WHO OMS

WORLD HEALTH ORGANIZATION - REGIONAL OFFICE FOR EUROPE - 8, SCHERFIGSVEJ DK-2100 COPENHAGEN

COLD CLIMATE SOLID WASTES MANAGEMENT GUIDELINES

HEALTH FOR ALL 2000

COLD CLIMATE
SOLID WASTES MANAGEMENT
GUIDELINES

WORLD HEALTH ORGANIZATION
REGIONAL OFFICE FOR EUROPE
COPENHAGEN, DENMARK

Prepared by

Daniel W. Smith

Second draft

July 1987

ICP/CWS 051

GUIDELINE FOR MUNICIPAL SOLID WASTE MANAGEMENT IN COLD CLIMATE CONDITIONS

Table of Contents

List of Figures and Tables

1. Introduction

In 1982, the Regional Office for Europe of the World Health Organization initiated a collection of material for a "Guideline to the design of cold-climate water and wastewater facilities". As a part of the International Water Decade a draft was produced, and it soon became evident that a full description of basic health problems in cold environments should also include the handling of garbage.

Professor Daniel W. Smith, University of Alberta, was asked to prepare a document covering "Solid Waste Management in Cold Climates".

The first draft was ready in late 1984 and soon thereafter sent to a number of reviewers.

Comments received at WHO before August 1985 have been included in the text of this second draft, together with additional illustrations and photos - mainly from Greenland.

Unfortunately, by the Spring of 1985 only some of the reviewers had replied with comments to the Guide and useful information on cold climate practices in their own country.

Due to the huge task of commenting the whole draft Guideline most of the reviewers have chosen to comment only the chapters dealing with their own field of work.

As a result of the afore-mentioned problems, the publication of the WHO Guidelines was delayed. In the mean time the Environmental Protection Programme of Canada had commissioned for publication a Cold Climate Utilities Manual based upon the work of the same technical editor, Professor D.W. Smith. The Manual was published in 1986. The Regional Office for Europe is aware of the similarities between both documents. However, additions have been made to the Guidelines by Mr P. Søgaard Christensen based on comments of the reviewers, and it is expected that the new input resulting from the Consultation to be held in Greenland in October 1987 will enable us to publish the final version of the Guidelines on Water Supply and Sanitation under Cold Climatic Conditions.

Acknowledgements

The Regional Office for Europe of the World Health Organization hereby acknowledges the efforts of Professor D.W. Smith as author of the first draft document, which constitutes the main frame of the Guidelines. We also acknowledge the work of Mr P. Søgaard Christensen in arranging the production of the second draft of the Guidelines, and the following reviewers for their invaluable and useful comments:

Mr John R. Benner, Acting Director, Technical Services, Technical Services and Contracts Branch, Department of Indian and Northern Affairs, Ottawa, Canada.

Mr James J. Cameron, Acting Municipal Planning Engineer, Department of Local Government, Government of the Northwest Territories, Rankin Inlet, Canada.

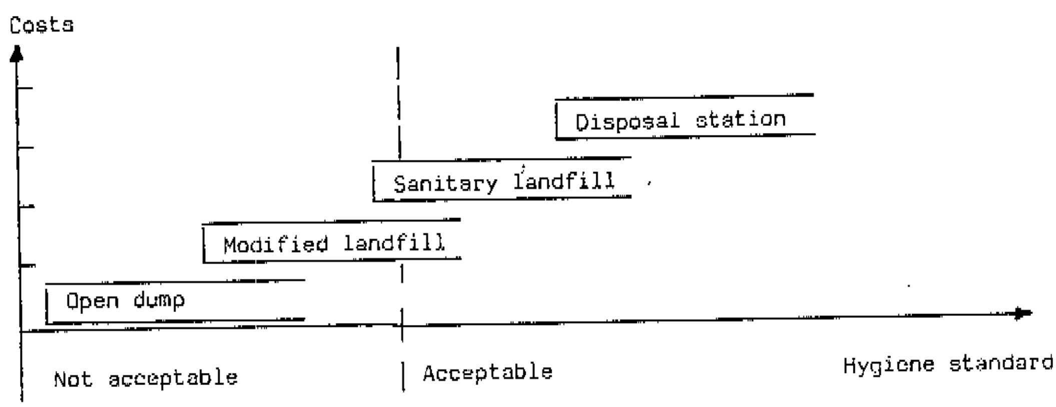
Mr Daniel R. Rogness, Director, Environmental Health Branch, Public Health Service, Department of Health and Human Services, Anchorage, Alaska, USA.

Mr Robert S. Sletten, Environmental Engineer, Civil Engineering Research Branch, Department of the Army, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, USA.

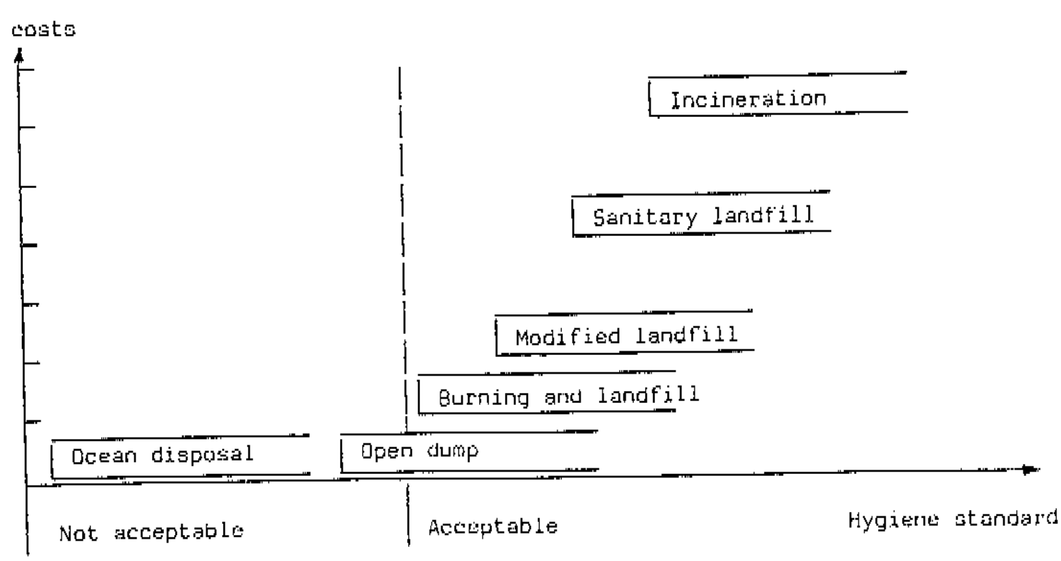
Finally we would also like to express our sincere thanks to the Greenland Technical Organization for their assistance in the preparation of the Guidelines, and in the organization and sponsoring of the Consultation on Guidelines on Water Supply and Sanitation, and on Solid Wastes Management, under Cold Climatic Conditions, held for the revision of the contents of the documents.

1.1 General

Solid waste management objectives and problems in cold regions are similar to those in warmer locations. Health and aesthetics are the primary concerns. In springtime melting of snow and ice reveals the winter accumulation of refuse. In many northern communities the disposal of human wastes (in honeybags) follows the solid waste management scheme. As a result the over-winter accumulations may include excrements which present greater health hazards than refuse alone. Springtime 'clean-up' of all types of litter has become a tradition in many northern communities. Solid waste management practices along with other factors do affect the rate of occurrence of some diseases (1).



Human Waste disposal



Garbage disposal

The objectives of solid waste management, north or south, are to collect and dispose of wastes without creating hazards, nuisances, or aesthetic blights for people or the environment, and to achieve this in the most economical manner. To achieve these objectives, it is necessary that each component of the system, namely, storage, collection and treatment/disposal, is properly carried out.

Reviews of northern practices in solid waste management are provided in the bibliography and references.

The purpose of this guideline is to identify aspects of solid waste management which may be unique or present different problems because of cold climate conditions. The term 'cold climate' also includes factors as remoteness, accessibility and mixed population with a new political responsibility. To provide continuity, some general aspects of solid waste management are included.

Generation, storage, collection, disposal and economics of solid waste management in cold climates are examined in this guideline. The emphasis is on municipal sources. However, four other types of sources are noted since they are very likely to be present at some locations. These are government communities and facilities, industries, undiluted human wastes and treatment plant sludges.

The contribution to solid waste production by local industries is included in the discussion of management options.

1.2 Legislation

In order to maintain or improve health standards in cold regions, management of solid waste must be handled by either the municipality or a contractor according to rules and regulations.

Rules for a community are made by the municipality and the health committee and an example of this, from Narsaq in the southern part of Greenland, is shown in the Appendix.

Rules may vary from one country to another but for cold climate regions, rules will follow those of the more temperate part of the country.

Legislation for solid waste management in Greenland follows the framework of the Greenland Health Service Act of 1961.

Greenland health service is managed and coordinated in the daily work by a Chief Medical Officer.

The health service is run by the Danish Government. A transfer to the Greenlandic Home Rule Authorities is not expected to materialize until after 1990.

Pursuant to the same act, a health board was established in December, 1975, at Nuuk/Godthåb, responsible for the superior management of the health service in Greenland. The board consists of: The High Commissioner ("Rigsombudsmanden") as chairman, two members elected by "Landstinget", the Social Welfare Director, as well as the Chief Medical Officer.

The assignments of the health board cover the planning and the control of the implementation of health service measures. Further, the board will make a statement on any case submitted to them by other authorities, and it may give recommendations to the political authorities.

Pursuant to the act on health service in Greenland, a health committee has been established in each municipality. It also functions as a quarantine board and an epidemics board. The chairman of the health committee is appointed by the local council from among its members, and the committee also includes the district medical officer, the police authority, and another local council member.

The health committee will inspect the hygienic conditions in premises where foods are processed and sold. It will inspect all hygienic conditions in public and private industries, shops, restaurants, etc., and the hygiene of the drinking water systems. Further, the hygiene of the transport and removal of day and night refuse, sewerage systems, as well as the flensing and cutting up of marine mammals.

Any projects relating to water supply, sewerage, and day and night refuse collection installations have to be submitted to the committee. This also applies to other kinds of projects where the implementation may involve pollution.

2. Municipal/Residential Wastes

Municipal solid waste includes all unwanted or discarded solid or semi-solid material from household, commercial and institution sources. Differences in culture will result in differences in solid waste. The management of human waste is discussed in section 5.

There are three different types of municipal communities in cold regions: residential, governmental, and industrial. While the types of municipal wastes are similar to those of southern communities there are differences in the proportions of the various components. Most 'goods' are shipped from the south. This leads to greater quantities of packing material which end up as waste. The isolation and high transportation costs make recycling of used machinery, automobiles, etc., as scrap raw material uneconomical and increase the quantities of solid waste to be disposed of locally. Other factors contributing to solid waste problems in cold regions are:

- lack of responsibility for and/or knowledge of proper management;
- nomadic, explorative and transient attitudes toward occupation of the region;
- shortage of transportation;
- shortage of trained personnel;
- relatively high cost of operations; and
- insufficient information on generation and characteristics (2).

