EUROPEAN FUSION DEVELOPMENT AGREEMENT

JET

EFDA–JET–PR(05)15

D. Campling, B. Patel and JET EFDA contributors

Sampling and Analysis for Beryllium at JET: Policy Cost and Impact

Sampling and Analysis for Beryllium at JET: Policy Cost and Impact

D. Campling, B. Patel and JET EFDA contributors*

EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, UK
** See annex of J. Pamela et al, "Overview of JET Results ",*
(Proc.20 th IAEA Fusion Energy Conference, Vilamoura, Portugal (2004).

Preprint of Paper to be submitted for publication in Proceedings of the
Symposium on Beryllium: Sampling and Analysis
(Reno, Nevada, USA 21-22 April 2005)

ABSTRACT.

This paper describes the sampling and analysis for beryllium at the JET fusion facility. The current policy requiring 100% Personal Air Sampling (PAS) and taking many surface contamination smears generates 40,000 samples/year. Sample processing, analysis and the QA program are described. Costs are summarized to derive a cost/sample of ≈£4.2($8). This is economical but as 99.8% of PAS measurements are <2μg/m^3 and the aggregated costs are high reviewing the policy is justified. The disadvantages of the present strategy, the options for a change of policy and the role that an accredited real-time analysis instrument could play are discussed. Retrospective analysis affects the machine operating time; a quicker technique would have a significant impact on improving experimental time. The project's experience is that turnaround times of 2-6 hours can be routinely achieved for large numbers of samples.

INTRODUCTION

The Joint European Torus (JET), located in Oxfordshire, UK, is the world's largest facility for investigating nuclear fusion reactions as a potential future energy source. Since 1989 up to 3 tonnes of Beryllium (Be) has been installed in the torus as solid components and as an evaporated deposit; its low atomic number, relatively high melting point and oxygen gettering properties make it an ideal first wall material [1]. The occupational hygiene aspects of working with Be are controlled by the Health Physics Group who also operate an on site analysis facility [2].

LEGAL STATUS OF BE IN THE UK

Beryllium as a toxic material is controlled under the UK Control of Substances Hazardous to Health Regulations, and has an exposure limit of 2μg/m^3 as an 8hr-TWA Workplace Exposure Limit (WEL) [3]. The WEL label implies that for this substance, exposures be controlled to the lowest level possible, even if measurement shows it to be below the exposure limit.

HEALTH EFFECTS

Even small exposures to Be may produce a physiological effect in some individuals as a hypersensitivity allergic reaction. Such sensitization can then lead to Chronic Be Disease (CBD) which mainly affects the lungs, causing inflammation and the production of granulomas. Some forms of Be notably soluble compounds and Be oxides are thought to produce a more toxic effect. Long term handling of Be is also thought to be risk factor for developing lung cancer.

USE OF BE AT JET

The predominant form of Be used at JET is as a metal, with much smaller amounts of Be ceramics and alloys. Although most of the handling is of pre-fabricated metal components, some minor machining has been carried out. Machine operations cause erosion of the first wall surfaces generating some dust. The potential for exposure occurs during entries to the torus vessel or in the breaches of containment when components need to be removed or exchanged. Further exposure can occur in the maintenance and decontamination of components and respiratory protective equipment in Be handling areas. The potential for exposure to higher concentrations is generally limited to the shutdown periods or particular campaigns of work on contaminated items. For most workers, exposure is therefore intermittent rather than continuous, although a few activities, such as waste handling occur throughout the year.

HEALTH SURVEILLANCE

The health surveillance program at JET relies on screening of individuals based on their medical history, making annual lung-function tests, as well as follow-up of reported symptoms of ill health. There is no routine screening of the workforce using the Beryllium Lymphocyte Proliferation Test (BeLPT), but such tests could be undertaken as part of a CBD diagnostic evaluation if needed. So far amongst the current workforce, there are no reported clinical signs consistent with CBD, although the rate of sensitization (if any cases exist) is not known. The presumption is that based on this surveillance, the current policy of workplace control and monitoring has been adequate for prevention of CBD.

