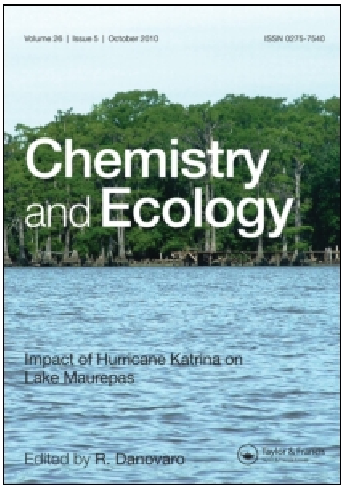

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GYPSUM WASTE DISPOSAL: LAND VS SEA OR RECYCLING

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1. INTRODUCTION

In British Columbia (B.C.), a province located on the west coast of Canada, approximately 300,000 tonnes of gypsum wallboard is manufactured each year. It is estimated that 6–10% of this new product ends up as construction waste material. Other sources of waste gypsum are demolition projects, rejects or culls from manufacturing plants, and moulds for plumbing fixtures.

The bulk of B.C.'s residential and industrial development is in the southwest corner of the province. This area, known as the Lower Mainland, encompasses the City of Vancouver, the greater Vancouver area and several municipalities. Much of this area is built on the estuary of the Fraser River. The Fraser River possesses one of the largest natural salmon runs in the world and produces more than one quarter of all salmon caught commercially and recreationally off Canada's west coast at a value of about 90 million dollars annually. The low-lying estuary makes the locating of landfill sites particularly difficult, when the potential exists for toxic leachate generation below the water table, or in areas susceptible to run-off (Atwater, 1980). Landfill sites, if not properly operated, pose an environmental risk to the Fraser River and tributary streams.

In the mid to late 1970's and early 1980's the Federal Department of Fisheries and Oceans implicated landfill sites in the deterioration of water quality in streams feeding the Fraser River. In addition to toxic leachates attributed to landfilled woodwastes from B.C.'s major forest industry, waste gypsum was targeted as a likely source of elevated sulphide levels in nearby streams (Birkbeck, 1987).

2. LAND DISPOSAL PROBLEMS

Gypsum wallboard consists primarily of gypsum rock or hydrated calcium sulphate ($CaSO_4.2H_2O$). Gypsum rock is mined from large deposits throughout the world, including the west and east coasts of Canada, and is relatively inexpensive. In the production of wallboard the gypsum rock is ground in a hammer mill to a fine material and then heated until it loses all water to become anhydrous calcium sulphate, or anhydrite. The anhydrite (or calcined gypsum) is combined with paper, starch and clay to become wallboard with a paper backing. In addition to sulphate in gypsum, the wallboard contains small amounts of two other sulphur-containing species i.e., alkyl ethoxy sulphates as foaming agents and lignin or naphthalene sulphonates as dispersing agents. It is thought that one or more of these compounds result in the elevated sulphide levels in leachates that can lead to the generation of toxic hydrogen sulphide (H_2S).

Gypsum is stable under normal conditions; however, in a moist anaerobic environment in the presence of organic materials the action of sulphate-reducing bacteria, such as *Desulphovibrio* or *Desulphotomaculum,* can reduce sulphate to sulphide ions (Meyer, 1977). These conditions potentially exist in low-lying fill sites, where waste gypsum has been mixed with putrescible garbage and covered over by subsequent dumping. Even without the garbage component the paper in the wallboard may provide enough organic substrate to promote H_2S formation over time. The production of sulphide ions may lead to the generation of malodorous hydrogen sulphide gas and toxic leachates. H_2S is known to be toxic to fish at low levels.

Hydrogen sulphide gas is detectable at very low concentrations. The B.C. Workers' Compensation Board considers air containing up to 10 ppm H_2S safe for breathing at industrial operations. Above 1000 ppm a human health hazard exists. In the early 1980's a serious odour problem developed at a Lower Mainland landfill site which has accepted 42,000 t of a manufacturer's reject wallboard, i.e., substandard board culled from the production line, over a four-year-period. Typical gases at this overall site contained about 55% methane, 45% carbon dioxide and up to 610 ppm hydrogen sulphide. The gases emerging from the area which received the waste gypsum contained in excess of 5000 ppm hydrogen sulphide.