These factors are not likely to change.

2.1 Quantities and Composition of Wastes

Information on solid waste generation in northern communities is limited. Tables 1(a), 1(b) and 1(c) summarize composition information for solid wastes from communities with little industrial activity but varying amounts of governmental activity.

Table 1(a) Quantities of Solid Waste from Communities

Community	Quantities m^3/p.d.	Quantities kg/p.d.	Ref
Northwest Territories			
Fort McPherson	0.006		7
Ft. Smith	0.004		7
Hay River	0.003 to 0.0045		7
Tuktoyaktuk	0.014		8
Saskatchewan			
Gordon Indian Reserve	0.001 (0.0007 to 0.0012)	0.19 (0.17 to 0.22)	14
Northern Ontario	0.005		9
Alaska	0.015		6
(average of communities 500) Fairbanks		2.8	
Alberta Communities Design Value		1 to 2	10
Denmark (household)		0.74	11
USSR			
Vorkuta		0.85	12

Table 1(b) Refuse Density Values (13)

Condition	Density kg/m^3
Loose refuse, no processing	60 - 120
From a compactor truck after dumping	200 - 240
In a compactor truck	290 - 420
Shredded	350 - 660
Baled	470 - 710
In landfill	290 - 660

Table 1(c) Composition of Solid Wastes

Classification	Per cent of Total Sample				
	Gordon Indian Reserves, Sask. (14)	Estimated Arctic Community	Anchorage Alaska	Denmark[4] (11)	North American Averages (15)
Paper	46[1]	50[3]	43.7	34.7	42.5
Food Wastes	37[2]	15	15.2	35.0	14.5
Garden Wastes			6.5		12.5
Wood			1.2	7.9	2.5
Textiles			2.1		2.0
Rubber and Leather			0.9		
Plastics	3		4.1	5.9	4.0
Glass and Ceramics	6		14.5	7.8	10.0
Metals	8	15	10.0	4.4	9.0
Inerts (dirt)			1.7	4.3	3.0
Moisture			20		
Totals	100	100	99.9		100.00

[1] 50% of paper was disposable diapers
[2] Organic wastes
[3] Combustibles (wood, paper, etc.)
[4] Households only

2.2 Household Storage and Collection

In larger communities the practice of storage and collection of waste does not differ substantially from the practices in southern communities. A source separation of glass and aluminium is practised in some communities if dictated by local or regional ordinances. Such a programme requires government assistance to be viable.

In smaller cold region communities garbage and refuse are commonly stored at the house in containers or oil drums, if available. Oil drums are probably the cheapest type of container capable of sustaining the abuse of weather, people and animals. Oil drums are large enough to hold animal carcasses and other bulky refuse and heavy enough not to be upset by wind or dogs. Also, combustible waste can be burned in them for volume reduction. This practice is usually encouraged. Oil drums are, however, difficult to lift manually onto the collection vehicle (Figure 1). Mechanical lifts can be attached to the side of the collection truck to avoid this problem. In some communities raised wooden platforms have been constructed to hold drums for garbage and honeybags so that they can be easily emptied (Figure 2). In many instances this attempt has been a failure, either because the platforms were not rugged enough, or they became an eyesore since they were covered much of the time with spillage. This eventually caused them to be abandoned. Smaller metal or plastic pails are also used for household containers. They are easier to handle, but they are blown over by wind or upset by dogs, do not hold bulky waste, and burning cannot be practised. Plastic containers are brittle at low temperatures. In all containers, garbage will freeze to the walls, making it difficult to empty them in cold weather. A pilot project using paper sacks in two northern Canadian communities was quickly abandoned because the residents did not perceive them as an improvement (16). In Greenland towns and hamlets there is a long practice of using paper sacks for household garbage (Figure 3). In summary, there is much to recommend the continuation of the use of the readily available oil drums for storage at the house, but it also should be coupled with educational efforts to avoid the situations shown in Figure 4. Periodic cleaning and painting of drums is recommended.

In all communities in the Northwest Territories and Greenland there is organized collection of garbage and refuse on a weekly or twice-weekly basis. Mandatory or universal collection is currently required in more than 50% of Alaskan communities where more than 500 people live (6). In all but the very small communities, weekly collection, whether public or private, should be required. Garbage and refuse collection should be separate from the collection of bagged toilet waste, since the latter requires daily frequency and a separate disposal site. Vehicles vary in sophistication from the garbage packer truck used in the south to tractor-drawn open carts (6). Figure 5 shows an open cart system. Vehicles of the open type often lose garbage within the community and along the road to the dump. This sets a bad example to the people and negates any educational efforts for clean-up. Enclosed or covered vehicles should be required with the appropriate degree of sophistication depending on the size of the community.

Garbage crews should also be made responsible for general street clean-up and maintenance, and thus set an example to the citizen. Without this, the appearance of many northern communities suffers from the indiscriminate disposal of garbage, refuse, vehicles and scrap items of all sorts in yards, on roads and beaches. This becomes progressively worse as the winter goes on, except when mercifully covered with snow. Extensive spring clean-ups occur in most communities. Community-wide clean-ups should be a general practice several times a year and their need particularly impressed upon the young in school.

figure 1 garbage collection
figure 2 garbage barrels on raised wooden platforms

Figure 1

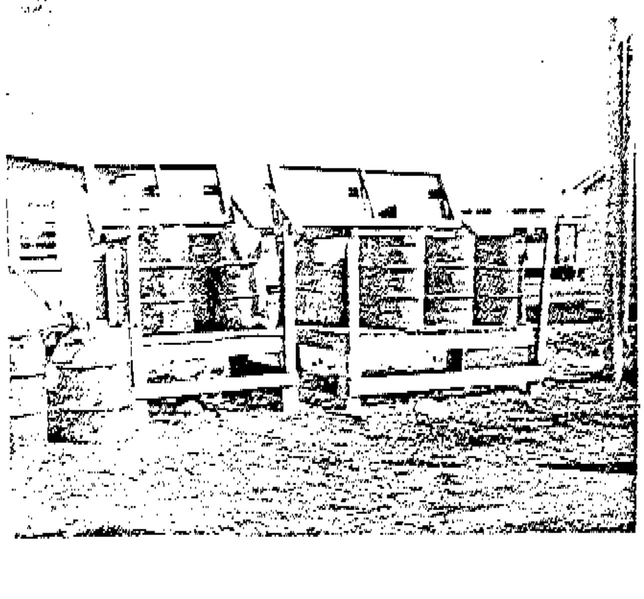


Figure 2

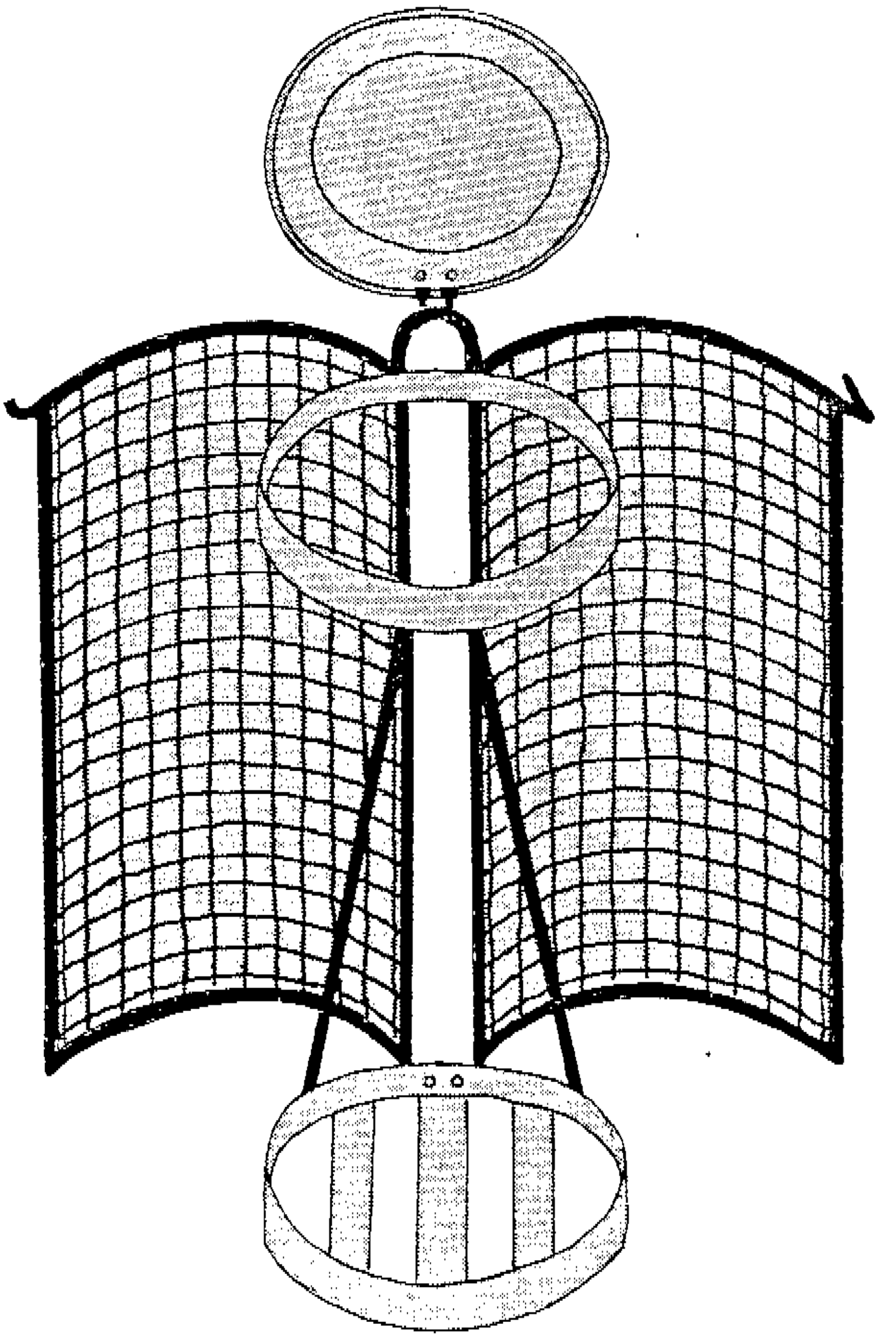


Figure 3.