BE DESIGNATED AREAS

The project operates 20 permanent Be ‘controlled’ working areas where there is a low-moderate risk of significant Be contamination being encountered if work is taking place [4]. Some of these (eight) are in continuous use with an elevated potential for high levels of surface and/or airborne Be contamination. The research nature of the project means that many tasks with Be are not routine and the fluctuations in the use of Be changes the potential for exposures.

There are a further 80 Be ‘restricted access’ areas which are only occasionally entered and where there is only a small chance of low level Be contamination being encountered. Most of these areas are iso-containers used for the storage of wrapped components. Treating the legacy of waste and used items is liable to generate increased levels in the future.

CURRENT SAMPLING POLICY

The current policy, which has remained in place since 1989, requires the full duration of all entries to all Be controlled areas to be monitored by Personal Air Sampler (PAS). The wearing of respiratory protective equipment in Be controlled areas is mandatory for all entries to areas where $>0.4\mu g/m^3$ could be encountered. In practice the vast majority of entries to Be controlled areas utilize some form of Respiratory Protective Equipment (RPE) even though concentrations are likely to be below $0.4\mu g/m^3$. In addition static air samplers run continuously in all Be controlled areas and are used to survey all tasks where airborne Be contamination might arise. Surface contamination smear surveys are carried out routinely, but with a varying frequency, in all areas. Components and items are required to be surveyed for surface contamination before transfer out of a Be area. An acceptance level of $<10\mu g/m^2$ ($0.1\mu g/100cm^2$) is used. This practice is designed to minimise the spread of contamination by ensuring that only clean items are removed from Be areas and that contamination control practices are effective within the areas.

This policy of 100% PAS and surface clearance sampling was adopted for the following reasons:-

- The widespread use of Be in fusion research applications was new and at least initially, it was not known what airborne levels might arise in an area or be associated with a particular task.
- The types of maintenance operations were wide ranging, from handling solid machined tiles to grinding or welding in the torus, where mg/m^2 and 10's of mg/m^3 of Be might arise and where pressurised suits would be required for protection.
- It provides reassurance to both the workforce and management that all exposures are monitored. All positive PAS results are subject to investigation.
- The absence of any measurements would require exposure assessments to be made which is time consuming, prone to errors, and would prompt a greater level of scrutiny from both staff and the regulator than would otherwise be the case.
- It covers accidental exposures and unexpected situations.
- It avoids non-Be workers becoming inadvertently exposed by checking surface contamination levels on all transferred items.

SAMPLE NUMBER

Approximately 40,000 samples of all types are taken each year, of which between ≈3,000 and 14,000 are PAS samples (Fig.1).

The bulk of the remainder and by far the most numerous are surface contamination smears. Static air samples from work areas, water and oil samples make up a small proportion of the total number of samples. The large variation in the proportion of PAS samples is due to changes in the configuration of the machine i.e. whether lengthy shutdowns are required and the nature of the maintenance work in each shutdown.

SAMPLE ANALYSIS AND QA

Surface contamination cellulose filter paper smears, and PAS and work area air samples on cellulose-nitrate filter papers are dissolved in 1ml of 98% sulphuric and 5ml of 70% nitric acids at up to 400^{o}C. Automatic sample digestion takes $2^1/_2$hr per batch of 40 samples. The method complies with the UK Health & Safety Executive's specified technique [5]. The end result is a Be-sulphate solution suitable for analysis by flame Atomic Absorption Spectrophotometry (AAS) using a nitrous oxide and acetylene gas mix. Two Perkin Elmer instruments, an 1100B and an Analyst 300 operated manually, achieve an analysis Limit Of Detection (LOD) of 0.03μg/sample. Sample turnaround times vary between 6 hours for routine samples and 1 hour for urgent/incident samples, subject to the analysis laboratory being manned. Extended days or shifts are operated if required. Although not currently accredited the laboratory is pursuing accreditation with the United Kingdom's Accreditation Service (UKAS) to undertake Be analysis.

The Quality Assurance (QA) surveillance consists of internal and external comparison schemes. For the former spiked samples are submitted blind to the analyzing technician, the 'observed' versus the 'expected' values are compared. In the external QA program samples are sent to a contractors laboratory and analyzed by Induction Coupled Plasma - Optical Emission Spectrophotometry (ICPOES) and again a comparison between the 'observed' and the 'expected' values is made. The results of these checks (carried out since 1990) are summarized in Fig.2 and show that the differences are just a few percent for all categories of samples.