A boat yard built on filled and reclaimed land adjacent to the Fraser River developed an odour problem in 1979. Tests on samples from ditches in the area showed elevated sulphide levels and leachate which was toxic to fish. Further investigation revealed that the area had been filled with wood-mill wastes and gypsum wallboard waste. Other landfills in the Lower Mainland have suffered problems of varying degrees as a result of the indiscriminate dumping of gypsum wastes. When law suits were launched in the early 1980's as a result of leachate contamination of the Fraser River, landfill operators took notice and became very selective as to what they would accept.

3. REMEDIAL ACTION

Landfill operators began taking steps to reduce or eliminate problems arising from past dumping practices. Some of these included: installing a flaring system to burn off the malodorous gases; segregating the waste gypsum from other wastes on site and placing it above the water table; and mixing the waste with sand and capping it with a layer of sand or clay-silt material. Methods were also employed to reduce the intake of waste gypsum. These included restricting the place of origin (i.e. the municipality), quantity and times of the day when the wastes would be accepted. In anticipation of having to give special treatment to this waste or simply to reduce intake, some operators greatly increased the dumping or tipping fees charged, i.e. up to $85 per tonne. Other operators totally rejected any loads containing waste gypsum, with the exception of small quantities mixed in with demolition debris.

At about the same time, a joint committee of provincial and municipal regulatory people produced a report on gypsum disposal in the Lower Mainland (Lower Mainland Refuse Project, 1985). The committee recommended that waste gypsum be crushed, mixed with a chemical oxidizing agent such as calcium oxide (CaO) to promote the oxidation of sulphide back to sulphate and be placed in separate cells isolated from other landfilled materials. A further recommendation was that manufacturers' wastes be banned from regular disposal at all Lower Mainland landfill sites.

Rather than have to deal with special treatment and the dedication of special areas within landfills of limited capacity, many operators opted for total rejection of wastes containing gypsum. By mid-1980, very few legitimate options existed for the disposal of this gypsum. Many builders began stuffing waste wallboard between wall joints or burying it in the back yard at construction sites. Home renovation wastes would be smuggled into landfills, buried, or dumped along the roadside in some remote area. Manufacturing plants were stockpiling reject substandard board. Disposal and construction companies and wallboard manufacturers were virtually forced into seriously considering other disposal options. The two most promising options which emerged at this time were recycling and ocean disposal.

4. RECYCLING WASTE GYPSUM

Various recycling options have been considered, with the principal ones being agricultural use and returning the waste to the wallboard-manufacturing industry. Beneficial uses in agriculture have been demonstrated and include: growth stimulation in leguminous crops; improvement of fertiliser utilization; softening of clayey soil; and neutralising of alkaline and saline soils (Pressler, 1984). At present, the agricultural usage in B.C. accounts for only about 1000 t annually, which does not make this application a significant means of waste reduction. The waste disposal industry is currently pursuing its use in the mushroom-growing industry and the use of the paper backing for bedding or nesting material in the broiler chicken industry. The paper and associated calcium sulphate may counteract the ammonia generation problem in nesting material at chicken farms. As will be discussed later, the removal of the paper backing makes waste gypsum more suitable for use in the production of new wallboard.

Manufacturers have identified several problems with using recycled board in new board production. One popular wallboard product is designated Fire Stop for its fire retardant properties. This board must be manufactured in accordance with formulations and procedures which restrict the amount of paper fibre in the core of the board. The structural strength of the board may also be affected by too high a paper fibre content. To limit the amount of paper backing introduced with recycled gypsum, large mechanical crushing and screening equipment has been developed. Construction waste material must also be screened for metal filings, nails, staples, etc., which can damage equipment in the manufacturing plant.

Wet gypsum waste can be added to gypsum rock prior to entering the hammer mill; however, too much can cause the conveyor belt to jam and the mill to plug up. Excessive wet material can also disrupt proper calcination of the gypsum. Because of the strong wallboard market, and the availability of inexpensive raw gypsum rock, there is not much incentive for manufacturers to take used products, which might affect the quality of their new wallboard.

