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Assessment of potential asbestos exposures from jet engine overhaul work

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ABSTRACT

Asbestos fibers have been used in a wide variety of products and numerous studies have shown that exposures from the use or manipulation of these products can vary widely. Jet engines contained various components (gaskets, clamps, o-rings and insulation) that contained asbestos that potentially could release airborne fibers during routine maintenance or during an engine overhaul. To evaluate the potential exposures to aircraft mechanics, a Pratt & Whitney JT3D jet engine was obtained and overhauled by experienced mechanics using tools and work practices similar to those used since the time this engine was manufactured. This study has demonstrated that the disturbance of asbestos-containing gaskets, o-rings, and other types of asbestos-containing components, while performing overhaul work to a jet engine produces very few airborne fibers, and that virtually none of these aerosolized fibers is asbestos. The overhaul work was observed to be dirty and oily. The exposures to the mechanics and bystanders were several orders of magnitude below OSHA exposure regulations, both current and historic. The data presented underscore the lack of risk to the health of persons conducting this work and to other persons in proximity to it from airborne asbestos.

1. Introduction

Thousands of products were manufactured that contained asbestos fibers, a recognized human carcinogen. Historical data on the airborne fiber exposure during use of these products have documented the exposures of the workers to airborne asbestos (HEI-AR, 1991; IOM, 2006; Madl et al., 2007; Finley et al., 2007). Unfortunately, there is limited published data for some occupations and the potential still exists that those performing maintenance work may still be at risk for exposure to airborne asbestos fibers.

One such occupation is aircraft mechanics that repair jet engines. Several studies have claimed anecdotal evidence of a possible increase in the risk of asbestos disease among aircraft workers (Bianchi and Bianchi, 2010, 2011; Garabrant et al., 1988). While there have been some exposure studies published on aircraft work (Blake et al., 2009, 2011), there are no studies directly related to engine maintenance and overhaul. Four non-peer reviewed studies, produced during litigation (ENSR, 1995; Schorn, 1995; Lehew, 2002; Mooney, 2003), indicate that the resulting airborne asbestos concentrations are several orders of magnitude below current regulatory levels.

None of the prior studies examined the possible exposure to aircraft mechanics during a complete jet engine overhaul. A study was conducted to assess the potential exposure to airborne asbestos fibers of mechanics performing overhaul work to Pratt & Whitney jet engines.

2. Materials and methods

2.1. Engine selection and history

The jet engine used for this study was a Pratt & Whitney model JT3D, a dual shaft turbofan engine derived from the JT3 turbojet of the late 1950s. The first three stages of the JT3 low pressure compressor were replaced by a much larger diameter two stage fan, along with an additional low pressure turbine stage, which improved both thrust and fuel efficiency significantly. The JT3 is called the J57 and the JT3D is called the TF33 in military applications. A photograph of the JT3D engine used in this study is shown in Fig. 1.

The first flight of the JT3D was in 1958 and about 8600 production engines were built from 1959 until 1985. The engine powered the Boeing 707, Boeing 720B, Douglas DC-8, Boeing B52H, and had a few other military applications such as the Douglas KC-135. Several different models were made, producing from 17,000 to 21,000 lb of thrust. The JT3D-7 engine is the latest of the models to be developed and produces 19,000 lb of thrust. It is estimated that over 1000 JT3D engines are still in service, primarily in cargo planes and the commercial fleets of foreign nations.

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Fig. 1. Pratt & Whitney JT3D-7 engine used in the present study.

The engine is approximately 137 inches long by 53 inches in diameter and weighs 4340 lb. Parts are made from steel, aluminum, titanium, magnesium, and nickel alloys. It also contains non-metallic parts such as gaskets, thermal and electrical insulation and cushioned clamps that hold the external stainless steel plumbing and wiring. The engine has a large external magnesium gearbox that drives most accessory components.