The small negative bias on the low, mid and high level sample categories refers to the in-house QA samples and is due to the small loss of liquor that results when the samples are transferred from the digestion tube or beaker to the calibrated analysis vial. This is considered acceptable as the comparison with the external QA samples carried out by ICPOES shows a similar percentage positive bias.

These values are recorded to facilitate detection of any undesirable trends. New working calibration solutions (1 and 2 μg/ml) are compared to the 'in use' standard and two other standards from different suppliers before they are put into use.

COSTS

It costs approximately £37($70) million/year to operate JET and the average number of operational days is typically only 150/year, so maximizing the machine's availability is crucial. Maintenance tasks are often in the torus operations area and the need to set up temporary Be controlled areas and undertake clearance of these areas to restore normal access can result in delays. As such the operational nature of the project demands the fastest possible sample turnaround times as delays of just a few hours will result in lost operational time. For this reason in 1995 a new purpose-built on-site Be analysis and Health Physics Laboratory was set up at a capital cost of £500k ($960k). The total overall cost including all the major elements required to undertake Be analysis and the running and operational costs over the following 10 years (1995-2004) are summarized in Figure 3.

Staff costs are comprised of, on average, four laboratory technicians, including a supervisor. Three stainless steel fumecupboards were purchased and installed when the laboratory was built; these are expected to last the lifetime of the facility. The cost for AAS instruments includes replacement of obsolete instruments; an older instrument has been replaced. Digestion equipment is comprised of automatic and manual hotplates of various types and includes replacement of several sets due to wear and tear in a hostile environment. Two industrial duty washing machines have been used for high quality decontamination of glassware, beakers, vials, digestion tubes etc. The integrated running costs include all the consumables routinely used in the analysis process. A large volume of waste (which is also radioactive) is produced in the analysis process and includes, acidic Be contaminated aqueous liquor, soft compactable wastes, contaminated glassware and plastic pipettes etc. Professional support is required to write risk assessments, produce laboratory standing orders and oversee quality assurance checks.

THE COSTS ASSOCIATED WITH AIR AND SURFACE

sampling is summarized in Figure 4. This includes the cost of all PAS and static air sample pumps including user replaceable spare parts and losses due to wear and tear. Also included are the sampling media costs, the manpower costs for the deployment, maintenance and calibration of the samplers. Professional support takes the form of providing advice as to when sampling will be required and monitoring and recording the PAS results.

The total overall cost for all the elements detailed in Fig's 3 & 4 is £3M($5.75M). Altogether these costs equate to an average of £4.2 ($8)/sample.

POLICY REVIEW

It is clear that the current 100% PAS sampling policy, the large number of surface contamination smears taken and the requirement to have fast turnaround times carries a significant cost overhead. The disadvantages of the current policy are the high cost in terms of both manpower and equipment, and the possible diversion of resources from other safety issues.

The original policy was formulated prior to the actual use of Be. Since then considerable experience has been gained, and on average, the actual exposures have been much lower than anticipated. It is arguable that resources currently devoted to sampling could potentially be more usefully invested in medical screening and surveillance or the improvement of workplace controls.

Allowing for RPE protection factors, 99.98% of personal exposures are below the UK WEL and a large proportion of surface smears are less than the 10μg/m^2 acceptance level. Table 1 summarizes the PAS sampling results from 1989 to the end 2004 and gives the results in seven concentration intervals as a percent of all PAS samples taken. All results above the WEL occurred prior to 1994 when (in the UK) the 2μg/m^3 level changed in its legal status from an Occupational Exposure Standard to the present WEL. A similar contamination profile exists for surface smear results.

TABLE 1

PAS results.
Respiratory protection factor corrected (8-hour TWA) Be concentration intervals (μg/m^3)

	<0.03	0.03- 0.1	0.1 - 0.2	0.2 - 1.0	1.0 - 2.0	>2.0
Percent of total (92 332)	94.72	4.83	0.297	0.120	0.018	0.013

In the absence of evidence of direct health effects and a large volume of exposure data it is appropriate to reconsider the extent of the sampling and the validity of the current policy.