Dry wallboard which is deemed substandard and culled at the plant can be recycled by cutting into 12.7 × 12.7 cm chips which are control-fed in with the raw gypsum rock. The dry waste can be recycled in larger quantities than the wet waste but is still limited by the percentage of paper fibre allowable or desirable in the new products.

5. OCEAN DISPOSAL CONSIDERED

5.1. *Regulatory process*

In 1988, the new Canadian Environmental Protection Act (C.E.P.A.) became law in Canada replacing several pieces of environmental legislation to create a comprehensive approach to environmental protection. Part VI of C.E.P.A. replaced the Ocean Dumping Control Act which had been passed in 1975 to fulfill Canada's international obligations under the London Dumping Convention. The disposal of wastes at sea is regulated through a system of permits and inspections administered by Environment Canada under Part VI of C.E.P.A. The ocean dumping provisions of C.E.P.A. call for a comprehensive waste management approach which requires a comparative assessment of land and sea disposal options. Dumping at sea is permitted only in cases where the disposal of wastes meets regulatory requirements under C.E.P.A., and no other environmentally preferable and practical alternative is available. The following waste management principles are taken into account whenever the sea disposal option is considered:

–whenever possible, recycle and reuse waste products;

–wastes that cannot be recycled or reused should be treated at the source to the extent possible;

–wastes that cannot be avoided or reused at a reasonable cost must be disposed of safely; and

–sea disposal should only be used if it poses less or no greater human health and environmental risks than practicable land-based alternatives.

In 1985 Environment Canada received an ocean dumping application from one of the major wallboard manufacturers in B.C. The company had been stockpiling reject substandard board in an open area close to their plant for several years. The plant was to be closed down and the land put to alternative use which would require the removal of about 5000 t of stockpiled waste. At another plant recently purchased by the company, 15,000 t of culled wallboard waste had filled up the available storage space and had to be removed or reduced to allow normal plant operations. Much of the waste at the closing plant had been exposed to weather for several years resulting in varying degrees of degeneration. Some of the older board showed little or no sign of paper backing. The company's efforts to find a landfill site which would accept these wastes were fruitless.

In evaluating the ocean dumping application, a Regional Ocean Dumping Advisory Committee (RODAC), representing research scientists, oceanographers and regulatory agencies, including the federal Departments of Environment and of Fisheries and Oceans, met to address the following questions:

-will disposal at sea result in floatable solids and/or a surface turbidity plume?

-will the dumped wastes adversely affect water quality or alter water column or sediment chemistry?

-will the wastes be toxic or have a physical smothering effect on benthic communities?

It should be noted that gypsum waste is not prohibited or even restricted from ocean dumping under regulations for Part VI of C.E.P.A., or in the London Dumping Convention.

5.2. *Surface effects*

Flotation tests were carried out on varying sizes of new 1.27 cm thick wallboard. The tests indicated that large pieces, i.e., 122 cm × 244 cm or 61 cm × 244 cm sheets, would float up to four days in sea water, whereas smaller pieces, i.e. less than 61 cm × 61 cm would sink in about one hour. Previously immersed pieces removed from the sea water for up to ten hours and then re-immersed would sink immediately. It was believed, therefore, that crushing and wetting the wallboard would enhance sinking. There remained some uncertainty as to the amount of floatables to expect and the time these might remain on the surface. The degree and persistence of a turbidity plume was also unknown.

5.3. *Water column and sediment effects*

In the application for disposal at sea, it was proposed that the dumping take place in the Strait of Georgia, a large body of water between the mainland of B.C. and Vancouver Island. The Strait of Georgia is about 160 km in length and 30 to 40 km wide with water depths up to 400 m. Since the major elements (or compounds) contained in gypsum waste occur naturally in sea water, a budget was worked out for calcium (Ca^{++}) and sulphate ($SO_4^=$) in the waters of the Strait of Georgia. The implications of introducing 80,000 t (representing several years waste generation) of waste gypsum into the system are discussed below (Macdonald, 1985, pers. comm.):