In order to mount the engine on an airplane, many additional external parts are needed, primarily for the mechanical, pneumatic, electrical and hydraulic connections. In addition, the generator, hydraulic pump, large fan ducts and tailpipe, as well as miscellaneous other smaller parts are added prior to installation. These parts are not supplied by Pratt & Whitney and are generally referred to as "Quick Engine Change" (QEC) parts.

A JT3D engine was located that was built in 1968, and which had a complete use and service series of log books. The reason for this was to insure that any asbestos exposures resulting from the overhaul work would be comparable to those experienced by mechanics currently performing these activities as well as those mechanics that have performed this work since the production of this engine began. The particular engine used in this project was a JT3D-7, Serial Number 670957. The suffix denotes the particular model of JT3D, as that engine type evolved and various changes in design were made. The engine had been installed on various passenger airliners and was in service until 1986 when it suffered a turbine failure and was removed from service. The engine was then warehoused until purchased for use in this study.

The complete log books detailing the history of the engine were available for review.

2.2. Facility

This study was conducted at JB Power LTD, an established jet engine service facility located in Miami, Florida. This facility is certified by the Federal Aviation Administration (FAA) as an Air Agency authorized to work as a Repair Station, and operates as such under FAA Repair Station No. J1BR251N. As of the date of this study, there were only four air stations certified to work on the JT3D jet engine.

The facility where this study was conducted consists of one large building that was constructed in 1995. The building is a concrete slab with preformed pre-tensioned tilt-up concrete walls and a galvanized steel roof. It contains 2500 square feet of office space and a work area of 34,500 square feet. The building is of irregular shape and measures 28 feet from floor to ceiling. The total volume of the building is 1036,000 cubic feet. There are five large overhead doors of various sizes (two – 20′ wide × 14′ high, two – 10′ wide - × 10′ high and one – 8′ wide × 10′ high), and two conventional doors (both 3′ wide × 7′ high). All work performed for the disassembly and reassembly of the engine was done in an open area within this building. The only exception to this was the rebuilding of the gearbox. There is a special room within the building where this work was performed. This room adjoins the offices, and it is 14′ long × 10′ wide × 8′ high. It, like the offices, is air conditioned.

While the office space and gear box room were air conditioned, there was no mechanical ventilation system for the work area for either heating or cooling. The building relies solely on natural convection. The Miami, Florida location obviates the need for a heating system. Cooling and air flow were provided by the five large overhead doors being opened during the work day, and the use of fans. The overhead doors were opened on every day of this study. Also, four fixed, 4-foot diameter, ceiling-mounted industrial fans were used routinely during the study as well as one or two movable, floor-level, roll-around, 3-foot diameter fans. Due to these operating conditions, no attempt was made to determine the air changes per hour (ACH) in the building. Local ventilation problems may exist in some areas, but there were no obstruction to airflow at the location of the work done during this study.

The walls and ceiling of the building are not insulated. The office space was built within the building and is located in the northeast comer of the building. The offices have 8 foot ceilings. The office area was insulated with two-foot wide batts of insulation. This insulation was placed on the top of the ceiling tiles and ceiling joists and so was exposed to the work area of the building. Samples were taken of the insulation, and it was determined to be fiberglass.

An inspection of this facility was conducted and there were no sources of asbestos found. Background air samples collected prior to disassembly showed no airborne asbestos fibers.

2.3. Overhaul work personnel

All work was done by, and under the supervision of, mechanics experienced in jet engine overhaul work. The owner of the facility where this work was done has approximately 20 years experience working on jets, has attended aviation school in Miami for both power plant and airframe training, and has worked on Pratt & Whitney JT3D engines his entire career. The owner reported that much of the work done by this facility is on the newer JT8D engine type, but JT3D engines are routinely overhauled at this facility, and he expected to perform about 12 such overhauls in during the year of this study.

The owner oversaw all aspects of the overhaul work. He was assisted by the company's director of quality assurance, and by a supervisor. The workers who performed the overhaul were all mechanics with experience in engine mechanical work ranging from 7 to 36 years.