A variety of modified policies is feasible and could consist of the following elements: -

- Reduce the number of surface contamination smears taken by concentrating on areas and tasks where raised levels are *likely* to be seen. A 60% reduction might be achieved.
- Retain 100% PAS but only in areas where raised surface or airborne are known to occur.

Alternatively a more cautious approach could be: -

- Take surface contamination check smears from all areas other than those where contamination is very rarely seen. A 30% reduction in numbers might be achieved.

- Retain the 100% PAS sampling policy as it is.

This second set of options recognizes that a change in the WEL is possible in the UK in the next few years and that exposures considered low at present (close to our LOD) may still be of importance [6].

Given the many years of experience, selecting those tasks and areas that could be subject to less rigorous surveillance should be easy. However taking this step could be made more confidently if a prompt assessment of the levels was available with a real-time (or close to real-time) monitor. Such an instrument would allow selection of just those operations liable to generate significant exposures and would trigger a higher level of surveillance with traditional analysis methods.

LASER INDUCED BREAKDOWN SPECTROMETRY AT JET.

In 1989 a prototype Laser Induced Breakdown Spectrometer (LIBS) instrument which could potentially offer much quicker analysis (a few minutes) was tested at JET. Although the instrument worked well with calibration filter papers (produced using a standard solution) there was found to be a poor correlation between twin air sample papers taken from operational areas when one was analysed by the LIBS instrument and the other by the wet chemistry method. On average the LIBS results were 30 times lower than the AAS results. It is thought that the discrepancy was due to the difference in form of the Be on the calibration papers and that on the work area samples. The Be on the work area papers would have been associated with graphite and in a particulate form. For this reason its use as a survey instrument was not pursued. It should also be noted that use of such an instrument for PAS assessments could only be realised if its performance was validated and the UK's Health and Safety Executive approved it. A suitable monitor would have to reach a sufficiently low LOD, be economic to purchase, easy to operate and be reliable. The economics of substituting traditional techniques with real-time monitors would have to be considered.

DISCUSSION

Recent epidemiological studies point to potential for sensitization or CDB in persons exposed to generally low beryllium concentrations [7]. Many of these studies relate to beryllium machining plants and generally to continuous or repeated exposures. Whilst there is much uncertainty in the effects of low levels exposures, and further research is needed, there is clearly a need to reduced exposures to levels As Low As Reasonably Practical (ALARP) below the exposure limit. Whilst in the US there are proposals for reductions in the exposure limit from certain groups representing industrial hygiene standards [8], so far there is no similar indication from the US federal OSHA body, nor from the UK the standard setting authority.

Nevertheless given that in the UK the statutory Be exposure limit may be reduced within the next few years it is unlikely that our 100% PAS policy will be changed. The reassurance of being able to prove that all personal exposures and not just work area levels are ALARP has important legal and worker relations benefits. Even if the current level of PAS and contamination survey sample numbers are not reduced the potential saving of machine downtime would be significant if shorter analysis times could be achieved.

One other major UK facility has reported its results of Be exposure monitoring between 1961-1997 [9]. The authors report much higher exposure profiles than those reported here, with one confirmed case of CBD. The processes involved (melting, casting, powder production, pressing, machining and heat and surface treatments) were much more hazardous than those employed at JET.

Based on our 16 years of experience and much lower exposure levels this gives some reassurance that our strict methods of exposure control may be successful in preventing CBD. It should be pointed out that without routine use of screening tests such as the Be lymphocyte proliferation test the rate of sensitization (as opposed to a diagnosis of CBD) is not known in the JET workforce. Therefore there are grounds for retaining both existing workplace controls and the 100% PAS sampling strategy.

In the field of fusion research the next step machine, the International Thermonuclear Experimental Reactor, (ITER) has been designed and is ready to build; only its host country is yet to be agreed. As this machine is expected to have a Be first wall and future modifications to JET in 2007-8 will involve more extensive use of Be the future benefits on any improvements in Be monitoring are likely to have a significant impact.