Budget

—sea water in the Strait of Georgia approximately 1×10^3 km^3

—$SO_4^=$ in sea water approximately 2.3 gl^{-1}

—Ca^{++} in sea water approximately 0.35 gl^{-1}

—$SO_4^=$ in the Strait of Georgia approximately 2.4×10^9 t

—Ca^{++} in the Strait of Georgia approximately 3.6×10^8 t

Introduced Gypsum

—approximately 8×10^4 t
—containing—$SO_4^{=}$ approximately 4.4×10^4 t
—Ca^{++} approximately 1.8×10^4 t

The amount of sulphate to be dumped would be naturally present in 2×10^7 m^3 of sea water. The volume of sea water contained within the bounds of a typical dump site established in the Strait of Georgia, i.e. with a radius of 1.85 km, and a depth of about 200 m, would be approximately 2.6×10^9 m^3. Therefore, even if all of the gypsum dissolved in the water column at the dump site (which we did not expect) we would expect an increase in sulphate of about 1%, a relatively insignificant amount. Since the waters of the Strait of Georgia are oxic, we would not expect sulphide to be produced from sulphate in the water column.

A considerable amount of gypsum would be expected to end up on the sea floor, where it would be subject to transport, burial and dissolution. Would the introduction of this waste increase the potential for generation of toxic hydrogen sulphide? To reduce sulphate to sulphide requires 2 atoms of metabolizable organic carbon as per the following generalized reaction (using carbohydrate as a carbon source):

$$2CH_2O + SO_4^{=} \longrightarrow H_2S + 2HCO_3^{-}$$

Considering the paper backing to be inert and the amount of starch minimal, the waste gypsum would not introduce an appreciable amount of metabolizable carbon. Since the sediments already contain carbon (0–3%) and sulfate (2.3 $g l^{-1}$ in pore water), we would not expect the addition of gypsum to alter the pore water chemistry or existing sediment chemistry.

Over time, the calcium sulphate that has not been dissolved will be buried by natural sedimentation to a depth where the sediments become anoxic. Sulphide produced there will diffuse upward and be lost to pyrite precipitation or oxidation in the oxic pore waters. Since sulphate is naturally present as a conservative compound at fairly high concentrations, the potential for gypsum to contaminate sea water is far less than its potential to contaminate lakes, rivers or ground water.

5.4. *Toxicity and smothering effects*

Although the constituents of the waste material were considered innocuous, 96-hour acute lethality bioassays were run by Environment Canada using rainbow trout in fresh water and chum salmon in sea water. At a concentration of 25% by weight the waste was not toxic to these species in the bioassay tests. It was expected that the waste would have a localized smothering effect on benthic infauna at the dump site. The impact on natural resources could be minimized by locating the dump site in an area of low benthic life and/or in an area with a relatively high rate of natural sedimentation to enable subsequent re-colonization.

6. TEST DUMP

Following the comparative assessment of land based disposal options and at sea disposal, Environment Canada issued a permit to conduct a test dump of some of the manufacturer's waste in the Strait of Georgia. The site chosen was a Department of National Defence disused ammunition dump in about 380 m of water and in an area removed from commercial and recreational fishing. Natural siltation at the site was about 2 cm per year.

The permit was conditional on the applicant monitoring the dumping and recording environmental impact. Approximately 5000 t of the weathered waste gypsum from the closing plant was thoroughly crushed and wetted and loaded on a flat scow. Off-loading was by front end loader over a period of about 10 hours.

A monitoring programme was designed to determine dispersion characteristics of the suspended solids associated with the dumping and to visually record any floating material. The equipment used to track the suspended solids was the Variosens Nephelometer/Guildline CTD Profiling system. The system is composed of two major components which provide a digital, *in situ* instrument package for sensing and recording turbidity, conductivity, temperature and depth. The Variosens (or sensor for various purposes) is a sensitive fluorometer/nephelometer made in West Germany. The Guildline Model 8705 digital CTD is a precision profiling system developed by Guildline Instruments of Ontario, Canada, in conjunction with the National Research Council of Canada and the Bedford Institute of Oceanography in Nova Scotia, Canada.