2.4. General description of work and sampling

The overhaul was performed in accordance with accepted industry standards, and with the guidelines published in the Pratt & Whitney engine manuals. The exception was that upon completion of the overhaul, the engine was not returned to flight readiness. While all engine components were reassembled, some time-consuming procedures normally part of an overhaul, principally installation of safety wiring, disassembling and weighing each individual blade from each compressor and turbine section, rebalancing each compressor and turbine section, testing the integrity of parts, rebalancing moving parts, torqueing of bolts, alignment testing of bearings, and balancing of compressor and turbine vane assemblies were not performed. This had no effect on the assessment of airborne asbestos exposure since no asbestos-containing part removal, replacement, or disturbance is associated with these activities.

Work of this type requires a number of specialized tools. The facility where the work was done had originals of these specialized tools, or replicas of them. The work practices used were the same as those used at any point in the history of this engine, according to the owner of the facility and the two aviation experts on-site.

2.5. Overhaul

The overhaul took place over a three week period. During the first week of the project, the mechanics disassembled the JT3D engine. The disassembly work took approximately 6–7 business days. No work was done during the intervening weekend. The disassembly was conducted in accordance with the procedures set forth in the Pratt & Whitney engine manuals (Pratt and Whitney, 1997), and accepted industry standards.

Weeks two and three of the project were spent reassembling the engine. Reassembly proceeded in reverse from disassembly, and was conducted in accordance with the procedures set forth in the Pratt & Whitney engine manuals, and accepted industry standards. Original replacement parts were used whenever possible.

During the period of time between disassembly and reassembly, no work was performed on the engine or any of its components, except that all the appropriate large, metal pieces were cleaned. Cleaning of these components is a normal part of an overhaul, and presents no opportunity for asbestos exposure. Accordingly, no air sampling was performed during this period of time.

2.6. Gear box rebuild

Once removed from the engine, the gear box for most jet engine types, including the JT3D, is typically rebuilt in a separate area, concurrent with the remainder of the engine rebuild. The gear box for this engine was rebuilt in this fashion. It was taken to a separate room, described earlier, and a mechanic whose specialty is this type of work performed the rebuild.

The gear box rebuild was done in one day. On the same day, and in the same room, some minor components of the engine such as the fuel control, the fuel pump, and the fuel oil cooler, were rebuilt as well.

Separate personal air samples were collected during the rebuild of the gear box and other components from the mechanics that performed the work. Area air samples were collected in proximity to this work in conjunction with the overhaul, as were samples from the two outdoor locations.

2.7. Sample collection and analysis

2.7.1. Bulk sampling

During the overhaul work, representative bulk samples of all types of parts removed and parts installed that could have contained asbestos were collected. These samples were collected to determine whether asbestos was present in the parts, and, if present, the type and amount. Bulk samples of the engine parts were collected by placing either the entire part, or a sufficient portion of it, in a clear plastic, resealable bag. By representative parts we mean that we sampled at least one of each type, though many identical parts may have been used on the engine. For example, if an insulated clamp was removed from the engine, that sample represented all such similar gaskets on all the same type of insulated clamp. If a second type of insulated clamp was found, this second type was sampled. This continued until at least one sample had been collected for all types of insulated clamps encountered.

Bulk samples were collected on various days during the overhaul work from any potential ACM present in the facility. These samples were collected to determine whether building components and/or materials could contribute to any airborne asbestos levels measured.

2.7.2. Air sampling

Air sampling was conducted to determine the airborne fiber concentrations in during the overhaul. Area sampling was conducted at four locations centered on the engine overhaul. The area samples were initiated at approximately the same time as work began, and were terminated at the end of the work day. Sampling was also conducted outside the buildings to allow comparison between outdoor and indoor fiber levels.

Personal air sampling was conducted to provide information regarding the airborne asbestos fiber exposure of persons performing the engine overhaul or service work. The personal air samples used to assess potential asbestos fiber exposure were collected in duplicate, i.e., using side-by-side personal sampling pumps and collection media. One set of these personal samples was submitted for analyses, and the other set was archived.