Galvanized steel support for garbage paper sacks;
used widely in Greenland. Shown in open position without a sack.

figure 4 an example of poor garbage storage at the home
figure 5 garbage cart and stand

Figure 4

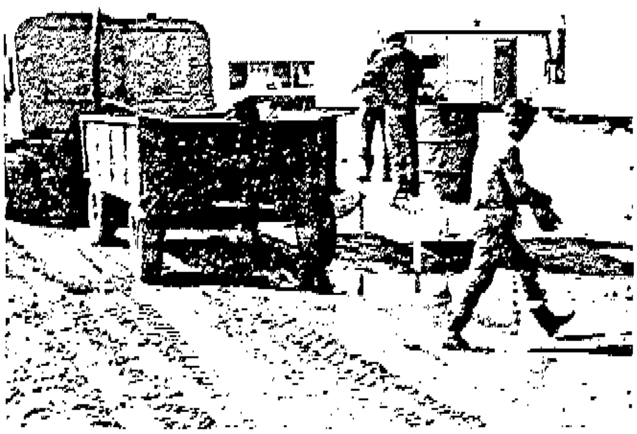


Figure 5

2.3 Disposal Options

Solid waste disposal options which are or have been used in northern communities include:

1. open dump/landfill;
2. modified landfill;
3. sanitary landfill;
4. burning and landfill;
5. incineration and landfill;
6. milling;
7. compaction;
8. recycling and reuse, and
9. ocean disposal.

In the Northwest Territories the most often used methods are the open dump landfill, the modified landfill, and burning with landfilling (5). In Alaskan communities the distribution of methods of disposal was (6):

open dump landfill	76%
ocean disposal	13%
incineration (federal facilities only)	11%

In Greenland, modified landfill with routine burning is used for disposal of community wastes. The sites selected are unsuitable for other uses, a minimum of 150 m from housing, and downwind of the town (18).

The processing methods of compaction (used in Fairbanks, Alaska) and milling (used in Anchorage, Alaska and Edmonton, Alberta) are suitable for large communities. The value of solid waste shredding is marginal for small Northwest Territories communities (19). The placement of shredded material dampens the effect of air temperature fluctuation on the underlying soil and the disruption of the shredded material results in deeper thawing of the permafrost.

2.3.1 Site selection

Parameters for disposal site selection include:

1. avoidance of water pollution problems;
2. avoidance of air pollution problems; direction and distance from community;
3. feasibility of construction and maintenance of access road;
4. site topography and size; drainage pattern of the surrounding area.
5. availability of cover material;
6. wind exposure.

The most important site selection criterion is that the dump should be located outside the watershed of the water supply source to eliminate any possible contamination. The site should be on high, dry ground to avoid drainage and groundwater problems. If there is a prevalent wind direction, the site should be located downwind from the community, so that unpleasant odours or smoke from burning at the dump are directed away from the settlement. The ground between the disposal site and the community must allow for the construction and maintenance of a year-round access road. The distance from the site to the nearest homes should be at least 1 km where possible. When there is a choice between alternative sites, the construction and maintenance costs for a multiple-use access road should be considered against those for a single-purpose waste disposal site access road.

A sloping site is preferable since it facilitates dumping and spreading operations. On flat land a slope can be created through deposition of waste and cover material, where available. The area for the dump/landfill operation should be large enough to allow for 5-10 years or longer operation, particularly when the cost of the access road is high. Usually, land area is not a problem. A smaller area may be prepared and fenced for current usage, with adjacent room for expansion available. The fenced site should be large enough to allow for deposition of garbage and refuse and close-by storage of cover material. The cold northern climate makes biological degradation of putrescible matter so slow that the value of occasionally covering the waste is really only in preventing garbage and paper from being blown around the site, and in reducing the danger of disease transmission through insects, birds and animals. Periodic compacting and covering of the waste is, therefore, recommended where practical. Availability of nearby cover material is, therefore, important. In some cases, snow has been used as a temporary cover material. The requirement for fencing is based on similar reasoning. It will confine the blowing of waste to the site and may keep out larger land animals. It has also the psychological advantage of creating the impression of an "engineered" operation. A protected, less windy site is preferable. The controlled burning of combustible material at the disposal site serves the useful purposes of volume reduction and odour control, but may create air pollution and smoke problems. In some areas it may not be permitted.

A designated area for dumping of bulky items such as automobiles, machinery, demolition material should also be considered. Where space allow, it is preferable to locate such an area near the garbage dump. This eliminates the need for a separate road. Without such a facility indiscriminate dumping will occur. It is also desirable to have available a tow truck or other vehicle capable of loading, hauling and unloading bulky waste material.

In permafrost areas, disruption of the thermal regime by mechanical damage will result in melting and, in-ice rich and/or finely grained soils, slumping. Proper site investigations will aid the selection of a site where the impact will be minimum.

2.3.2 Open dump/landfill

The main reasons for the use of the open dump are its simplicity of operation, its low cost, and the lack of suitable alternatives. The main arguments against its continued use are the many instances of complete disregard of even the most simple techniques of discrimination in the selection and operation of existing disposal sites. These poor practices, which are avoidable, make it difficult to convince regulatory authorities and the public to accept the open dump/landfill.

If the simple guidelines of site selection (2.3.1) and operation are adhered to, the environmental effects of the open dump/landfill are minimized. Under these circumstances, the advantages of cost and ease of operation make it the most sensible method of waste disposal at the present time. The site should be selected by experienced people with the help of aerial photographs and inspection of alternative sites.

It should not be left up to the garbage crew to choose the site(s). Reclamation of land from the ocean by the building of a berm off shore and the filling in with solid waste, earth and rock is carried out in most towns in Greenland, and Pangnirtung, Northwest Territories. This may have application in other areas where land is scarce.

Human wastes should be disposed of separately from solid waste (see section 5).

Figures 6 and 7 show some of the situations experienced at existing disposal sites.

2.3.3 Modified Landfill

The proper application of sanitary landfill procedures (daily coverage with soil/gravel) is usually impossible in permafrost areas. The low temperature does not permit the degradation of putrescible matter to occur, but merely places the waste in cold storage. Excavation is extremely difficult and may create difficulties through destruction of the insulating layer. Earth cover material must often be transported considerable distances to the disposal site and is therefore expensive. Daily or even weekly covering becomes economically impractical. Due to the small population of most communities it is seldom practical to keep a bulldozer on the site continuously, as it is needed for other tasks in the community. For these reasons sanitary landfill is generally not a practical method of disposal in permafrost areas. In discontinuous permafrost areas, and where cover material is available at reasonable cost, and the size of the operation allows the continuous presence of equipment, a form of landfill approaching the practices of sanitary landfill is practical (Figure 8).

Another form of the modified landfill is the trench method (Figure 10). In larger communities, tractor-mounted back-hoes are normally available. These can be used to dig trenches at the solid waste disposal site, up to about 3 m deep. The refuse is dumped into these trenches and, when full, they are covered with excavated material (about 1 m). New trenches are then dug. This method can be used in some types of permafrost areas, provided the machinery is able to dig the trenches and the thermal impact does not cause problems.

2.3.4 Sanitary Landfill

A sanitary landfill requires controlled compaction and covering of solid wastes with earth after each day's accumulation. In permafrost areas or locations that are very cold for extended periods it is often not possible to operate a sanitary landfill the year around. Exceptions may exist where dry sand or gravel exists on the site.

For small communities it would be impractical to have a person and machine at the site to cover wastes each day or even each week. The use of regional or multi-community sanitary landfills may be suitable where relative location, transportation routes and costs are all favourable (Figures 9 and 10).

figure 6 Garbage dump behind an offshore berm

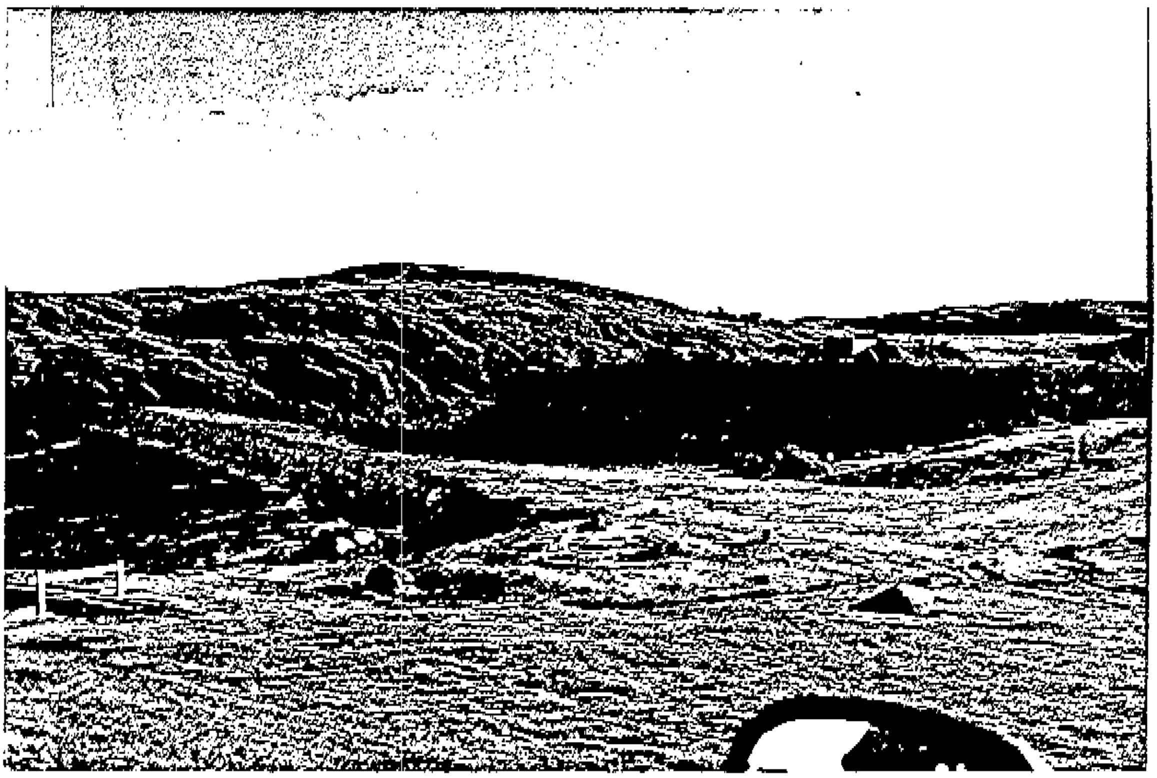
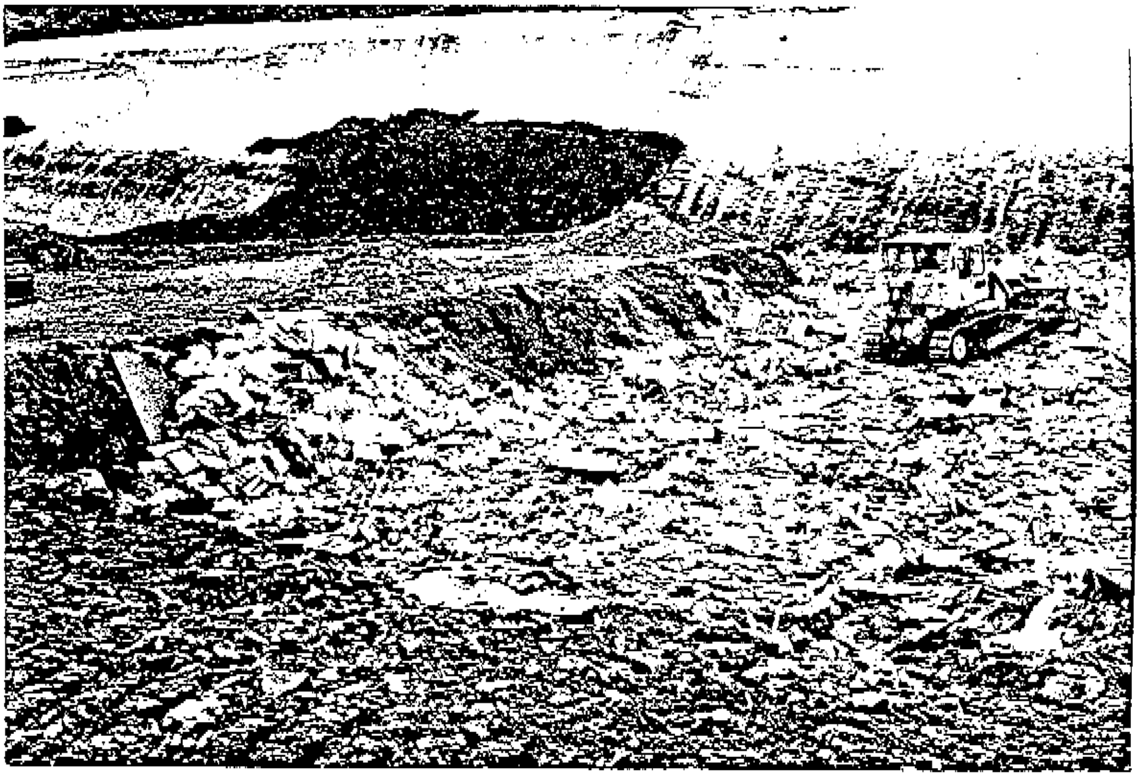


