPRAYING

	Recommended Procedure	Reason
1.	Keep the reservoirs, lines, and nozzles clean.	These must be kept clean so they do not contaminate the solvent being sprayed on the parts. The materials of construction must not be attacked by the solvent and the reservoirs, lines, and nozzles must not be left vented to ambient air for extended periods of time.
2.	Use clean solvent for the spray.	Unclean solvent not only contaminates the parts being sprayed but also contaminates the reservoir, lines, and nozzle. Previous remarks concerning purity of solvents also apply here.
3.	Assure that the pressure of the spray, the nozzle-to-part distance, and time duration of spraying are maintained constant from part to part.	After a satisfactory spray procedure is derived, subsequent spray operations on like parts should be controlled to yield more consistent spray cleaning.
4.	Keep the spray area free of settled-out particulates and relatively free of suspended (airborne) particulates.	You do not want to stir up a group of particles and either impact them or have them settle out on the part.
5.	Use properly designed fixtures to hold the part or assembly while in the spray cleaning operation.	Unless it is absolutely impossible to do it otherwise, never hold the surface being sprayed by gloved or bare fingers. There is a high probability that the solvent will attack the glove material or the skin of the fingers and the part will be contaminated by the residue. Be sure that the materials of the fixture or support are not susceptible to solvent attack.

D. SOLVENT SPRAYING

	Recommended Procedure	Reason
6.	Clean the holding fixtures before use.	An unclean fixture will transfer contaminants to the part Depending on its size, the fixture should be either ultrasonically cleaned or wiped clean with a solvent-moistened, lint-free cloth.
7.	Optimize the orientation of the parts used for the spray operation.	If there are some surfaces on the part that are more critical, this should be the first consideration regarding orientation. As a general rule, the part should be sprayed from the top to the bottom so that run-off (which may contain removed contaminants) is over the areas to be sprayed rather than over the already sprayed areas.
8.	Permit the freshly sprayed parts to dry prior to handling.	Handling a wet part always increases the recontamination risk. If there is a callout regarding a dry nitrogen blow-off, follow the same advice given in Section B on this subject.
9.	Assure that the area in which the spray operation is performed is adequately vented.	Because of the toxicity of most solvents, the vapors must be vented to the outside of the building.

E. VAPOR DEGREASING

	Recommended Procedure	Reason
1.	Use proper fixtures to suspend the parts in the vapor zone.	The fixture should be simple and low in mass. Generally, the fixture should support the parts from underneath. The notable exception to this is wire hooks that are quite adaptable to some degreasing operations. The handle or suspension portion of the support fixture should be of sufficient length that no portion of the body is ever in the vapor zone.
2.	Assure that precautions are taken to preclude deposition of contaminants onto the part from surfaces above the part.	Guard against skin oils, plasticizers from protective clothing, and/or contaminants from suspension fixtures dropping onto the part as a result of these items being in the vapor zone.
3.	Degrease the fixture and the portions of the suspension that will be in the vapor zone by itself prior to the start of a degreasing operation.	If the degreasing is one load after another without a time break, there is no need to degrease the fixture after each load. However, when there is a break in the action and the fixture is in the ambient air for more than a few minutes, then it should be degreased.
4.	Assure that the specified solvent is used in the degreasing operation.	This is particularly important when your facility utilizes more than one degreaser with more than one type of solvent.
5.	Keep the contaminant level in the boiling sump within reasonable limits.	Excessive contaminant levels in the sump may increase the contaminant level in the vapor zone to an undesirable level. Some precautions

E. VAPOR DEGREASING

	Recommended Procedure	Reason
5.		should be taken to keep the degreaser from becoming a "catch all" cleaning station where large, grossly contaminated objects are degreased.
6.	Regulate the amount of heat applied to the boiling sump properly.	Excessive heat input can cause abnormal amounts of contaminants to be present in the vapor zone.
7.	Control the amount of solvent in the boiling sump.	Some contaminants can and do get into some portion of the vapor zone from the boiling sump. A good rule of thumb guide is not to permit the amount of solvent to drop below 30% of boiling sump capacity and not to fill the sump to over 70% capacity.
8.	Maintain an adequate coolant flow.	There should be sufficient flow of coolant to prevent "overshoot," i.e., the rise of the solvent above the cooling zone. "Overshoot" causes excessive loss of solvent and also reduced efficiency of degreasing.
9.	Control the position of the parts in the vapor zone.	Various locations within the vapor zone may yield varying effectiveness. The upper portions of the vapor zone contain the highest purity vapor, so this upper portion is the more desirable. However, do not position the parts too high because you may reach the point where insufficient vapor exists for adequate condensation to occur.