Bystander air samples were collected on a person in the vicinity of the disassembly/assembly operation. The bystander's primary area of responsibility was to maintain paper work related to the sample collection activities of this investigation. As such, this person moved about the area, ranging from 0 to 20 ft or more from the operation. The bystander moved about the facility and came in contact with stored boxes and other materials during the course of the work day.

All filter cassettes were changed once per day at lunchtime (12:00 PM), and also at any significant change in work performed. In addition, filters were changed as necessary to avoid filter overloading. The timing of these changes was based on the professional judgment and experience of the field researchers regarding the nature of the activity and the associated dust generation. As a result, sample times for the individual samples varied.

Air sampling equipment adhered to the requirements of the National Institute of Occupational Safety and Health (NIOSH) Method 7400 (NIOSH, 1994a) and the Asbestos Hazard Emergency Response Act (AHERA) (USEPA, 1987). Normally personal pumps were operated at a flow rate of 2–3 liters per minute (lpm), area samples at 10 lpm. The samples were collected on cellulose ester membrane (0.8 μm pore size, 25-mm diameter) filters mounted in a new cassette with a 2-inches conductive extension.

2.7.3. Sample analytical procedures

All bulk samples were analyzed in accordance with published protocols (Perkins and Harvey, 1993).

Air samples were analyzed in accordance with NIOSH 7400 (NIOSH, 1994a) and NIOSH 7402 (NIOSH, 1994b). When asbestos was observed during the NIOSH 7402 analysis, that sample was also prepared and analyzed in accordance with ISO 10312 (ISO, 1995).

All analyses were conducted at the RJ Lee Group laboratory that is accredited for asbestos analysis by the National Voluntary Laboratory Accreditation Program (NVLAP) and the American Industrial Hygiene Association (AIHA). The laboratory operates under the quality guidelines established by these, and other, accrediting organizations.

2.8. Statistical analysis

PCM concentrations were calculated using the observed fiber counts with no blank filter correction. The NIOSH 7400 method detection limits are based on counting 5 fibers in 100 fields of view.

The asbestos concentration was determined by multiplying the PCM fiber concentration by the asbestos ratio determined in accordance with NIOSH 7402. For data evaluation purposes, all samples with no asbestos structures counted were treated as 0 f/ml and not as "less than" a detection limit (Oehlert et al., 1995).

Standard statistical procedures, both parametric and nonparametric, were used in evaluating the data. Analysis of Variance (ANOVA, a parametric procedure) was used to evaluate differences among the observed concentrations (Neter et al., 1990). Because standard statistical approaches based on normality assumptions are apt to give poor approximations to significance levels because asbestos sample data are generally highly skewed, the Mann–Whitney U test (Daniel, 1978) (a nonparametric procedure) was also used to test for differences.

3. Results

3.1. General

A total of 425 bulk samples, 197 area air samples, 189 personal air samples, and 72 blank samples were collected. Personal air samples were collected in duplicate and 78 of these duplicate personal air samples collected were archived and not analyzed. All anticipated personal samples were collected from the mechanics performing the work and the bystander. Regarding phase contrast microscopy (PCM) and transmission electron microscopy (TEM) analyses, only 2 of the 458 (0.4%) personal and area air samples were not able to be analyzed, and both of these voided samples were area air samples. In both cases the filter was damaged and/or obstructed.

3.2. Bulk samples

A total of 425 bulk samples were collected, 420 were collected from the overhaul work and 5 from the facility or its contents. Of the 420 analyses of samples associated with the overhaul work, 403 of these were of Pratt & Whitney engine parts, and 17 of these were from parts designated as Quick Engine Change (QEC). These QEC parts are not Pratt & Whitney products.

Of the Pratt & Whitney parts, 37 (9%) were positive for the presence of asbestos. In all cases the type of asbestos was chrysotile, and the percent asbestos present in these samples ranged from 30% to 90%.

Of the QEC parts, 5 (33%) were positive for the presence of asbestos. In all cases the type of asbestos was chrysotile, and the percent asbestos present in these samples ranged from 40% to 90%.