The monitoring programme consisted of 6 casts, one prior to commencement of dumping and 5 during the dumping. The data reported by the consultant firm (Gillie, 1985) suggested that the turbulent surface water conditions and the prevailing currents and strong winds dispersed the dumped material rather quickly. The maximum levels of suspended solids measured were in the order of 3 mg/1. Aerial observations during the dumping tended to confirm a very localized surface turbidity plume, immediately downwind of the scow, and very little observable paper floating on the surface.

Despite what may be taken as relatively positive results from the test dump, RODAC remained concerned that under different circumstances, such as calmer weather or different waste characteristics, floatables or turbidity might cause a significant aesthetic impact. The Strait of Georgia in general, is used extensively for commercial and recreational fishing, and during summer months, for pleasure boating. To ensure that the amenities of the Strait of Georgia and nearshore coastal waters would not be affected, RODAC established guidelines that any subsequent at-sea disposal of waste gypsum wallboard would take place at a deep ocean site beyond the continental shelf. The guidelines further stipulated that waste gypsum from construction and demolition projects must be thoroughly sorted through to remove all floatable foreign material and any plastic or vinyl wall board coverings.

7. DEEP-OCEAN DISPOSAL

7.1. *Preparing the waste*

In 1986 a company was established in the Lower Mainland for the purpose of handling and disposing of waste gypsum wallboard and other gypsum products (Waters, 1988). At a gypsum transfer station, a yard and warehouse were set up where truck loads of construction and demolition debris could be sorted and the wallboard crushed and stored prior to loading for deep-ocean disposal. From every 10,000 t of waste trucked into the yard, about 60 t of scrap metal is recycled and 200 t of assorted debris (i.e., plastics, vinyl coverings, fibreglass insulation, wood, bottles, cans, etc.) is taken to landfill. The remainder is waste gypsum wallboard or other minor gypsum products.

In 1987, Environment Canada issued a permit to the gypsum transfer company to dispose of up to 15,000 t of waste gypsum over a twelve-month period. The site chosen for disposal was located about 100 km west of Cape Flattery (see Figure 1) in 1000 m of water beyond the continental shelf. This site, known as the North Pacific Ocean Dump Site (N.P.O.D.S.), had been previously designated for materials not suitable for disposal in internal waters, such as contaminated dredge spoils and excavation soils. The dump site was approximately 300 km from the transfer station requiring a $2\frac{1}{2}$ day round trip for a sea-going tug and scow at a cost of about $40,000 per trip. Conditions of the permit included that the waste be crushed and wetted and that a government inspector be present during loading