figure 7 Tractor compaction at a modified landfill



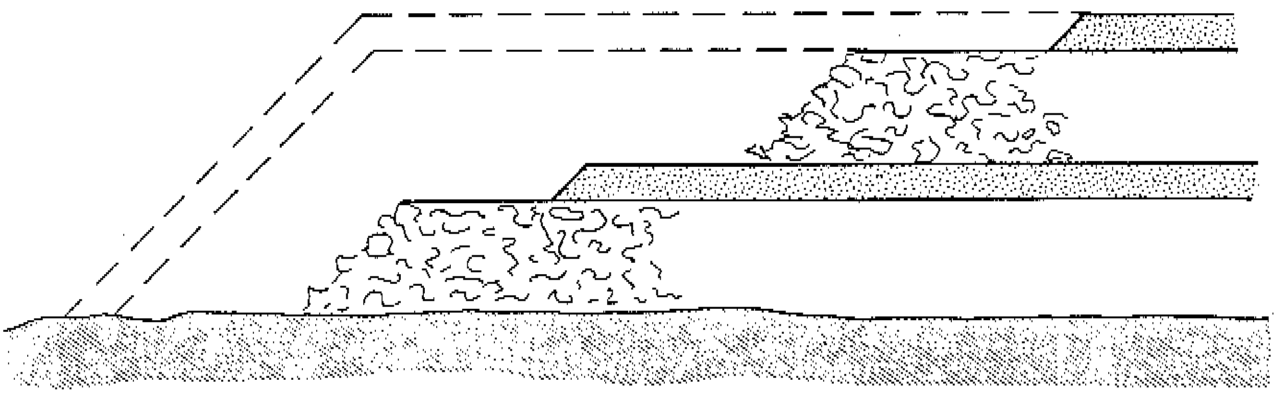
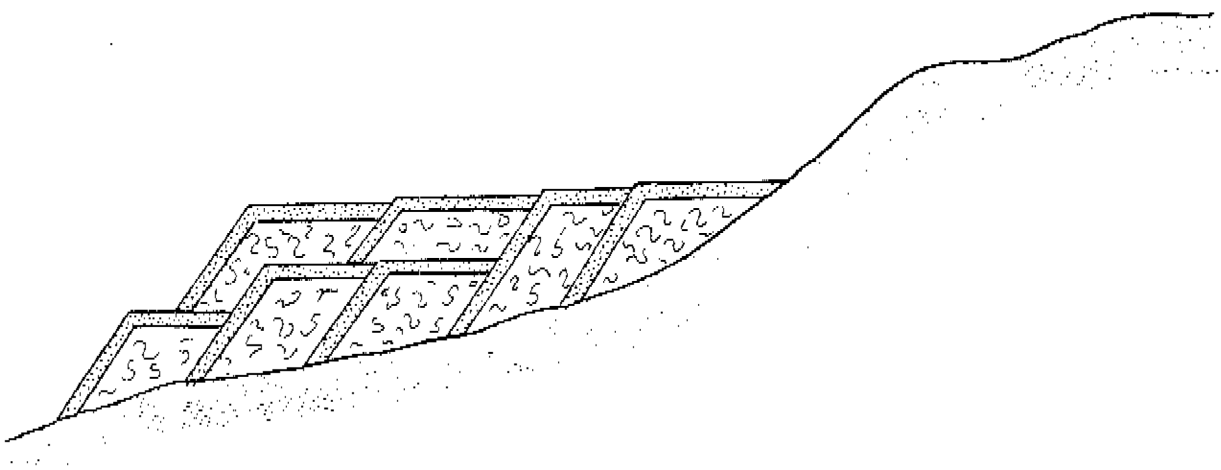


Figure 8. Modified Landfill.

figure 9 sanitary landfill



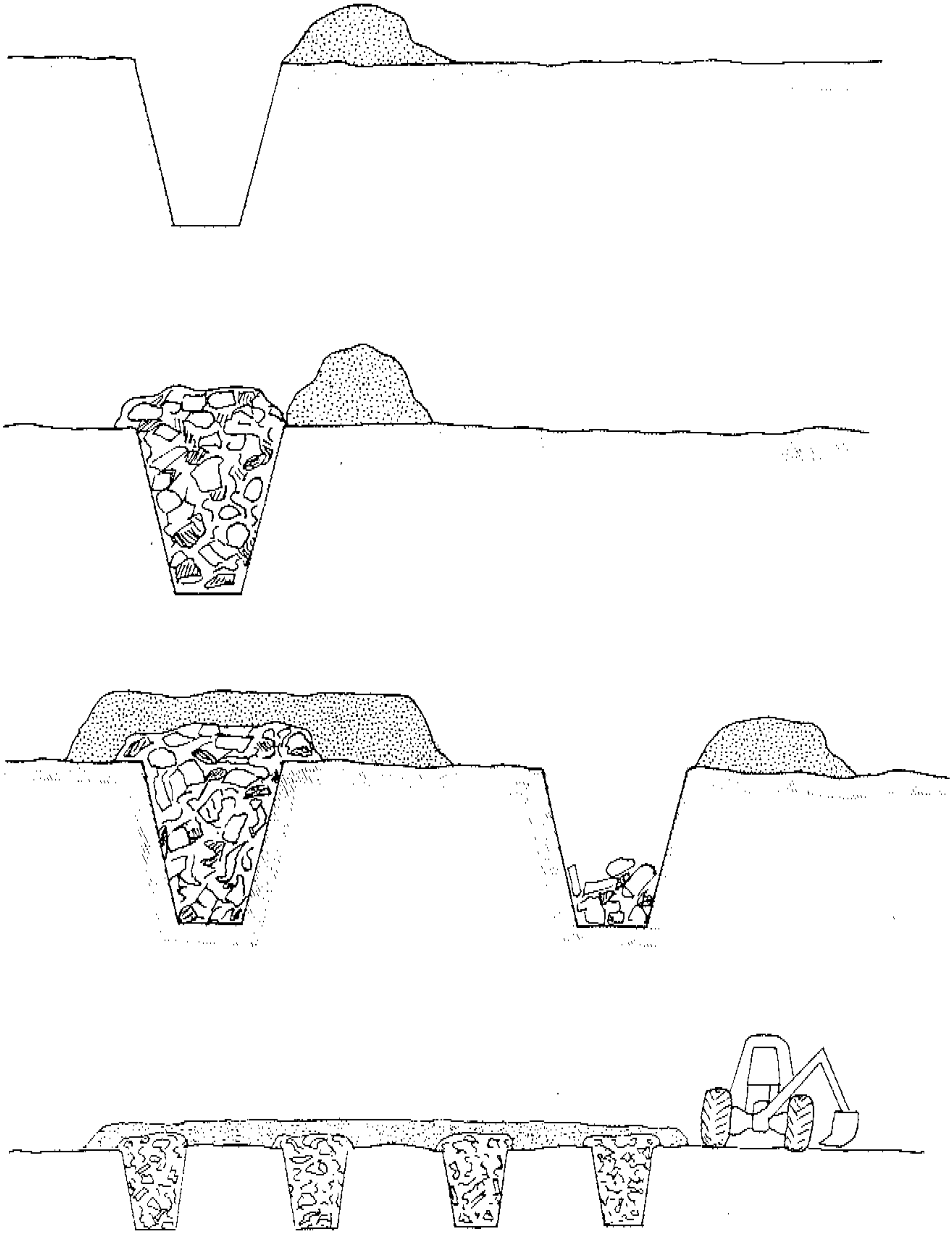


Figure 10. The trench method/Modified Landfill.