Of the 5 analyses of samples associated with the facility, none were positive for the presence of asbestos.

3.3. Personal air samples

A summary table of the PCM results of personal air sampling, indoor area air sampling, and outdoor area air sampling is presented as Table 1 where the data are average by operation (disassembly or assembly). These are task-based concentrations, not 8-h

Table 1
Summary of task-based air samples, phase contrast microscopy f/ml.

Location	Number	Average sample time, min	Median detection limit	Geometric mean concentration	Mean concentration	Standard deviation	Percentile distribution				
							10	25	50	75	90
Disassembly											
Worker	28	194	0.0071 (10)[a]	0.0073	0.0099	0.0069	0.0016	0.0048	0.0092	0.0129	0.0184
Bystander	13	226	0.0062 (2)	0.0118	0.0131	0.0056	0.0058	0.0088	0.0125	0.0176	0.0209
Indoor	52	238	0.0012 (4)	0.0029	0.0031	0.0013	0.0017	0.0023	0.0030	0.0038	0.0048
Outdoor	26	232	0.0012 (14)	0.0010	0.0013	0.0007	0.0003	0.0008	0.0012	0.0018	0.0025
Assembly											
Worker	53	236	0.0053 (20)	0.0067	0.0081	0.0058	0.0035	0.0048	0.0070	0.0090	0.0144
Bystander	17	282	0.0048 (4)	0.0079	0.0136	0.0139	0.0017	0.0048	0.0078	0.0189	0.0323
Indoor	74	288	0.0009 (4)	0.0021	0.0027	0.0027	0.0011	0.0015	0.0020	0.0027	0.0046
Outdoor	33	290	0.0009 (9)	0.0011	0.0013	0.0006	0.0006	0.0008	0.0013	0.0017	0.0021

[a] Number of samples below detection limit.

time weighted average values. A total of 111 personal samples were analyzed, and the worker personal samples averaged approximately 221 min in duration.

The PCM personal worker sample analyses resulted in a mean of 0.010 f/ml sample concentration during disassembly and 0.008 f/ml during assembly operations. Bystander concentrations were slightly higher with 0.013 f/ml during disassembly and 0.014 f/ml during assembly. The maximum sample concentration observed during all testing was 0.050 f/ml, a bystander value during assembly operations. It is unclear why the bystander concentrations are higher than the worker concentrations other than the worker is in closer contact with oils and other fluids while the bystander moved about dustier storage locations. These PCM values represent all fibers present.

No asbestos fibers were detected by TEM in the analyses of the personal samples. The proportion of asbestos fibers present among all the fibers detected by TEM is used to adjust the PCM results to reflect only the asbestos component, resulting in PCME concentrations. Since zero (0) asbestos fibers were found in every sample, the effective multiplier for the PCM results is zero. All of the fibers counted in the PCM analyses were non-asbestos.

The average PCM concentration of area samples collected in the vicinity of the work was 0.003 f/ml during both disassembly and assembly. Asbestos fibers were detected on two (1.4%) of the 138 area samples by NIOSH 7402; no other asbestos was observed on any area sample. Both samples were collected during assembly operations. The two positive samples were further analyzed using ISO 10312. One sample was determined to contain two chrysotile fibers shorter than 5 μm; the other sample contained 1 chrysotile fiber longer than 5 μm.

A statistical comparison of the PCM data indicates the worker exposures were marginally higher during disassembly than during assembly ($p = 0.0626$, Mann–Whitney U), reflecting that the engine is dirty for the disassembly. This difference (disassembly higher than assembly) extended to the area samples ($p = 0.0002$), but not to the bystander samples ($p = 0.35$). There was no difference in the outdoor air concentrations during either operation ($p = 0.60$).