E. VAPOR DEGREASING

	Recommended Procedure	Reason
10.	Control the time that the parts remain in the vapor zone.	The time for like parts to remain in the vapor zone should be kept constant. As the cool parts are lowered into the vapor, the vapor condenses on the part surface and runs off. When thermal equilibrium is reached condensation ceases.
11.	Assure that proper loading practices and limits are observed.	Perhaps the most commonly observed malpractice in loading for degreasing is the overlapping of parts in a contacting fashion, i.e., stacked parts with no air gaps between. Keep all blind holes oriented downward if at all possible.
12.	Take precautions to assure that the part temperature is no greater than room temperature when the part is inserted into the vapor degreaser.	Warm parts lessen the effectiveness of the degreasing since the time to reach thermal equilibrium is decreased.
13.	Take precautions to prevent the parts from being dipped into the solvent liquid in the boiling sump.	We have already established that the sump solvent is contaminated. If the parts are dipped into the solvent, thermal equilibrium is reached much sooner and also the contaminated solvent can place more contamination on the parts than it removes.
14.	Allow the degreased parts to dry prior to handling.	We cannot overemphasize -- do not handle wet parts with any material which may be attacked by the solvent.

F. ABRASIVE SPRAY CLEANING

	Recommended Procedure	Reason
1.	Locate this operation in any area other than the clean assembly area.	Not only does this operation contaminate the parts being processed with the abrasive agent, but it also contaminates the area where the operation is performed. Some contaminants, for instance oxides, are most difficult to remove, and abrasive spray, either wet or dry, is one of the more effective methods of removal. This method is one of those rare ones in which one contaminant is used to remove another contaminant.
2.	Clean the parts immediately following the abrasive operation.	One reason for cleaning immediately following the abrasive spray operation is to remove the abrasive agent before it is scattered to other areas via the container or by the pat s themselves. Another reason is that the sooner contaminants are removed after being deposited on a surface, the easier they are to remove.
3.	Limit the abrasive spray operation to piece parts and do not use on assemblies or partial assemblies.	The reason for limiting this operation to the simple piece parts is that other complicated parts usually contain crevices and holes where the abrasive agent may become entrapped. These entrapped contaminants may cause trouble where they are entrapped or they may be relocated to an area where they will cause trouble.

F. ABRASIVE SPRAY CLEANING

	Recommended Procedure	Reason
4.	Maintain good pressure regulation.	Consistency in cleaning operations is a most desirable attribute. Good pressure regulation in abrasive spray operations is mandatory if any degree of consistency is to be maintained.
5.	Maintain a standardized nozzle-to-part distance.	The comment made in the preceding paragraph is also applicable to this aspect of the operation.
6.	Standardize the time duration of like parts.	After optimum orientation and duration have been established, all like parts should be abrasively sprayed in the same manner. Again, this is for consistency.
7.	Assure that the same type of abrasive agent is used on all like parts and this agent is obtained from the same source.	This is related to maintaining consistency. If only one type is used in a given plant, the mode of control would be in the ordering of a new supply of abrasive agent.

G. COMBINATION VAPOR DEGREASERS AND ULTRASONIC CLEANERS

	Recommended Procedure	Reason
	NOTE: The points covered in the individual sections on vapor degreasing and on ultrasonic cleaners are in general applicable here. However, a few areas should be checked that are not called out in the referenced individual sections.	
1.	Maintain the proper purity levels in both the ultrasonic wash tank and the reservoir.	The reservoir is the storage area for the distilled solvent that overflows into the ultrasonic wash tank and is also the source of the solvent that goes through the spray ring or spray wand. Regarding the soluble contaminants that may be in the solvent, it is apparent that filtration is not the answer - redistillation is. In order to remove the solubles, the solvent must be redistilled.
2.	Maintain sufficient solvent flow through the filtering devices.	Since these filters retain the particles in the solvent, they will after X amount of time become clogged and this causes reduced flow rates. Periodically check to see that sufficient solvent flows through the filtering devices.
3.	Keep the cooling system free of leaks.	On the majority of these combination cleaning systems, water is used as the coolant for the condensation of the solvent vapors. The more expensive models may use refrigerant type Freon. Past experience has shown

G. COMBINATION VAPOR DEGREASERS AND ULTRASONIC CLEANERS

	Recommended Procedure	Reason
3.		that leaks may develop in the cooling system. These leaks may be into the solvent tanks or onto the floor.
4.	Take precautions on two-solvent systems to preclude the first solvent from drying on the part.	The first solvent may be TWD-602 or similar solvents which typically contain trichlorotrifluoroethane, water, and a detergent. These solvents are quite effective in removing a variety of contaminants. However, if this detergent solution is permitted to dry on the part it will be extremely difficult to remove.