The balance of JET experience shows however that even with a 100% sampling policy and large sample numbers, an in-house analysis facility can deliver results within a few hours. Improvements could possibly be made to traditional wet chemistry and AAS techniques by increasing the level of automation.

For an accredited real-time Be analysis instrument to replace traditional mass-based measurement techniques it must meet a number of operational criteria and in particular show that it is cost effective in saving machine operational time at projects like JET and at any future fusion machines. If future studies indicate that Be disease is caused by sub-micron sized particles then a reassessment by us of real-time particle sizing instruments (as compared to analysis instruments) would be required.

CONCLUSION

Overall the result of this analysis and review is that although there is scope to significantly reduce the number of surface contamination smears we are unlikely to change the policy with respect to PAS sampling, despite the extremely low frequency of positive results. This is on the grounds that the benefits of having a result for each and every exposure provide both workforce and management with a high level of reassurance. In addition a likely reduction in the maximum exposure limit for Be in the future together with a recognition that the sensitization rate, if any, is unknown indicates that changing this policy now would not be prudent.

With respect to surface contamination smear surveys there is clearly some scope for reducing the number of samples taken. This might save a significant proportion of the analysis laboratories running costs.

The arrangements for sampling and analysis at JET have largely remained unchanged for over 16 years. Following this review and despite the costs there is strong justification to retain the full scope of sampling. Using traditional analysis methods, sample turnaround times of 2-6 hours are routinely achieved and have minimal influence on machine downtime.

REFERENCES

[1]. Patel, B., Parsons, W., 2003, "Operational Be handling experience at JET," Fusion Engineering and Design, Vol. 69, pp. 689-694.

[2]. Campling, D.C., Litchfield, R.A., Russ, R.M., 1995, "The operation of the JET Be analysis laboratory." *Proceedings of the 18th Symposium on Fusion Technology,* Herschbach, K., Maurer, W., Vetter, J.E., Ed., Elsevier, 3 pp.

[3]. EH40/2005. Workplace Exposure Limits – containing the list of workplace exposure limits for use with the Control of Substances Hazardous to Health Regulations 2002. Her Majesty's Stationary Office, St Clements House, 2-16 Colegate, Norwich NR3 1BQ. ISBN 0717629775.

[4]. Russ, R., 1992, "Beryllium safety at JET." *Proceedings of Symposium on Fusion Technology.*

[5]. UK Health and Safety Executive - Method of Determining Hazardous Substances. 29/2 - Be and Be compounds in air (AA). 1996. Her Majesty's Stationary Office, St Clements House, 2-16 Colegate, Norwich NR3 1BQ. ISBN 0717611302.

[6]. Kelleher, P C., Martyny, J. W., Mroz, M. M., 2001, "Beryllium particulate exposure and disease relations in a machining plant." *Journal of Occup Environ Med,* Vol. **43**, pp. 238-49.

[7]. Infante, P. F., Newman L. S., 2004, "Beryllium exposure and chronic beryllium disease," *The Lancet*, Vol. 363, pp. 415-416.

[8]. American Conference of Government Industrial Hygienists, TLVs" and BEL"s, Notice of Intended Changes, 2002 edition.

[9]. Johnson J. S., Foote K., McClean M., Cogbill G., 2001, "Beryllium exposure control program at the Cardiff atomic weapons establishment in the United Kingdom," *Applied Occupational and Environmental Hygiene,* Vol. 16, No. 5, pp. 619-630.