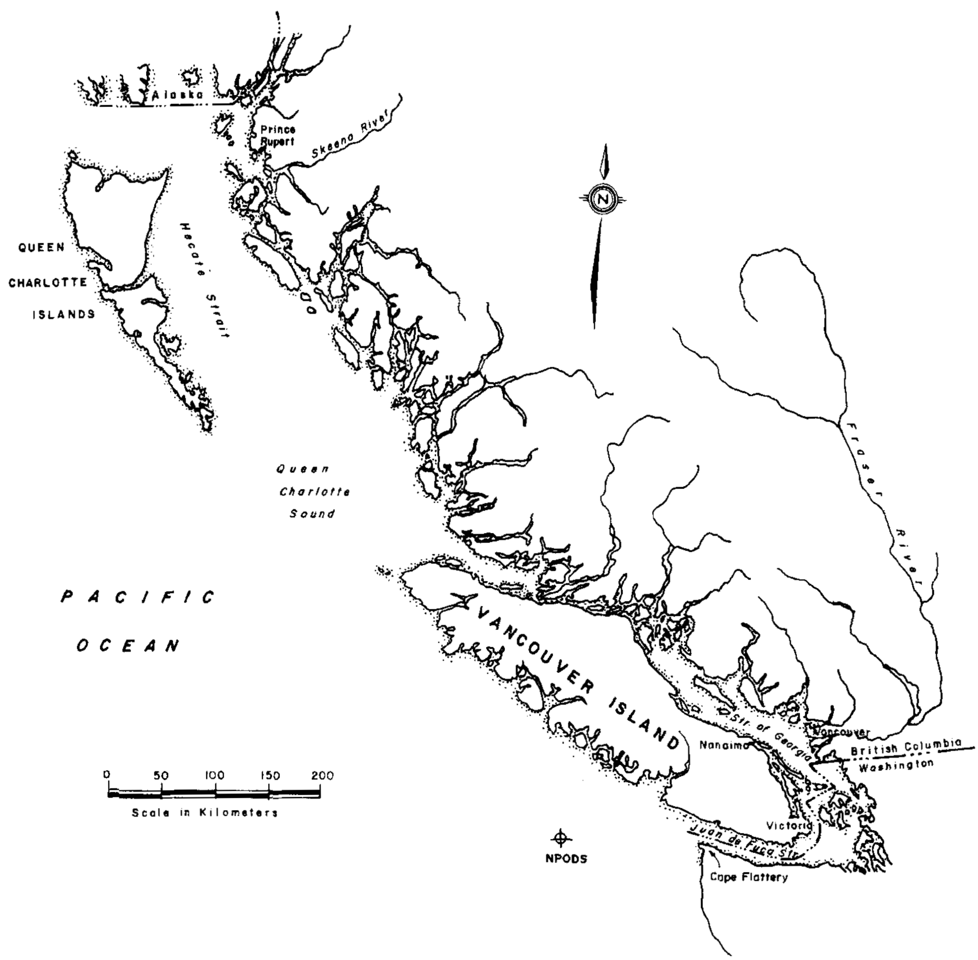

Figure 1 North Pacific Ocean Dump Site location.

and dumping operations. The permit holder was also required to have aerial observations and photographs taken during a portion of the disposal operation.

7.2. *Flat scow dumping*

The first load of about 3500 t of waste went to N.P.O.D.S. on a flat scow. Off-loading was accomplished in 10 hours using a front-end loader with a 3 m^3 bucket and a power shovel with a 1 m^3 bucket. In addition to the visual observations and photographs taken by the on-site inspector, aerial photographs were taken from a small chartered aircraft. Although the waste had been wetted down prior to loading, by the time off-loading began, very little if any of this pre-treatment was apparent. There was an immediate dust problem which was irritating to the operators on the scow, and much of the paper backing had separated from the gypsum. The paper, being quite dry, formed a trailing mat downwind of the scow that extended for several kilometers by the end of the dump. Although the bulk of the waste gypsum sank readily, the extent of the paper trail was unacceptable, since it was unknown how long the paper would remain floating nor its extent of dispersion.

In an attempt to resolve the dust and paper problems, the next load of waste was wetted down using fire hoses during the loading. The Canadian Armed Forces provided additional aerial surveillance by making several passes and keeping a photographic record of the dumping operation and the spread of floatables. Three oil spill markers developed by the Institute of Ocean Sciences, Sidney, B.C., and Novatec Limited were also deployed. The spill markers are designed to be dropped from a light aircraft to track the drift of spilled oil. The battery-operated markers emit a low-frequency signal (approximately 150 mHz) which can be picked up at a distance of 42 km. In this application, they were released by the on-site inspector at the start of dumping, half way through and on completion of the dump.

It was intended to have the Canadian Forces plane track the paper trail until it dissipated. The floating paper was again very extensive despite the more efficient wetting procedures. Although the paper trail was observed by the plane the day after the dumping, no spill marker signals were picked up, and fly-overs on subsequent days failed to locate floating paper. The problem appeared not to be with the spill markers, but rather with the signal-receiving equipment aboard the aircraft. The second disposal operation, therefore, offered no additional information as to the spatial or temporal distribution of floatables other than to confirm that the wetting-down procedures could not eliminate or even significantly reduce the paper trail. There was, however, a noticeable reduction in dust generation on the second trip, much to the delight of the operators on the scow.

7.3. *Bottom dumping*

Following a review of the second disposal operation, Environment Canada indicated to the applicant that no further dumping would be approved unless a significant reduction in floatables was assured. It was fortunate for the applicant that a marine contracting firm in the area had recently acquired large 2000 t capacity bottom dump or hopper scows suitable for off-shore operations. This type of scow offered several advantages over the flat scow although the load capacity was reduced by about 50%.