H. STORAGE OF CLEANED PARTS

	Recommended Procedure	Reason
1.	Store cleaned parts in covered, dust-proof containers.	This should be done regardless of the air cleanliness. No occupied area is particle-free, and we do not want the part to become recontaminated.
2.	Assure that the container materials are either glass or stainless steel.	Plastic containers are much cheaper but are potential hazards to cleaned parts because of the following four facts: A. Plastic may acquire static charges which will pick up and hold dust particles. B. Plastic surfaces are easily scratched; the loosened material may be deposited on the part being stored or worse yet, may become trapped in an assembly being stored. C. Most plastics can slowly out-gas onto the stored parts. D. Many plastics are extremely susceptible to attack by the organic solvents used in cleaning operations.
3.	Use container access covers of the type that assures no friction occurs when the cover and container are mated.	We want to minimize the generation of particles when putting on or removing the container cover. Any lip on the container cover should fit on the exterior of the container, and the lip should not fit too snugly on the container.
4.	Use containers of a configuration that is easy to stock, efficient to store, difficult to spill, and easy to clean.	The reasons for these characteristics are readily apparent and no explanation is necessary.

H. STORAGE OF CLEANED PARTS

	Recommended Procedure	Reason
5.	Assure that the containers are properly cleaned prior to each use.	The container should be as clean as or cleaner than the parts to be stored in it. Usually the cleaning specifications define the cleaning process. It is almost always the same process as the process for cleaning the beakers for the ultrasonic cleaning operation.
6.	Assure that parts in storage containers and clean but empty containers are stored in either a clean assembly area or a controlled-access area that is relatively dust- and fume-free.	Dust-proof containers are usually not as dust-proof as they are claimed to be. For this reason, container storage should be in as clean an area as is economically feasible.
7.	Store parts that oxidize quickly or that are attacked by smog vapors in a recirculating clean hood with both HEPA and charcoal filters.	HEPA filters do not remove harmful vapors that can attack clean parts, but the charcoal filters can minimize the corrosiveness related to some smog vapors.

I. PERSONNEL SELECTION AND TRAINING[7]

	Recommended Procedure	Reason
1.	<u>Production Operators</u>	
	a) Screen out potentially poor operators during the employment interview.	Although some poor operators will get through any screen, this is the least painful time to "remove" them from your operations.
	b) Use tests to determine how well the potential employee understands printed or verbal instruction.	The key word is "understands" - all can hear and read, but many cannot understand and appreciate the meaning of instruction.
	c) Use dexterity and psychological tests to determine if a potential employee has the physical and mental ability to perform the type of production operations required, within the constraints of a comprehensive contamination control program.	These tests provide some painless ways to avoid having to transfer or terminate these people later. Not everyone has the physical and mental characteristics for critical contamination control operations.
	d) Use audio-visual training aids to check the potential employee's performance on a small sample of the prescribed production sequence.	Another good screening tool applied early enough to be effective.
	e) Insure that operators receive adequate training not only in production operations, but also in contamination control practices.	Train. Practice. Retrain. Repractice. These are necessary prerequisites for production uniformity.
	f) Provide operators with documentation of the specific methods or procedures to be	Verbal instructions need written verification and reinforcement. Moreover, substitute operators are

I. PERSONNEL SELECTION AND TRAINING

	Recommended Procedure	Reason
1.	Production Operators (cont.)	
	f) used at their stations on the production line, including contamination control precautions.	a necessity; hence, specifications are also necessary.
	g) Use audio-visual aids where-ever possible to assist in training and retraining of operators.	Such aids have the double impact of training through two of the human senses.
	h) Train alternate personnel for each critical operation to provide coverage during vacations and sicknesses.	These absences occur in addition to the natural attrition that requires new (and trained) operators.
	i) Take full advantage of probationary periods to screen out operators who are unable to follow the rigid contamination control practices.	Action during probation is much easier than procrastination until major deficiencies must be proven before a termination can be enforced.
	j) Weed out each operator who will not follow documented procedures and good contamination control practices.	Sounds redundant, but there are always a few that know more than the supervisor, the manufacturing engineer, and the other operators.
2.	Production Supervisors	
	a) Insure that the production supervisors are adequately trained in contamination control principles and their relationship to the specific production line.	Supervisors must lead and demonstrate knowledge. Without sound knowledge on their part, we are dead!

I. PERSONNEL SELECTION AND TRAINING

	Recommended Procedure	Reason
2.	Production Supervisors (cont.)	
	b) Provide supervisors with daily feedback of operator performance, especially on rejections due to contamination.	Such reviews can provide the information needed for retraining and promotions.
	c) Require supervisors to discuss poor performance with operators and to provide extra training for the purpose of assisting them in improving their efficiency.	Knowing - but not acting - is worse then not knowing.
	d) Transfer poor operators from critical processes where contamination can occur to other tasks more suited to their particular skills and abilities.	Some operators cannot discipline themselves for contamination control work, but would make good employees on other jobs.
	e) Maintain good housekeeping practices throughout the production areas.	A clean, orderly production area promotes the higher esprit de corps among the workers so necessary for critical processing and assembly.
	f) Require parts and materials with short shelf lives and susceptibility to contamination to be delivered from the stock room and used on a first-in, first-out basis.	Always a good procedure for all parts, but mandatory for short shelf-life piece parts and precision componentry.
	g) Provide predetermined workspace layouts and audio-visual aids at critical work stations and require their use.	Such aids provide confidence to workers and good audit information for supervisors and quality-control monitors.

	Recommended Procedure —	Reason
2.	Production Supervisors (cont.)	
	h) Require that all unnecessary parts and equipment be removed from workspace area.	This ties in with orderliness (item e), but also minimizes possibility of wrong tools and fixtures being used. Also helps to cut down contamination transfer from unnecessary equipment.
	i) See that all parts and sub-assemblies are placed in specific, properly sized containers that provide protection agains contamination.	Keeps clean parts clean, unmarred from contacting each other, and in proper place for next assembly.
	j) Provide female operators with a specific location outside the workspace area for storage of purses and other personal possessions.	You know they will carry such gear to the workspace unless you provide a safe alternate storage space.
	k) Require that the product layouts and assembly instructures be recorded so they may be duplicated exactly when the operations are set up again.	Minimizes relearning period, poor initial lot quality, and saves lots of grief to all concerned.
	l) Check that tools and equipment are operating correctly and that the operator is following the specified instructions before questioning the validity of the production layout.	Give the tooling and procedures a fair trial. Then demand corrective action by designer and manufacturing engineer if you can prove they will not produce satisfactory material.
3.	Manufacturing and/or Industrial Engineers	
	a) Insure that these engineers are adequately trained in	Those that lead and direct must be willing to learn and capable of

	Recommended Procedure	Reason
3.	Manufacturing and/or Industrial Engineers (cont.)	
	contamination control principles and their relationship to the specific production line.	demonstrating this knowledge to the supervisors and operators.
	b) Try to debug all new tooling and processing operations in a methods or pilot-plant laboratory before introducing them to production personnel.	This will minimize costly delays and personal embarrassments and is well worth the effort.
	c) Check all tooling and equipment at the end of each production run so that potential defects and abnormal wear conditions can be corrected before, rather than during, the next run.	Postponing new tooling orders or tool maintenance between production runs is a costly procrastination.
	d) Keep tooling drawings and process descriptions current with actual tooling revisions and design/manufacturing changes.	It is just as important to have change-order controls on the tooling and process drawings as on the product drawings.
	e) Design and provide special tooling for critical operations rather than allow continued use of "temporary" tooling which was hurriedly made for prototype models.	"Soft" temporary tooling wears prematurely and is often poorly designed for high-volume use.
	f) Provide proper light intensity for the type of operations being performed, adequate air circulation and fume hoods for	These are not only for "creature comforts," but for morale, higher quality of product, and fewer contamination control problems.

	Recommended Procedure	Reason
3.	Manufacturing and/or Industrial Engineers (cont.) toxic and unpleasant operations, comfortable heating and air conditioning systems, and work benches compatible with the value of the subassemblies and components being produced on them.	
	g) Provide proper handling, stacking, storing, and packaging materials and containers that will protect delicate and contamination-sensitive parts and assemblies.	Safe storage and packaging procedures safeguard the cost and effort that went into the fabrication, cleaning, and assembly of the parts and assemblies.

III. Conclusions

An effective contamination control program requires a well-planned and soundly executed manufacturing control program in addition to a good functional product design. The recommended manufacturing practices listed in the previous nine sections are not all-encompassing and were never intended to be. They do provide some valuable monitoring points that have proven to be helpful in solving contamination control problems in the past. Advanced design concepts, improved materials, and new fabrication processes will generate new contamination control problems which in turn will result in new recommended practices.

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