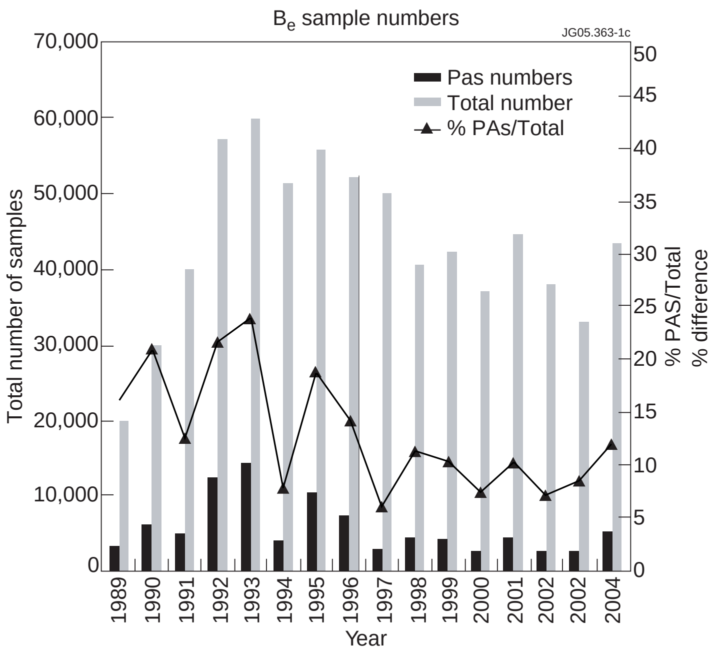

Figure 1:

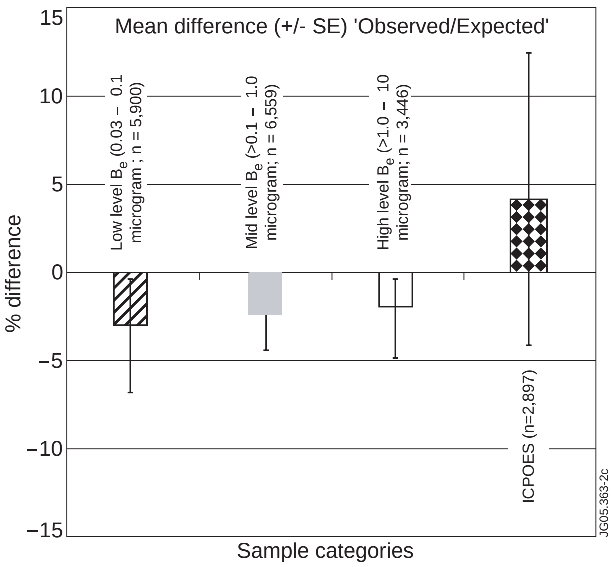

Figure 2:

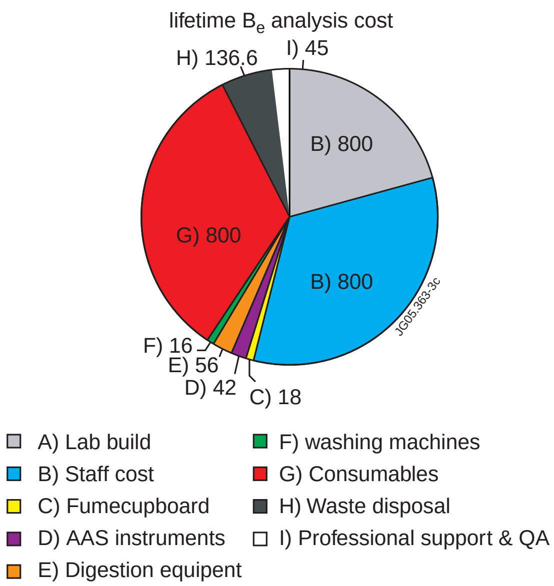

Figure 3:

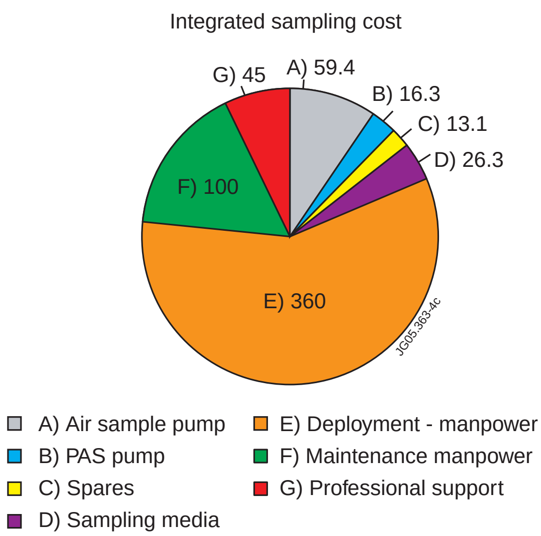

Figure 4: