STUDY INTO THE APPLICABILITY OF THERMOCHEMICAL CONVERSION TECHNOLOGY TO LEGACY ASBESTOS WASTES IN THE UK

A. Downey
British Nuclear Group

D. M. Timmons
ARI Technologies, Inc

ABSTRACT

Waste asbestos from abatement activities within UK decommissioning nuclear sites has traditionally been disposed to licensed landfill or, in the case of radiologically contaminated wastes, the national Low-Level Waste (LLW) repository at Drigg. However, the combination of a number of factors required alternative disposal methods to be investigated for future abatement programs. These include:

- Legislative events which have increased landfill costs and could lead to the banning of asbestos landfill
- Finite capacity within the LLW repository
- Decreasing social desirability and acceptability of landfill which does nothing to reduce the toxicity associated with asbestos wastes

A Value Engineering (VE) study was conducted to identify potential alternative asbestos treatment and disposal methods. Of these alternatives, Thermochemical Conversion Technology (TCCT) appeared particularly attractive because the process converted hazardous asbestos into a harmless substance suitable for construction applications. Furthermore, the process offered significant volume reduction, could be used to treat radiologically contaminated asbestos, could potentially be used to treat other wastes and compared favorably on costs.

The TCCT process has been developed, demonstrated and permitted in the USA and has been subjected to independent verification by the US Department of Energy (DOE) National Energy Technology Laboratory (NETL).

The VE study has investigated the applicability of TCCT within the UK against technical, regulatory, environmental and cost criteria and has concluded that this process appears to offer a number of advantages over the alternatives. Detailed engineering studies will be required to produce plant specifications and target costs to support this conclusion.

INTRODUCTION

British Nuclear Group currently manages a number of nuclear sites within the UK consisting mainly of 11 Magnox gas cooled reactor sites and the Sellafield reprocessing facility. The power stations and parts of Sellafield were constructed in the 1950's and 1960's when use of asbestos containing materials (ACM) was commonplace. Applications for ACM include thermal insulation, asbestos cement building cladding, insulating board, fire protection materials, ceiling and floor tiles and electrical equipment.

The majority of asbestos abatement activities takes place in the early stages of decommissioning and has been completed on 3 power station sites and is in progress on a further 2. Abatement activities are expected to peak around 2007/08 and should be completed by ~2014.

REASONS FOR CHANGE

The following factors outline the main reasons prompting the requirement to investigate alternatives to the traditional disposal routes:

Legislative Framework

A number of legislative changes have been introduced both in Europe and the UK over the last few years which have resulted in landfill disposal being increasingly unavailable for some types of waste and more expensive for the wastes which are still accepted. With respect to asbestos wastes, the main legislative events are as follows:

1. EU Directive 96/61 which introduces the concept of Integrated Pollution Prevention and Control (IPPC) which is to be implemented across Europe between 1999 and 2007. Article 16(2) of this Directive requires that all existing industrial activities covered by the directive must have operating permits based on Best Available Techniques (BAT).
2. EU Directive 99/31 which bans the co-disposal of hazardous and non-hazardous wastes and introduces the requirement to treat wastes prior to landfill.
3. Pollution Prevention and Control Act 1999 – The UK Act of Parliament implementing EU Directive 96/61.
4. Landfill (England and Wales) Regulations 2002 - A new set of regulations implementing EU Directive 99/31 which came into effect on July 16 2004.

In addition to the above legislation, the Chancellor of the Exchequer introduced Landfill Tax from October 1 1996 to provide enhanced financial signals under 'the polluter pays' principle.

The essence of IPPC introduced by EU Directive 96/61 is that operators should choose the best option available to achieve a high level of protection of the environment taken as a whole. The requirement to use BAT ensures that the cost of applying techniques is not excessive in relation to the environmental protection they provide. EU member states should exchange information on BAT, which is then published by the European Commission as BAT Reference (BREF) documents. The BREF documents do not contain any binding requirements, but member states are to take account of them in their own determination of BAT. Whilst it will remain possible to employ non-BAT techniques, these are expected to be very much the exception and the onus will be upon the applicant to demonstrate that there are valid reasons for this. Formal adoption of any asbestos treatment technique as BAT will increase the pressure for a ban on asbestos landfill.

As a result of EU Directive 99/31, a number of EU states have introduced legislation which paves the way for landfilling of asbestos to be banned, although at this stage, no specific dates have been set from which such ban would be enforced. Although similar legislation has not yet been introduced in the UK and there are currently no known plans to do so, a future ban on asbestos landfill presents a significant risk to the decommissioning plans for the sites currently managed by British Nuclear Group.

EU Directive 99/31 and the Landfill Regulations introduced 3 classifications for landfill, which are: hazardous, non-hazardous and inert. Asbestos waste is now only permitted to be disposed to hazardous waste sites or non-hazardous sites where separate engineered cells have been constructed exclusively for this use. As a result, the number of landfill sites in the UK licensed to accept asbestos waste reduced from approximately 270 to <20. This reduction in the number of sites able to accept asbestos wastes had a profound effect on the cost of disposal causing it to literally double overnight. Although the number of sites is expected to increase to between 50-60 as new asbestos waste cells are constructed, the disposal cost is not expected to decrease. As well as the increased disposal cost, most producers of asbestos waste will face additional transportation costs caused by the reduction in number of sites.

The introduction of Landfill Tax in the UK was intended to provide greater incentive to waste producers to reduce the quantity of waste sent to landfill utilizing the reduce, re-use, recycle principles. Landfill Tax is a charge over and above the disposal charge levied by the operator of the landfill and was set at £7/tonne initially. This charge has risen slowly to the current level of £15/tonne but has proved largely ineffective in reducing the quantity of waste sent to landfill. The government has announced its intention to increase this tax by at least £3/tonne/year with effect from April 2005 up to a medium to long term rate of £35/tonne. However, a government committee believes that UK legislation has been too timid on waste management issues and is not convinced that Landfill Tax will have much of an effect until it reaches a rate of £35/tonne [1].

Although EU legislation covers all member states, the national legislation in individual countries can often vary significantly. In France, legislation was passed in December 1992 requiring that asbestos could only be disposed to Special Waste centers reserved for industrial wastes. Furthermore, this legislation mandated the requirement for all asbestos waste to be stabilized[a] from March 30 1998. However, it has been recognized that few techniques exist and Circular 96/60 in July 1996 identified only plasma gun vitrification. Recognizing the high cost of vitrification (~£540-£980/tonne), the French Department of the Environment has since suspended the obligation for stabilization until such time as a technology is developed which is competitive with other disposal methods.

LLW Repository Capacity

A recent project to remove asbestos thermal insulation from a power station site revealed that projections for the quantity of contaminated waste could be significantly higher than previously assumed. Extrapolation of these projections across the remaining sites suggested total quantities far exceeded those assumed within inventories used to plan the lifetime of the Drigg LLW repository.

Conditions for Acceptance at Drigg stipulate that where possible, all waste must have been subjected to volume reduction techniques which, in the case of asbestos, has been achieved through supercompaction. Bags of asbestos waste are placed within 200-liter steel drums, compressed and then packed within half-height ISO freight containers. Previous experience shows that approximately 235-240 compacted drums can be packed into each half-height ISO container. Based on a typical volume reduction factor of 80%, the actual volume of waste within each container is ~9.5m^3. The Drigg disposal charge is levied on the external volume of the disposal container, which in this case is 19.5m^3. The packing efficiency of this waste is therefore less than 50%. These containers are then pumped full of grout and stacked within the repository.

Drigg itself has a finite lifetime dictated by the Environment Agency (EA) disposal authorization, which dictates total activity levels at site closure and volumetric constraints dictated by the consented area. The Drigg management team use inventory details to optimize its use within the given constraints. There was concern that a significant increase in any particular waste-stream could both affect the plans and timetables of other consignors and the ultimate lifetime of Drigg. This, combined with the fact that the anticipated activity levels within asbestos wastes are close to the lower threshold defining LLW prompted the management team to encourage the investigation of alternative treatment and disposal methods.

Social Issues

Over the last few years, greater environmental awareness has resulted in decreasing social desirability and acceptability of landfill as a method of waste disposal. This cultural shift is based on numerous factors ranging from the simple NIMBY (not in my back yard) attitude to legitimate health concerns. With respect to asbestos wastes, landfill does nothing to reduce the toxicity of the waste with the result that there will always be a health risk should the material be disturbed at any time in the future. This on-going, long-term hazard means that such landfill sites can never be returned to normal, unrestricted use.

As identified above, the introduction of new legislation has resulted in the majority of UK licensed asbestos landfill sites closing. Although some new asbestos landfill capacity is being created through the construction of hazardous waste cells on existing sites, this capacity is limited. Construction of further landfill capacity on 'new' sites will become increasingly difficult due to public opposition and the lack of suitable sites in what is a relatively densely populated country.

Whilst not directly concerned with waste disposal issues, introduction of the Control of Asbestos at Work Regulations (2002) has doubled the number of asbestos consignment notes that demolition companies are generating. Indications from industry suggest that over the next 5-10 years there will be a noticeable increase in asbestos removal from buildings, as the regulations require it to be identified, and in the interests of minimizing liabilities and meeting insurer pressure, companies elect to have it removed [2].

Decreasing landfill capacity coupled with increased waste generation will inevitably lead to increasing disposal costs even before future legislative effects and taxation are taken into consideration. A number of alternative technologies have been developed over the last few years which can treat asbestos materials resulting in an end product which is harmless and potentially recyclable thereby removing the need to landfill. However, these technologies have traditionally been unable to compete with landfill disposal on cost. However, in the UK, the point has now been reached where some of these alternative technologies compare favorably on cost – a situation only likely to improve further with the passage of time.

OPTIONS CONSIDERED

A Value Engineering (VE) study was conducted to consider the two main problems associated with the traditional methods of asbestos waste disposal which were:

- Pressure to reduce or avoid use of LLW repository for contaminated asbestos
- Restricted future landfill capacity, rising costs and risk of future ban

As mentioned previously, contaminated asbestos waste has previously been sent to Drigg following supercompaction. Typical waste volume reduction achieved by supercompaction is 80%, a level unlikely to be significantly improved upon by alternative volume reduction techniques. As most of the contaminated asbestos wastes are expected to be close to the lower threshold defining LLW and the main contaminant is Co-60 with a half life of 5.27 years, radioactive decay would cause the contamination level to fall below the LLW threshold after a period of storage. Initial monitoring results suggest that a storage period of 3-5 years will allow the majority of the waste to be treated as free releasable.

For non-contaminated wastes, including those that have undergone decay storage, methods of volume reduction were considered prior to disposal to landfill. Although this would reduce the volume of waste sent to landfill, the cost of disposal would not fall significantly since most of the charges, including landfill tax, are levied on weight rather than volume. The cost of compacting the waste would far exceed any volume reduction savings and this technique does not mitigate against the risk of a future landfill ban.

In order to protect against the risk of a future landfill ban, it was necessary to consider alternatives that did not ultimately rely on such disposal. Asbestos destruction techniques fitted this criterion as their end product is potentially recyclable and has the added advantage that it is also non-hazardous. Many different asbestos destruction techniques have been developed but only two appeared to be proven and commercially available. These are:

- Vitrification
- Thermochemical Conversion Technology

Vitrification Process Description

A number of different technologies can be employed to achieve vitrification of asbestos waste, the most common being the plasma gun as mentioned earlier. This technique was originally developed by Aerospatiale for space and military applications but was developed for use on asbestos by Inertam.

This technique uses a plasma gun to heat the waste to temperatures in excess of 1600°C where it melts to form glass. Asbestos fibers are completely destroyed in this process and the resultant glass could be crushed and re-used in low-grade construction applications such as road building.

The plasma torch is directed at a relatively small area to achieve the required temperature therefore the efficiency of heating is relatively low. Concentration of the heating area also means that throughput of the plant is limited and that heat losses are proportionately higher due to the very large temperature difference between the melted material and the surrounding environment and the limited size of the heated area.

Vitrification processes require that the raw material remains reasonably constant in both chemical and physical properties. For this reason, melting of asbestos to glass requires tight control over raw material input, including control over the particle size of the raw material. This degree of control is difficult to maintain economically in asbestos waste due to the presence of other materials such as fiberglass, calcium silicates, water-soluble silicates, portland cements, clays, calcium sulfate (gypsum), silica, lime, oxychloric-bonded dolomites and a variety of other components used within insulating materials and building products. Asbestos content by weight may vary from 5% or less to almost 100% of these composite materials.

In order to control the vitrification process, the amount of asbestos waste entering the process must either be kept low relative to the amount of glass formers required or, the type of waste entering the vitrification process needs to be controlled to preclude wide variation in raw material chemistry. Whilst some very limited separation of materials may be carried out as part of the asbestos abatement process, it is both impracticable and undesirable to be separating materials on the scale required to maintain chemical and physical properties. Therefore control of the process would normally be achieved through limiting the asbestos material feed rate thus increasing processing costs.

Vitrification processes present a number of technical challenges associated with extreme temperatures and control of the rate of corrosion of the carbon electrodes. The aggressive atmosphere presented by molten silicates also significantly increases both the capital and maintenance costs of this equipment.

Although this technology has been proven, it appears only to be offered as a service to be carried out at the company's premises in France. This introduces a number of potential problems concerning exporting of asbestos wastes, high transportation costs and the inability to utilize the process for contaminated wastes. These reasons, combined with the technical challenges and high cost of processing (~£540-£980/tonne) resulted in the VE study concluding that this technique should not be considered further at this time.

TCCT Process Description

Thermochemical Conversion Technology (TCCT) is a patented process developed by ARI Technologies, Inc that uses a combination of chemical treatment and heat to cause remineralization of asbestos and other silicate materials. The remineralization process accomplishes several goals including:

- Conversion of asbestos minerals into non-asbestos minerals without melting
- Destruction of organic compounds through pyrolysis and/or oxidation
- Immobilization of metals and radionuclides.

The process involves shredding and then mixing asbestos containing material (ACM) with proprietary fluxing agents and heating the fluxed mixture. The presence of fluxing agents at elevated temperatures (approx. 1200 to 1250°C) results in the rapid remineralization of asbestos fibers. The process also results in the destruction of organics including polychlorinated biphenyl's (PCB's) to 99.9999% efficiency. Toxic metals and radionuclides are stabilized in the sintered product through molecular bonding that exhibits excellent chemical durability and surpasses US Environmental Protection Agency (EPA) and DOE leaching standards.

The processing equipment consists of four primary systems including feed preparation, rotary hearth converter, off-gas treatment and product removal. The system is modular and can be modified independently of other systems to accommodate a variety of feed materials. Each of the systems is described below:

- The feed system consists of waste handling conveyors, a shredder, mixer, hopper and feed mechanism which compresses the ACM into a brick and simultaneously pushes the compressed ACM onto the rotary hearth

- The rotary hearth is a flat circular oven that rotates. The rotary hearth can be direct fired using natural gas, propane or kerosene or can be electrically heated. Waste to be processed is pushed onto the hearth and is then removed after one rotation
- The off-gas processing system can be designed to accommodate a variety of wastes as well as asbestos and consists of secondary thermal oxidizer, quench cooler, caustic scrubber and High Efficiency Particulate Air (HEPA) filtration
- The treated product is scraped off the hearth and dropped into a water bath to cool. The product handling system removes the treated product from the water bath using an auger. The auger transfers the treated product into holding bins to await verification testing

Operation of the plant typically follows this sequence:

- All waste arrives at the plant in the same form as it left the abatement activity (i.e. double bagged or wrapped)
- The waste is moved into an air-locked material handling area maintained at negative pressure to prevent asbestos fiber escape and ventilated using HEPA filters
- After being weighed, the bags of ACM are loaded onto the process conveyor that drops them into a shredder where they are reduced to <2 inch (50mm) diameter particles. NOTE the process accepts all material normally placed within asbestos waste bags including binders, cement coatings, sealants and paints, chicken wire, expanded metal, Personal Protective Equipment (PPE), polyethylene tenting material etc
- Potential worker exposure is limited at all times. Abated asbestos is typically wet when removed and contained within double, 1000 gauge, polyethylene bags. These bags are loaded complete onto the process conveyor where all processes are within enclosed areas served by a separate HEPA filtered extract system
- The shredded material is dropped into a mixer where the fluxing solution is added
- The mixed material is then transported to the feed hopper via an enclosed conveyor
- From the bottom of the hopper, a feeding mechanism compresses the ACM into a brick and pushes it into the rotary hearth
- After 1 rotation of the hearth (currently about 20 minutes), the converted ACM is removed from the hearth to a water bath for cooling
- The treated product is transferred by auger from the water bath to holding bins
- The off-gases are routed through a secondary thermal oxidising unit for the destruction of residual organic compounds that may be present in the gas
- The off-gases are then routed through an off-gas treatment system consisting of quench-coolers, caustic scrubbers and HEPA filtration before exhaust to atmosphere
- Off-gas sampling takes place from the stack to ensure compliance with discharge authorizations
- Samples of converted product are analyzed using Transmission Electron Microscopy (TEM) to confirm absence of asbestos fibers

The TCCT process takes a hazardous product (asbestos) and converts it to an inert, non-hazardous, non-toxic product that resembles coarse sand/gravel and can be used in low-grade construction applications.

The presence of the fluxing agents means that the conversion takes place more rapidly than would otherwise be the case due to the refractory nature of asbestos and at a much lower temperature than that required for vitrification. As the conversion is achieved at temperatures significantly below the melting point of asbestos, the energy input is much lower than that of vitrification and the capital cost of materials capable of withstanding molten silicates is avoided.

Volume reduction ranging from ~50% for asbestos cement products to >90% for friable asbestos is achieved through the removal of OH^+ groups, reduction of pore space and increase in density. The process also results in mass reduction of ~50% primarily through the removal of the OH^+ groups but also from destruction of plastics and organic compounds. Additives in the form of fluxing agents form <1% of the weight of the feedstock.

Continual development of the technology has resulted in increased capacity achieved by reducing the residence time in the rotary hearth. Tests carried out by the developer of the technology have proved that complete asbestos destruction can be achieved with residence times as low as 10 minutes. These developments when applied to commercial scale plant should allow residence time to be safely reduced from the current 20 minutes to 12-15 minutes with a resultant increase in plant throughput.

In addition to asbestos, TCCT has been successfully employed for the treatment of other waste streams. Potential applications include man-made mineral fiber insulation (MMMF), oils, wood, personal protective equipment (PPE), plastics, solvents and putrescent waste subject to receipt of appropriate permits.

The TCCT process has successfully received approval from the US EPA both to convert asbestos and to destroy PCB's. Following receipt of these approvals, second generation modular units have been constructed which are smaller in size with higher processing capabilities. Asbestos conversion has been carried out successfully for the US DOE (Savannah River), US Navy and US Army. The Savannah River work was subject to independent verification by the US Department of Energy (DOE) National Energy Technology Laboratory (NETL) [3].

A Pollution Prevention and Control (PPC) permit would be required from the Environment Agency (EA) before TCCT could be employed in the UK. Although the issuing of permits in the US will assist any application and initial discussions with the EA have been positive, this stage could still take many months to achieve. Plans for a similar TCCT plant in Ireland were announced over 2 years ago and it is believed that following a great deal of background work, a formal application for a permit has recently been made to the Irish Environmental Protection Agency (EPA). A successful outcome to this application could assist any other applications within the EU as they all fall under EU Directive 96/61 for IPPC as outlined earlier. The second draft reference document for BAT for the Waste Treatment Industries currently identifies TCCT as BAT for the processing of asbestos [4]. Inclusion of this technology as BAT in the formal issue of this document should lend further support to any PPC application. Processing of any radiologically contaminated material would be subject to a separate permit application under the Radioactive Substances Act 1993.

The VE study concluded that TCCT offered an attractive proven solution which could be used to process both contaminated and non-contaminated wastes as well as a number of other waste streams at a cost which compared favorably with landfill disposal. However, it was noted that further work was required to investigate regulatory issues, potential siting and fuel types to confirm some of the assumptions made.

ECONOMIC EVALUATION

In order to support the VE study, cost information for the different options has been obtained and is presented below in Table I. Fees for each of the options are levied in different ways but are presented here in terms of cost per tonne of waste to provide direct comparability.

The current method for disposal of contaminated wastes is to the LLW repository at Drigg, having first been volume reduced by supercompaction. For previous abatement programs, supercompaction has been achieved through use of a service provided by a specialist contractor. For completeness, costs are presented both for use of this leased service and for the purchase and operation of a dedicated supercompactor.

TCCT costs have been determined primarily from data provided by the technology developer as modified by known UK information (energy and manpower costs etc). These costs can be reduced with an increase in system scale.

No costs are presented for decay storage of asbestos wastes. The facilities already exist and whilst some refurbishment cost will be incurred, this is judged to be negligible in comparison with total waste quantities.

Table I. Cost Comparison of Asbestos Waste Disposal Options

	Cost £/Tonne
Landfill[b]	140 - 180
Drigg/Leased Supercompactor[c]	9,100 – 11,100
Drigg/Bought Supercompactor[d]	3,800
TCCT[e]	70 - 150

CONCLUSION

The VE study has confirmed that traditional methods of disposal for asbestos waste from UK decommissioning sites are becoming increasingly unattractive, costly and ultimately, unavailable. Evaluation of the factors emerging from the VE study have revealed that:

- Landfill disposal costs already exceed those of some alternatives. Recent experience of legislative effects show that future costs are highly unpredictable leading to financial risks
- Disposal to Drigg is both expensive and an inefficient use of a finite resource. Decay storage should be used as a method of minimizing or eliminating contaminated waste
- There is a real risk of introduction of a landfill ban within the current decommissioning timeframe. A viable alternative is needed to mitigate against this risk
- Asbestos destruction techniques remove the requirement for landfill disposal and can compare favorably on cost
- Existing disposal methods have significant environmental and health risks. Asbestos destruction techniques address these risks whilst providing potential public relations advantages

- The benefits identified will be maximized by early adoption of asbestos destruction techniques

Whilst a number of asbestos destruction techniques have been developed, the study concluded that, of the options currently commercially available, TCCT appeared to offer the most complete solution under present legislative and regulatory conditions within the UK. The main factors underpinning this outcome were the ability of TCCT to process both contaminated and non-contaminated asbestos as well as a number of other waste streams at a cost which compared favorably with landfill disposal.

A detailed engineering study will be required to develop exact plant specifications, optimum plant siting, fuel supplies and manpower resources from which more accurate pricing can be determined. Further work will also be required to investigate the regulatory and planning issues necessary to support this option. Only when these stages are completed can a final decision be made regarding adoption of this technology.

REFERENCES

1. House of Commons Environment, Food and Rural Affairs Committee, The Future of Waste Management, Eighth Report of Session 2002-2003 Volume 1, May 2003.
2. UK Environment Agency, Hazardous Waste Management Market Pressures and Opportunities: Background Paper P1-484/TR, 2003.
3. US Department of Energy National Energy Technology Laboratory (NETL), Tech ID 3114, Technology Deployment for Asbestos Destruction, September 2002.
4. European Commission Integrated Pollution Prevention and Control, 2nd Draft Reference Document on Best Available Techniques for the Waste Treatment Industries, January 2004.

FOOTNOTES

[a] Stabilized in this context means that the waste has been treated so that the hazard has been removed and that the treatment is irreversible.

[b] Figures supplied by ALCO Waste Management and are inclusive of landfill tax of £15/tonne but exclusive of transportation costs.

[c] Figures based on 1000-drum compaction campaign. Lower cost for work carried out at operator's site and higher cost for work at client site. Cost includes Drigg disposal charge of £2,200/tonne.

[d] Based on 10-year operational life of plant at 15,000 drums/year. 9% discount rate applied to capital cost.

[e] Based on 50 US ton/day plant with 10-year operational life and availability of 80%. 9% discount rate applied to capital cost. Range in cost due to type of fuel used and license obtained.