4. Discussion

This study has demonstrated that the disturbance of asbestos-containing gaskets, o-rings, and other types of asbestos-containing components, while performing overhaul work to a jet engine produces very few airborne fibers, and that virtually none of these aerosolized fibers is asbestos. None of the 111 personal samples and 2 of the 138 indoor area samples contained asbestos. The two area samples positive for asbestos contained a total of 2 chrysotile fibers greater than 5 μm in length as determined by NOISH Method 7402, and 1 chrysotile fiber >5 μm in length as determined by ISO Method 10312. All other analyses for airborne asbestos fiber concentrations as measured by TEM were below the analytical limit of detection for all the personal and area air samples collected. Because TEM analyses reflect airborne asbestos fiber concentrations, they are the most pertinent data to answer questions related to the potential health risks from exposure to asbestos during jet engine overhaul work.

The overhaul work was observed to be dirty and oily. During the first week of work, approximately two gallons of oily fluid was discharged from the engine as various parts were removed. On all days, almost all of the gaskets, o-rings, seals, and similar items observed as they were being removed were oily, or at least not dry. The workers reported that their work was typically dirty and oily, and the aviation experts on site noted that this was their experience as well. There was no visible airborne dust created by the overhaul work. The oil and fluids may have suppressed the generation of airborne fibers during this study.

The two aviation experts on site also reported that the facility was dirtier, dustier, and more cluttered than those with which they have experience. They both also stated that the work practices of the employees were sloppy.

During this project, removal of the gaskets, seals, o-ring, and similar items was observed to be done by hand. Occasionally, a screwdriver or similar tool was used to assist in loosening such items. Powered grinders, powered wire brushes and other powered tools were not used to remove gaskets and seals or any other items. The mechanics reported they never used such powered tools for removal of gaskets. This was unnecessary because all or almost all gaskets came off by hand or with a screwdriver. Any items that could not be removed in this fashion were sent to a wash tank and the wash process would remove the gasket, or allow it to be removed by hand. In addition, they reported that using a grinder or other powered tool to remove a gasket could potentially damage the metal seating surface below the gasket, and that using powered tools for this purpose was not a part of approved protocol. The two aviation experts on site concurred that there was not a need nor a practice to use powered grinders or powered wire brushes to remove gaskets, seals, o-ring, and similar items.

Overall, the results of bulk sampling showed that various gaskets, o-rings, seals, and similar parts associated with jet engines can contain asbestos, that the type of asbestos found is chrysotile, and that these asbestos-containing parts are used in all sections of the engine. When removed or replaced, these asbestos-containing parts were in non-friable condition. The owner and the workers reported that in general such parts were easily removed – usually by hand, or else with a screwdriver, or with a knife, and this was observed to be true in this study.

Analysis of air samples showed that jet engine overhaul work can result in the aerosolization of low concentrations of fibers. The personal sample results show that the workers and the bystanders were not exposed to any asbestos fibers. The indoor area sampling results showed that actual asbestos fiber concentration as measured by TEM and PCME was extremely low. The average asbestos fiber concentration for all indoor area samples as determined by PCME was approximately 0.000005 asbestos f/ml. This value is lower than what is considered to be ambient rural asbestos levels by the Health Effects Institute-Asbestos Research (HEI-AR, 1991) and the Agency for Toxic Substances and Disease Registry (ATSDR, 2001).

This study assessed the asbestos exposures of jet engine mechanics while performing an overhaul of a Pratt & Whitney JT3D engine, using tools and work practices similar to those used since the time this engine was manufactured. Results of this study support the conclusion that the asbestos exposures of persons who performed overhaul work to similar jet engines, and bystanders to these activities, are negligible, or the same or less than ambient background levels. Although performing this work may produce some airborne dust, including a low number of fibers as analyzed by PCM, TEM analysis shows virtually none of these airborne fibers to be asbestos. The airborne asbestos personal exposure of workers engaged in the overhaul of jet engines was at or below background ambient levels. The airborne asbestos area exposures of workers engaged in the overhaul of jet engines was at ambient levels, several orders of magnitude below OSHA exposure regulations, both current and historic. The data presented underscore the lack of asbestos risk to the health of persons performing similar work practices and to other persons in proximity to it from airborne asbestos.

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This study was supported by Pratt & Whitney, which has participated in asbestos product litigation. The authors have also participated in asbestos product litigation.

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