The bottom dump scow could be off-loaded or opened by remote control from the towing vessel and dumping would be almost immediate. This feature reduced the time spent off-shore at the dump site and eliminated the need for operators on the scow. The bottom of these scows is not water tight; therefore, much of the waste gypsum located below the water line would be exposed to water while loading and during transport to the dump site. The wetting down procedure had been further improved by having the load operator use his large clamshell bucket to occasionally pick up water and release it on the load. When loads are dumped in large clumps or all at once, even positively buoyant material, such as the paper backing, tends to be pulled under water initially, thereby losing trapped air and becoming less buoyant.

The third waste gypsum disposal operation with the use of a bottom dump scow was a great improvement over previous dumps. There was a marked reduction in paper floatables and virtually no dust was generated. The waste gypsum sank rapidly leaving a localized turbidity plume in surface waters which dissipated quickly. While the new wetting-down procedures and exposure to water from below increased the negative buoyancy of the waste, it also made the material more cohesive or sticky. The result was that the load did not discharge immediately upon opening the scow, as one would expect with a load of dredge spoil or gravel. It was necessary to tow the scow in an open position for about one hour to release all of the load. Nevertheless, Environment Canada considered this method as an acceptable method of at-sea disposal of waste gypsum wallboard with a minimum impact on the marine environment.

Subsequent loads of waste have been dumped at a new site designated in 1988 at the request of the Department of Fisheries and Oceans. The request was in response to concerns that commercial trawlers may be fishing in the vicinity of N.P.O.D.S. The new site was located about 50 km further off-shore in 2,500 m of water. To date approximately 12,000 t of waste gypsum have been dumped at this site.

FUTURE WASTE GYPSUM MANAGEMENT

The amount of waste gypsum wallboard requiring at sea disposal is expected to be greatly reduced in the future. The gypsum transfer station has developed and put into operation an effective paper removal system which leaves the gypsum in a powdered form suitable for recycling in the production of new wallboard. One of two wallboard manufacturers in B.C. has signed an agreement to purchase the powdered gypsum for $1.00 per tonne, up to a tonnage equivalent to 15% of it's annual production, or about 18,000 t per year. Negotiations are currently underway with the other manufacturing company to strike a similar agreement.

The transfer station, presently the only one operating in the Lower Mainland, expects to take in about 26,000 t of waste gypsum in 1989. At the encouragement of Environment Canada, and recognizing that recycling is more economical than at-sea disposal, the transfer company intends to process all the suitable waste gypsum taken in. A small amount of gypsum, which arrives mixed with a foreign material such as dirt or sand, is unsuitable for recycling and will be ocean dumped. It is anticipated that 90% or more of the waste gypsum generated by all sources will be recycled by the end of 1989.

SUMMARY

The disposal of waste gypsum wallboard at landfill sites in British Columbia (B.C.), Canada, resulted in the generation of hydrogen sulphide gas and toxic leachates. Although some remedial measures were taken to reduce or eliminate problems resulting from past dumping practices, many landfill operators refused to accept new waste for fear of litigation over the pollution of nearby streams and rivers. With the availability of legitimate disposal sites greatly reduced, a serious waste management problem arose. The two most promising options for reducing the accumulating waste appeared to be recycling and ocean disposal.

Agricultural use of the waste for soil conditioning would account for only a small portion of the waste generated annually. Manufacturing plants were reluctant to accept waste gypsum with a high paper fibre content for fear it would lower the quality of the new wallboard product or interfere with the existing equipment and processes in the plants. The technology for economically removing and separating the paper from the used or substandard wallboard had yet to be developed.

The environmental implications of disposal at sea were assessed by a government advisory committee under the provisions of the Canadian Environmental Protection Act. Although results of a test dump in internal waters of B.C. were positive, the committee felt that valuable amenities of nearshore waters would only be assured by restricting dumping to a remote offshore location. An acceptable disposal method with minimal impact on the marine environment was eventually found with appropriate pretreatment of the waste and the use of remotely controlled bottom dump scows. Recent progress in the processing of waste wallboard to make it acceptable to the manufacturing industry should significantly reduce if not eliminate the need to dispose of gypsum wallboard wastes at sea.

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