Proposed Sanitary Landfill

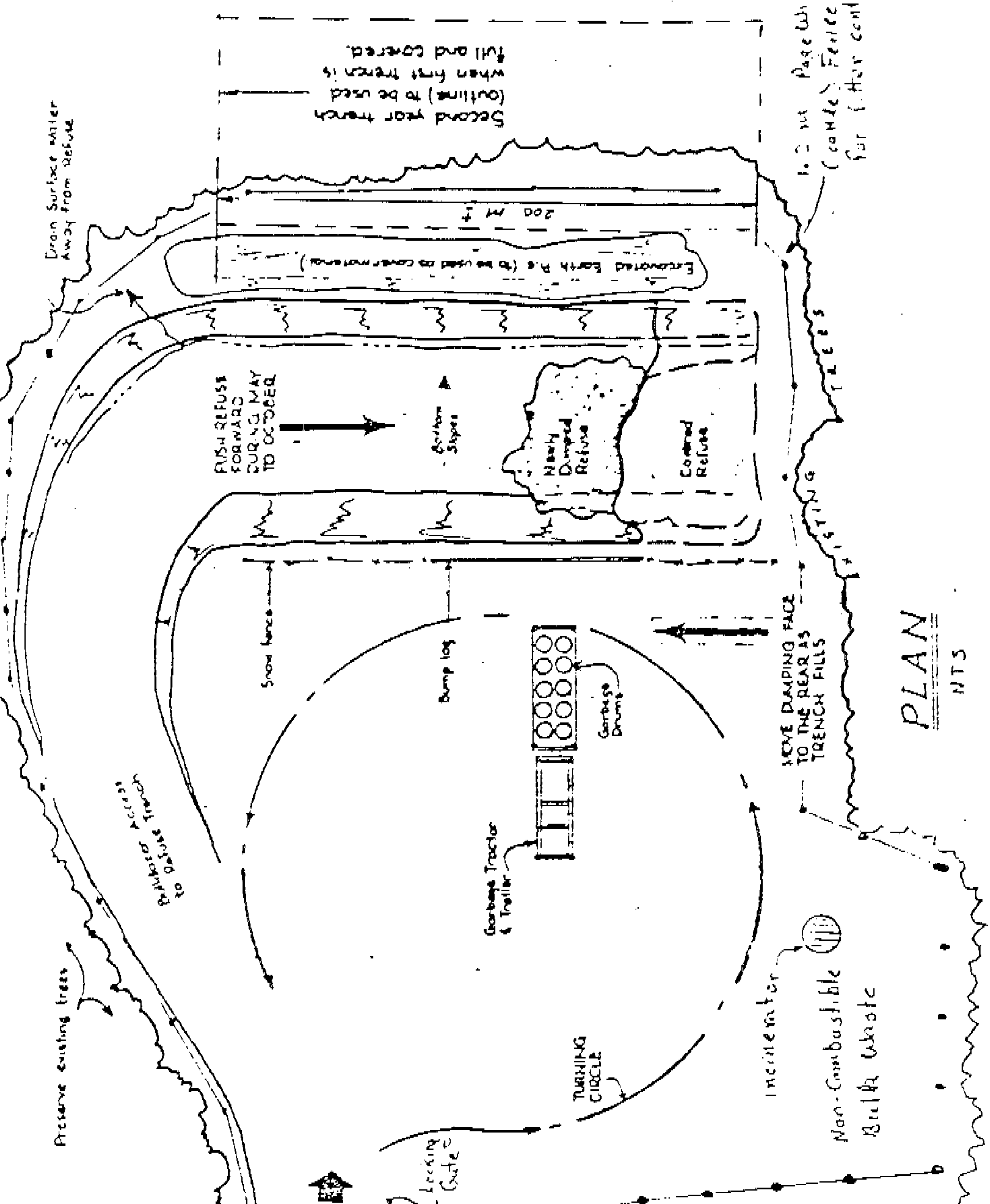


FIGURE 11: SANITARY LANDFILL

2.3.5 Burning and Landfill

Burning can be an effective method of reducing solid waste and of rendering it less putrescible. Burning as treatment does not result in the complete reduction of the material. In all cases a landfill is required for ash and unburnt materials. Burning can be controlled or uncontrolled with the actual processes being:

- open burning;
- trench burning;
- individual drum burning;
- controlled trench burning.

Each of these follows procedures similar to those used at more sourthern locations. The major cold climate concerns are impact on soil conditions, fire hazards, air pollution, ash disposal and poorer combustion.

Open burning reduces volume and mass of garbage by 40 to 70 per cent. Moist and putrescible material is not completely burned, and may result in the attraction of birds and animals and creates a health hazard.

Another concern with open burning is, if ice-rich permafrost is present, the thermal regime of the site may be disrupted resulting in soil slumping and soft, muddy conditions.

Wind spreading of refuse or burning material may be a significant problem and must be addressed in site plans with fencing a desirable option.

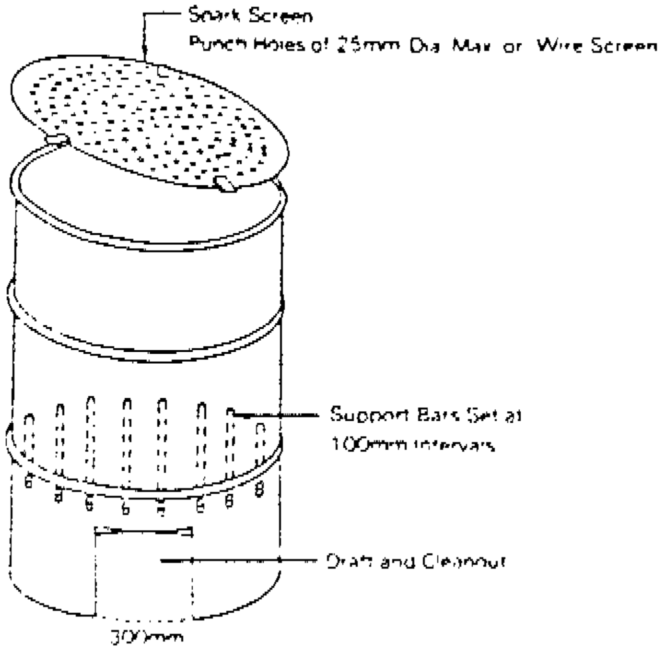
Trench burning can be used where soil conditions permit trench excavation. Wind spreading and the fire hazard will be reduced. However, fencing is usually required. Other aspects are similar to open burning.

Individual garbage burning is practised in many smaller communities in the Northwest Territories. Oil drums (205 l) are used and with proper ventilation burning will reduce volume and mass as much or more than open burning (Figure 12). Collection and burning of the drums' contents at the landfill site has been practised.

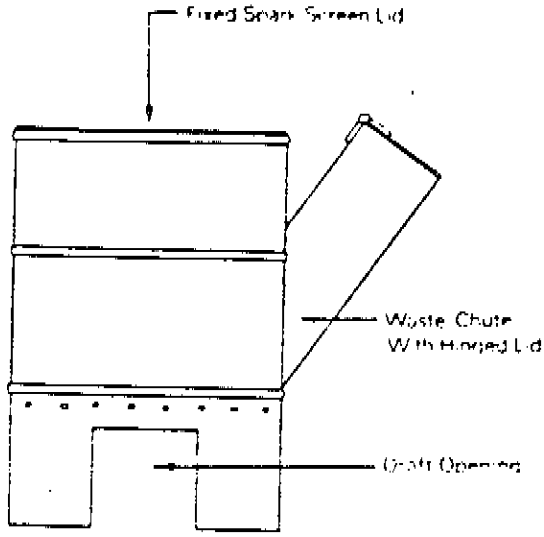
Controlled trench and pit burning improves the burning process considerably. In both cases air is added to the combustion process to improve volume and weight reduction and reduce air pollution problems. The trench burning system involves construction of a narrow trench which is filled with wastes and ignited. A portable over-fire air blower is used to enhance burning and recirculate gases and ash to further oxidize them. A screen placed over the trench mouth can further reduce ash release (see Figure 13). Air pollution problems may be more severe during times of inversions due to the proximity of the landfill site to the residents.

2.3.6 Incineration and Landfill

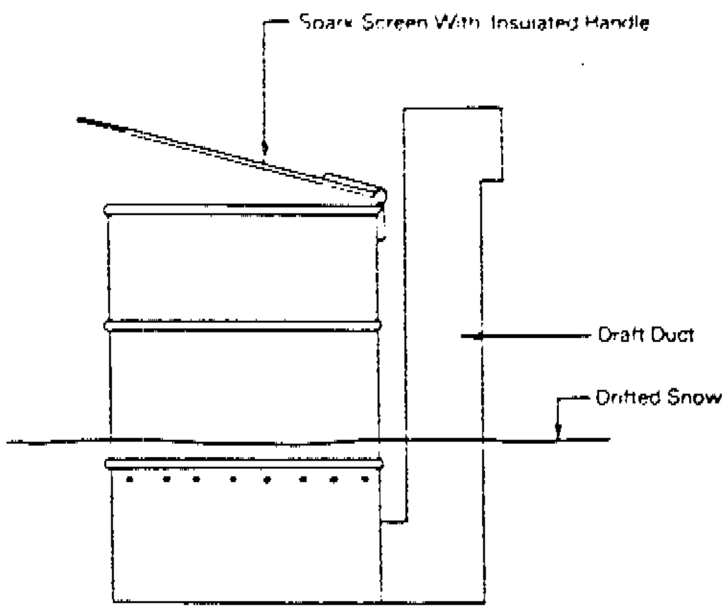
Incineration is a controlled process for oxidizing combustible waste to carbon dioxide, water and ash. Normal domestic garbage and refuse has an average heating value of about 11.6 MJ/kg and thus can be considered a valuable fuel resource, particularly in northern areas where fuel must be brought in at great expense. Some years ago it was thought that incineration



Basic Improvements to
Oil Drum Incinerator



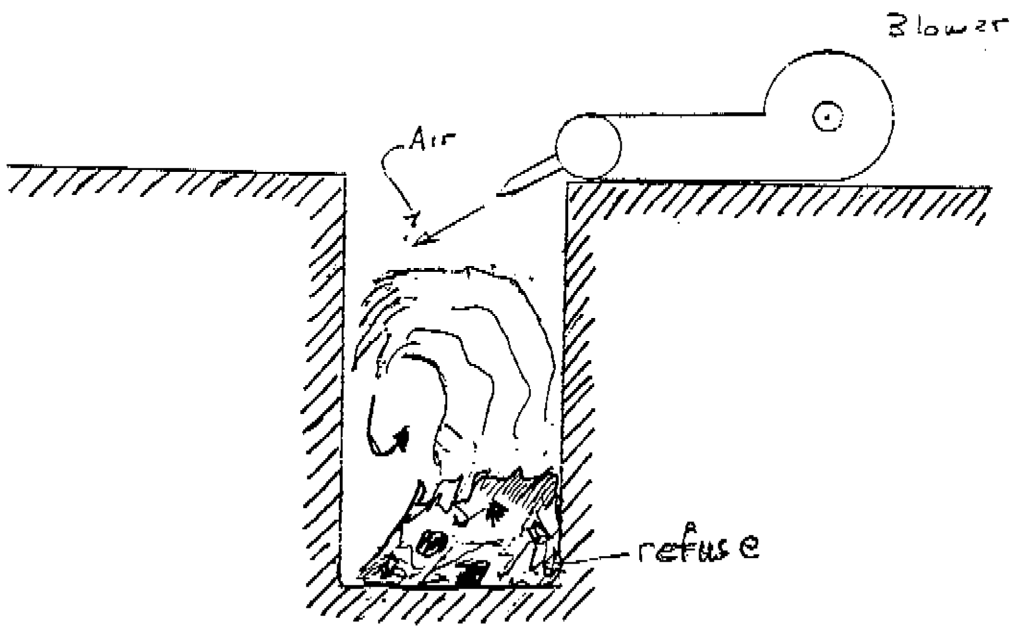
Chute Feed



Alternate Draft

Figure 12 drum incinerator

figure 13 basics of trench controlled burning



had great potential for Alaskan communities and might replace the practice of open dumps (6). However, the experience of the few installations that have been built at federal facilities (6,27) and in parts of the Alaska Village Demonstration Project (AVDP) has been that incineration of solid wastes is not economically feasible for small northern communities because of high operative and maintenance costs.

Testing of a controlled pit, refractory-lined metal or concrete chamber with over and under fire air being supplied, proved satisfactory for remote locations (14). The combustion chamber volume of 2.7 m^3 was designed to reach a temperature of 870° and receive up to 840 m^3/h of air through manifolds and nozzles mounted on both sides. Volume reductions from 70% to 85% were achieved. The unit tested required three burns per week for the community of 780 persons.

Multiple chamber incinerators for reduction of municipal solid wastes are not used in the far northern regions covered by this document. Reasons include too small a quantity of waste for economical operation and the requirements for meeting emission requirements.

Controlled air incinerators or pyrolysis-combustion units have been used for reduction of municipal wastes. Costs of fuel and manpower have resulted in most units being decommissioned in northern locations. Design procedures follow normal practice except for housing and foundation aspects.

2.3.7 Milling and Compaction

The purpose of milling and compaction is to reduce volume, and thereby make handling and disposal of the wastes cheaper and more manageable. Included here are methods to shred, mill or grind wastes, and to compact or bale wastes. They may be used ahead of landfilling, incineration or in conjunction with materials recovery. To date the record of a number of pilot or full-scale projects appears to increase overall disposal costs, rather than decrease them.

Refuse milling (or shredding, or grinding) is a process by which refuse is passed through a mechanical device, such as a hammermill, which grinds it to a homogeneous mixture of a specified maximum size. This mixture is inoffensive, light, highly compactable, and easily handled. Paper, plastic, wood, and cardboard are generally broken into 70 to 100 mm pieces. Glass is shattered so thoroughly into sandlike particles that it is impossible for the casual observer to detect it. The raw garbage is generally absorbed and is so finely mixed with paper and other materials that there is very little odour. The biggest problem is with soft plastic bags, which tend to stretch rather than tear apart (6).

Milling ahead of landfilling reduces the need for daily cover and the 'nuisance aspects' of open drums (odour, flies, rats, windblown material). It also reduces the volume to be transported and disposed. Difficulties in northern operation of a hammermill, or other type of mechanical equipment, are with the input of frozen wastes and increased frequency of mechanical breakdown and difficulty of repair. Many communities are too small to justify the high capital cost and operating costs. Forgie (19) reported on a Canadian pilot project on shredding of solid waste. It showed that shredding by a hammermill may be technically feasible but failed to provide information on the economic feasibility for northern applications.

Compacting or baling is a process whereby waste, raw or milled, is compressed into bales, with a significant increase in density (up to 1 kg/l, which is the density of water). After being banded, these bales are hauled to a landfill site, where they can be stacked in place. In this manner, greater landfill density can be achieved, and transportation costs are reduced, since greater payloads can be hauled. High pressure baling, which does not require banding, is used in Fairbanks, Alaska.

2.3.8 Ocean Disposal

A few small communities on the ocean dispose of their garbage and "honeybag" wastes by placing them on the ice in the winter, relying on spring breakup to wash away the material (6). Legislation should prohibit this practice. In Canada, the Ocean Dumping Control Act places strict limitations on the types of material that may be disposed of in the coastal regions. It is unlikely that disposal of municipal-type solid wastes would be authorized, but organic waste from fishing industries could be allowed.

2.3.9 Recycling and Reuse (haulback)

Recycling of waste into regenerated products is popular. There are difficulties achieving this objective in the economic framework of southern communities, and in remote northern communities the picture is even less attractive. Recycling and reuse require, in many cases, sorting and separation of wastes. Items which may be considered are:

- paper,
- waste lubrication oil,
- metal cans,
- glass products,
- batteries, and
- scrap metal.

The size of the operation and the availability of markets for the 'usable' waste products are important economic considerations. A northern location compounds the difficulties experienced in the southern communities. Populations are generally small; therefore, volumes of recovered materials are small. There are usually no local markets and, therefore, material must be shipped south over long distances and at high costs.

2.4 Cost of Service

Cost estimates should be separated into collection, transportation and disposal. However, it is difficult to completely separate these costs in most communities. Cost distributions are shown in Table 2.

Actual charges to the homeowner are not well documented. However, information is available on the actual cost for garbage collection and disposal in some northern communities. It is important to differentiate between actual costs and charges. The latter are mostly subsidized, and set without knowing real costs.

TABLE 2

Solid Waste Management Cost Distributions

Activity/Item	Per cent of Total
Bag (cost is zero when oil drums are used)	18
Collection	41
Transportation	22
Treatment/Disposal	19
	100

Reference 23

Gamble and Janssen (24) and Cameron (17) describe a method to estimate the cost of garbage collection in small communities. For the example cited, the highest cost per pick-up in 1984 in the Northwest Territories was about $1.50 (CDN).

In Alaska, the average charge to the homeowner for collection of garbage (one drum per week) in incorporated municipalities of over 500 population was $4.80 ($2.50 to $15.00) per month per household in 1975 (6) or about $1.20 (US) per drum.

In Figure 15 typical ranges are given for the costs (labour, vehicle O & M, overhead, etc.) to maintain garbage collection and disposal in some representative northern communities (25). The costs are given as cost per person per year to maintain such a system. From Figure 15, it can be seen that the smaller communities have the higher per capita cost. This is expected because each community will require similar infrastructures to allow for the garbage collection system.

3. Military and scientific Facilities

Locations which are funded and operated by government have a different economic base and therefore a different supply and disposal character of solid waste than 'natural' communities.

3.1 Types and Characteristics

Some data on solid waste generation rates at government facilities and construction camps are available. Generally, the quantities are higher than in municipal communities. Table 3 presents available information. Density data from Table 1(b) can be applied with caution to compute volumes.

Composition information is more limited for these facilities. Tables 3(b) and (c) provide some information.

3.2 Storage and Collection

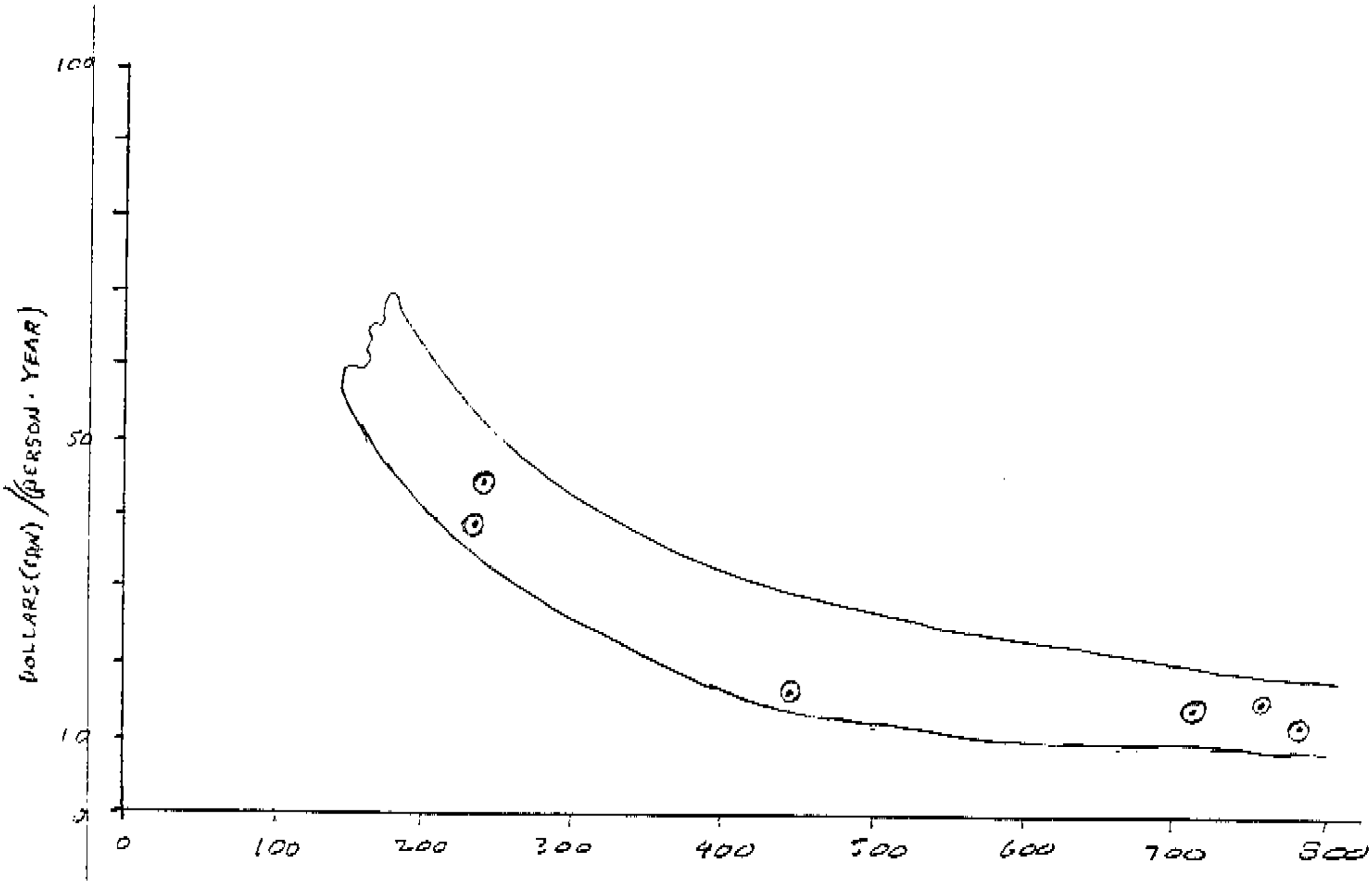
The on-site storage and collection practices do not differ from practices in southern communities. Packer and side-loading trucks are frequently used for collection of refuse placed in small (100-150 l) metal containers or plastic bags. At weather and military stations smaller multi-purpose vehicles may be used.

3.3. Disposal Methods

Solid waste disposal practices may follow or require complex approaches. Open burning is usually not permitted. Open dumps are also discouraged. Modified sanitary landfills, sanitary landfill, shredding, baling and incineration are all practised at government communities and facilities.

Military sites frequently use controlled air incineration to reduce volume and weight of material to be landfilled and to reduce animal scavenging. Modified sanitary landfills (periodic cover) are normally used. The incinerators used are normally oil fired. Because of much better qualified operators than in communities, maintenance problems and costs are substantially reduced. Operating costs are generally not available. They are probably high when considered within an economic framework of a community, but are not significant when considered against the overall cost of industrial or military camp operations.

Figure 14 garbage collection costs (based on 1976-77 data)



Community Population

TABLE 3

(a) Quantities of Solid Waste from Government Facilities and Construction Camps

Source	Quantities kg/p.d.	Ref
Air Force Facilities	2.3 1.0	22 21
Fort Greely Army Base	6.1	5.26
Alaska Federal Facilities	2.7	6
Pipeline Construction Camps	2.7	27
Northwest Territories Camps	2.7-4.4	28
Alaska Dept. of Env. Conservation Design Valve	3.6	6
Fairbanks (1971)	2.2-2.8	27

(b) Government Communities and Facilities Solid Waste Composition

Classification	Per cent of Total Sample		
	Juneau, Alaska	Anchorage, Alaska	Madison, Wisconsin
Food Waste	15.2	15.2	15.3
Paper Products	45.8	43.7	42.4
Plastics	4.0	4.1	1.8
Rubber and Leather	1.3	0.9	--
Textiles	3.0	2.1	1.6
Wood	0.6	1.2	1.1
Metals	12.5	10.0	6.7
Glass and Ceramics	17.12	14.5	10.1
Garden Waste	--	6.5	13.8
Inerts (dirt)	0.4	1.7	7.2
Totals	99.9	99.0	100.0

TABLE 3 (continued)

(c) Military Station Solid Waste Composition

Classification	Per cent
Combustible	48
Non-combustible	12
Garbage	49

(d) Density of Refuse from Military Facilities

Density	Facility Reference	kg/m^3	
Air Force Site, Alaska		84	22
as collected		(Range: 69-111)	
Air Force Base, Alaska			
compacted in landfill		420	21
Alert, Northwest Territories			
as collected		91	28

Shredding and baling have been used in large military base communities (Anchorage and Fairbanks, Alaska) to reduce volumes to be landfilled. Design of these units follows standard practice.

3.4 Costs of Service

Costs of collection, transport and disposal in government communities and facilities are not available. It is expected that shift labour and equipment costs would lead to higher costs per pick-up than found in similar sourthern communities.

4. Industrial Solid Wastes

Industrial solid wastes may come in smaller variety but greater quantity than community solid wastes. The generation of these waste materials normally conforms to practices in southern locations. Included under this heading are special wastes such as trailers, machinery and other bulky waste, as well as special wastes associated with temporary camps.

Only limited information is available on the solid waste problems of industry in Alaska and the Canadian northern territories and provinces. Kelton (5) has provided some information on the special problem of seafood processing wastes in Alaska, which are disposed of in the ocean or in landfills. A great part of industrial activity in the North is connected with the extraction of raw materials (oil, gas, various minerals, etc.). It is beyond the scope of this manual to discuss the special solid waste management problems of these industries in detail. Reference should be made to the relèvant information on such industrial wastes in other areas.

Special wastes, other than garbage and refuse, from industry and camps include discarded vehicles, trailers, construction equipment and materials, ski-doos, bulky containers and shipping material, and others. These wastes do not accumulate on a frequent basis and are normally not collected and disposed of routinely. However, provisions must be made to provide an incentive for reuse, where this is feasible, and more importantly, for a dumping area which is controlled and operated by the municipality. In the absence of this, discarded material seems to be left almost everywhere.

Some quantity information is available. Alter (2) stated: In cold regions it may be assumed that the following per cent of the total weight or volume of each item transported to the north becomes solid waste annually:

- Lumber, steel and other building material used in construction of fixed facilities such as buildings	3%
- Heavy equipment, tractors, machinery and vehicles	10%
- Miscellaneous freight such as canned goods, furniture, appliances, etc.	2-10%
- Magazines, books, newspapers, etc.	90%
- Office and household furnishings	5-10%
- Clothing	30%

TABLE 4

Industrial Solid Wastes Sources

Mines

Gold, placer and hard rock
Silver
Nickel
Lead
Zinc
Tantalite-Columbite
Iron
Copper
Uranium
Radium
Tungsten
Manganese
Bismuth
Coal
Semi-precious stones

Timber-related Developments

Lumber
Pulp

Oil and Gas Developments

Chemicals (Refineries)
Household (Base camps)
--"-- (Exploration camps)
--"-- (Drilling)

Fish Packing Plants

Organic waste

Slaughterhouses

Organic waste

These estimates may be low. For example, machinery and cars accumulate more likely at a higher rate. Kelton (6) estimated that of the 170 000 vehicles registered in Alaska in 1973, about 20 000 are junked each year. At an average weight of 1.5 tons per vehicle this amounts to 30 000 tons of scrap per year. Recycling in the larger and less remote communities may be economically feasible, but not likely to be the case in the more remote communities because of high freight rates. There is a choice to be made either between subsidizing backhaul or providing local junk yards.

The special problems of solid waste management for temporary and semi-permanent camps (together with their water supply and wastewater disposal problems) are discussed in Section 15.

4.1 Types

The types of industrial solid waste are listed in Table 4. The majority of industrial activities are mining. These consist of the mining operation, supply areas spoil or waste material areas, staff housing and in some cases processing facilities. Oil and gas developments also involve many activities and produce a variety of wastes for disposal. In coastal areas, at rivers and lakes, fish and other aquatic food materials are often processed and the waste is disposed of on the site.

4.2 Characteristics of Industrial Solid Wastes

The majority of solid waste on a volume or weight basis is the material disposed of during mining operations. Site plans detail disposal areas for each type of operation. Such plans follow normal design procedure except to the consideration of ice-rich permafrost and low winter temperatures.

Waste quantities are a function of local site conditions and the techniques used to extract product material.

4.3 Collection

As stockpiles of unwanted equipment increase, backhaul has been an economic alternative for disposal.

Some apparently successful projects of recycling scrap metal have been reported by Kelton (6). In one project, approximately 36 000 tonnes of heavy metal scrap was removed from a Fairbanks junkyard and transported by the Alaska Railroad to Seward, where it was shipped to Taiwan for recycling, all without a government subsidy. A similar procedure is practised at the US-bases in Greenland. Another example is in Anchorage where a private wrecking firm collects, crushes and transports junked automobiles to Seattle, at a government subsidy of $22 (US) per vehicle (1975).

At oil and gas drilling sites after completion, clean-up and removal of all materials are becoming more common. Careful control of drilling muds is also common practice.

4.4 Disposal Methods

Burning is practised for many materials. Landfills are the most common disposal technique with careful control of the materials allowed to be placed. Controls on hazardous solid wastes must be followed.

Incineration is one of the most common methods of disposing of solid wastes from industrial and military camps. It is most effective in reducing animal scavenging of the camp site and the environmental effects of incineration are low. For very small, short duration camps for exploratory purposes backhaul or open burning is practised.

5. Undiluted Human Wastes

The use of bucket or bag toilets (Figure 15) for the collection and disposal of human wastes is common in areas of permafrost and other soil conditions which prevent the use of other methods. These units have provided a method for removing wastes from the dwelling and community environment. A number of alternative methods have been proposed (29) but operation complexity and economic factors have limited their success. Health data supporting the elimination of the bagged wastes (1) are shown in Figures 16(a) and 16(b).

Although a piped sewage system based on water flushing toilets is preferable, the use of bucket or bag toilets will, also in the future, be a permanent part of most cold climate community sanitation systems.

Features of the bucket/bag system are:

- Low costs of establishing.
- Does not require a piped water system.
- Simple to operate, requires no special training of personnel.
- Low risk of contamination, when correct chemicals are used in the bucket, and cleaning is done regularly.
- No odours when installation is made with proper ventilation.

5.1 Characteristics

Undiluted human wastes range from 6 to 9% solids. The volume ranges from 1 to 2 l/p.d. Table 5 summarizes the characteristics (30).

5.2 Storage at the House and Collection

Health officials recommend that bagged waste be collected from all households daily. This also assists the collection procedure since a half-full bag is less likely to break. However, collection frequencies vary from daily to once a week. In Greenland, normal practice is 3 times a week.

There are three methods in Canada and Alaska of honeybag storage and collection (31):

(a) collection from oil drums in front of each household;

(b) collection from the bathroom of each household;

(c) collection from the service porch of each household.

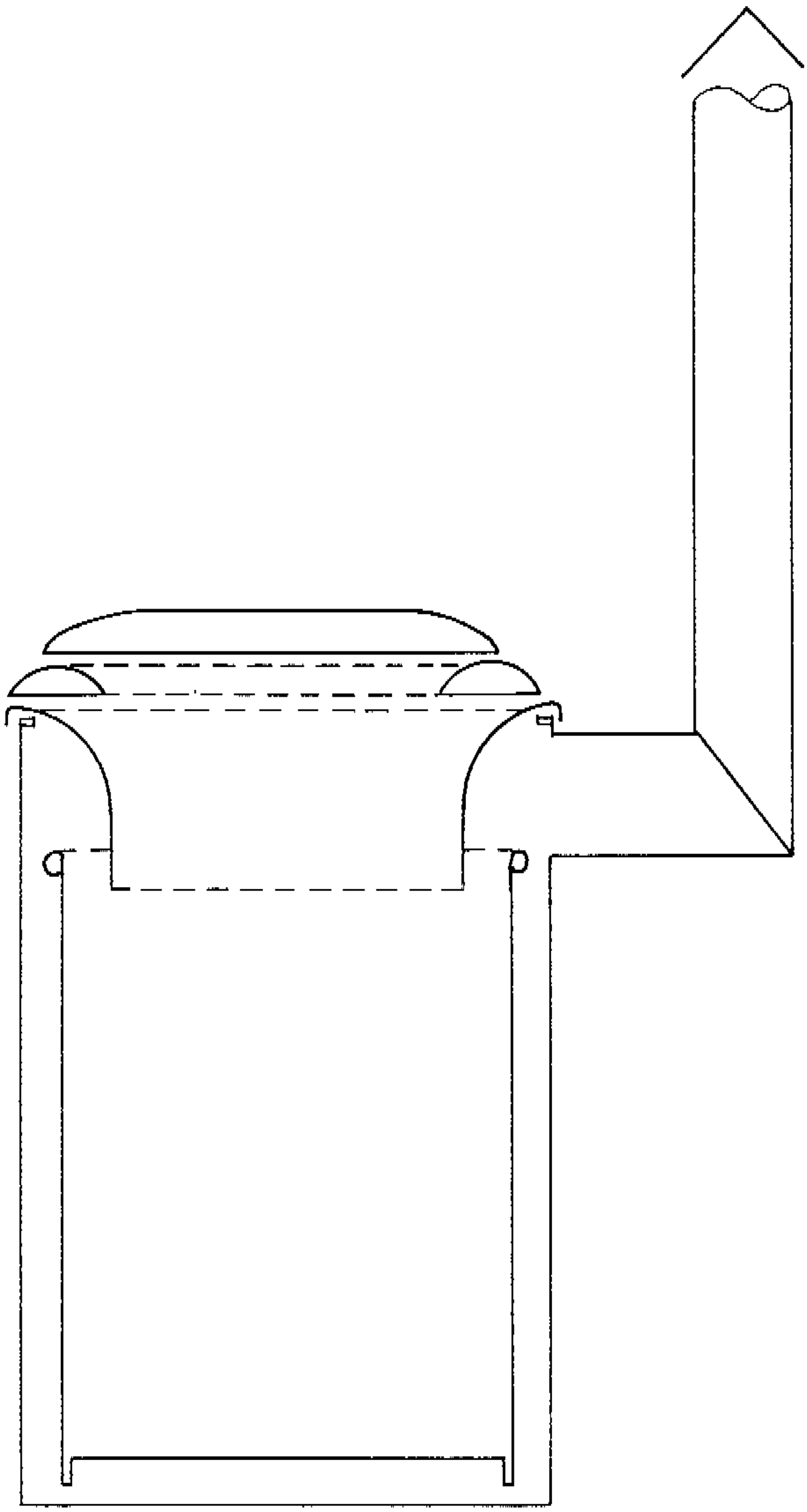
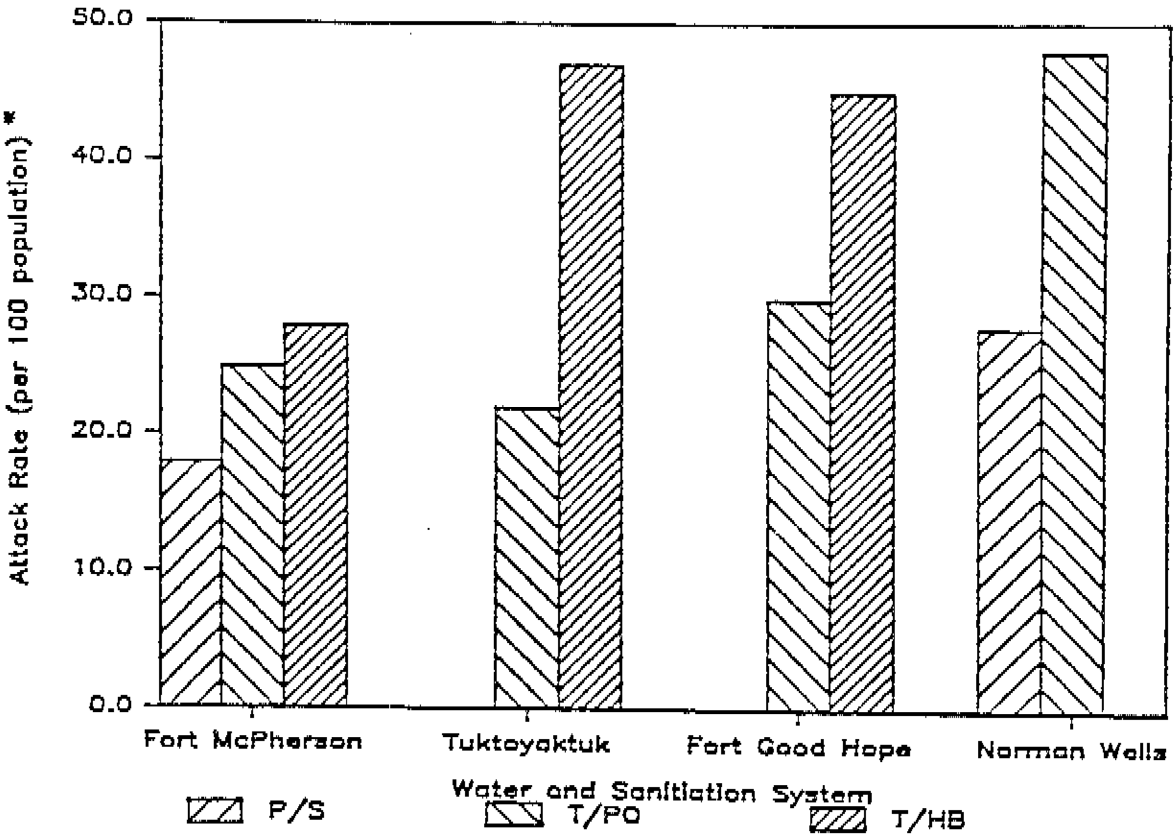


Figure 15. Bucket toilet, to be used with or without a bag.



* Gastro-Intestinal and Skin Diseases.

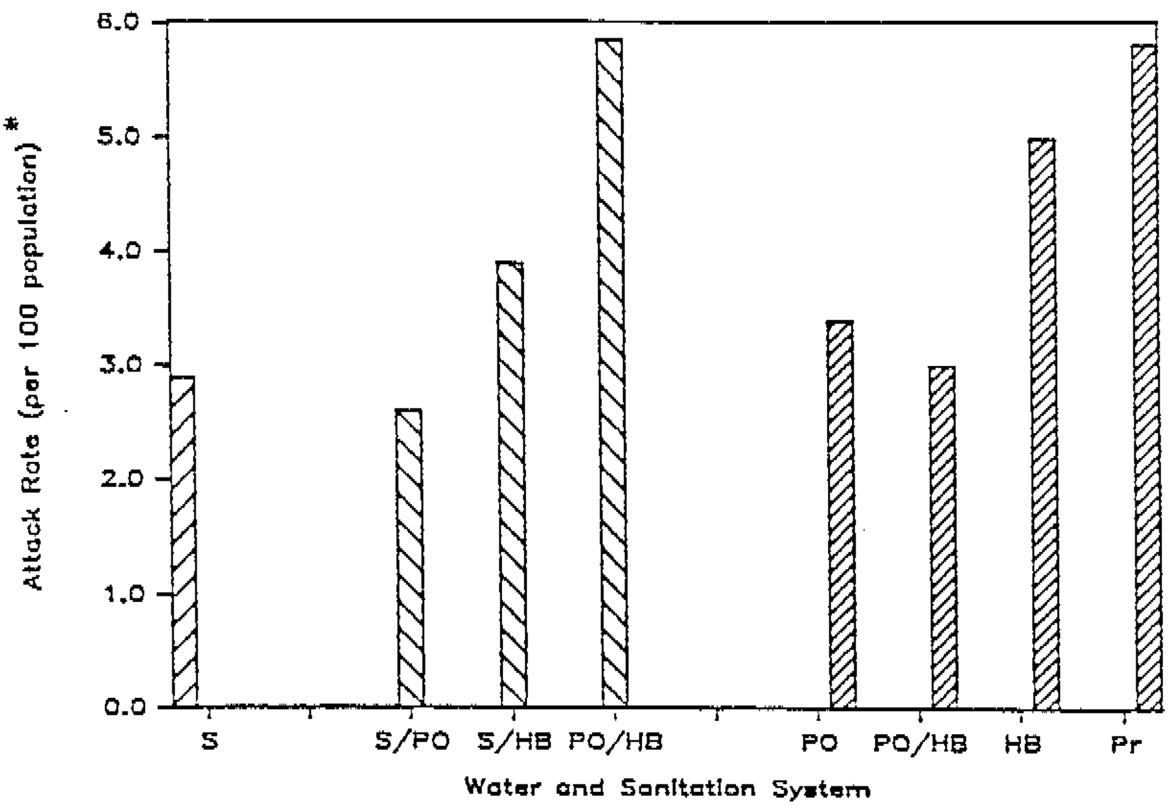
P/S - Piped Water and Sewer

T/PO - Trucked water and Pump Out Sewer

T/HB - Trucked Water and Honey Bags

Figure 16 (a) Effect of Water and sanitation system

Figure 16(b) effect of water and sanitation system



S - Piped Sewer Only
S/PO - Piped Sewer & Pump Out
S/HB - Piped Sewer & Honey Bag
PO/HB - Pump Out & Honey Bag
PO - Pump Out Only
HB - Honey Bag Only
Pr - Pit Privies Only

* Intestinal Infection - Other Organisms
Other Intestinal Helminthiasis
Viral Infections - Unspecified
Dermatophytosis,
Pediculosis & Phthirus Infections
Acariasis

TABLE 5

Characteristics of Human Waste (Undiluted)

Parameter	Average	Range
Volume, litres per person per day	1.3	-
pH	8.78	8.6 - 8.9
Alkalinity, mg/l	14 990	11 900 - 17 000
Total solids, mg/l	78 140	65 990 - 85 030
Volatile solids, per cent of total solids	77.53	71.53 - 80.18
Dissolved solids, mg/l	39 290	32 500 - 53 620
COD/mg/l	110 360	80 750 - 134 820
Supernatant, COD, mg/l	48 510	39 990 - 61 280
TKN, mg/l	8 070	7 280 - 9 520
NH_3-N, mg/l	3 920	3 470 - 4 060
Org. N., mg/l	4 150	3 696 - 5 520
Phosphorus (PO_4), mg/l	3 730	3 400 - 4 250
Volatile acids, mg/l	2 490	2 300 - 2 670
Total Coliform Count, No. per 100 ml	5.4×10^8	1.5×10^8 - 2.3×10^9

(a) The householder removes the honeybag from the bucket toilet and places the sealed bag in a drum reseved for this purpose, in front of the house. Often, the bag is left on the ground, where it is broken by birds, dogs or children, or where it can freeze to the ground in winter. The presence of honeybags lying around the settlement is aesthetically unpleasant. If broken, the bags constitute a danger to health. Removal of honeybag debris is unpleasant, inconvenient, and difficult. Handling, first by the householder and then again by the collector, increases the possibility of breakage. This method is not recommended (Figure 17).

(b) A system of in-house collection of honeybags from the bathroom has been implemented in some communities. The honeybag collector enters the house and removes the honeybag and pail to the truck. After dumping, a new bag is placed in the pail and the pail is returned to the bathroom. The system is advantageous in that handling of the honeybag only once by the collector minimizes the chance of breakage. It is convenient to the householder, requiring no conscious actions on his part. Honeybags are not left around the roads of the settlement where they may be broken. Residents in at least one community have objected strongly to collection from the bathroom as a serious inconvenience which dirties up the house and invades their privacy and about which they were not consulted before the system was placed in operation.

(c) A variant of (b) is the service porch or "two-bucket" system. Each household has two plastic or metal pails for its toilet (Figure 18). Each morning the householder ties the top of the bag and places the plastic pail and full bag in the service porch for collection. The second pail, with an empty, unused plastic bag inside, is placed in the toilet for use. The collector removes the used bag from the pail and replaces it with a fresh bag. The pail is left on the service porch for use the next day, and the 'full' honeybag is taken to the collection vehicle for disposal. The two-bucket system is advantageous in that it minimizes handling of the bag, is clean, and does not leave honeybags lying around the settlement. The major objection to the in-house system - the invasion of privacy - is not present. The two-bucket system requires that all homes have an accessible service porch and two toilet pails.

In Greenland, only (b) and (c) are practised.

Trucks, on which tanks or drums are mounted for storage, are used to haul the wastes to the disposal site (Figure 20). The most practical tank is a half-round shape with a large manhole having a hinged lid on the back in the flat cover. The flat top allows for a lower emptying point. Steps are provided on the side so that honeybuckets can be carried up and emptied into the tank. The tanks usually have a capacity of 2000 to 3000 l. The truck should be kept as small and manoeuvrable as possible to get close to the houses. The tank should be capable of being dumped at the disposal site. At the rear a large valved outlet pipe (at least 200 mm in diameter) is provided which can be opened to empty the tank. A small heater is needed to keep the short pile and valve from freezing. The truck exhaust can also be routed to keep this valve warm and eliminate the need for a heater. A full opening, non-rising stem gate valve has proven best for this application as it must be capable of passing solids such as plastic bags. A steam cleaner should be mounted on the side of the tank so the honeybuckets can be cleaned before replacement in the house. Typical costs for the truck, tank and cleaning unit would be about $40 000 (1977).

Figure 17 manual handling of honeybags stored in drums in front of the house until collection

Figure 18 metal buckets used for collection of human waste

FIGURE 17

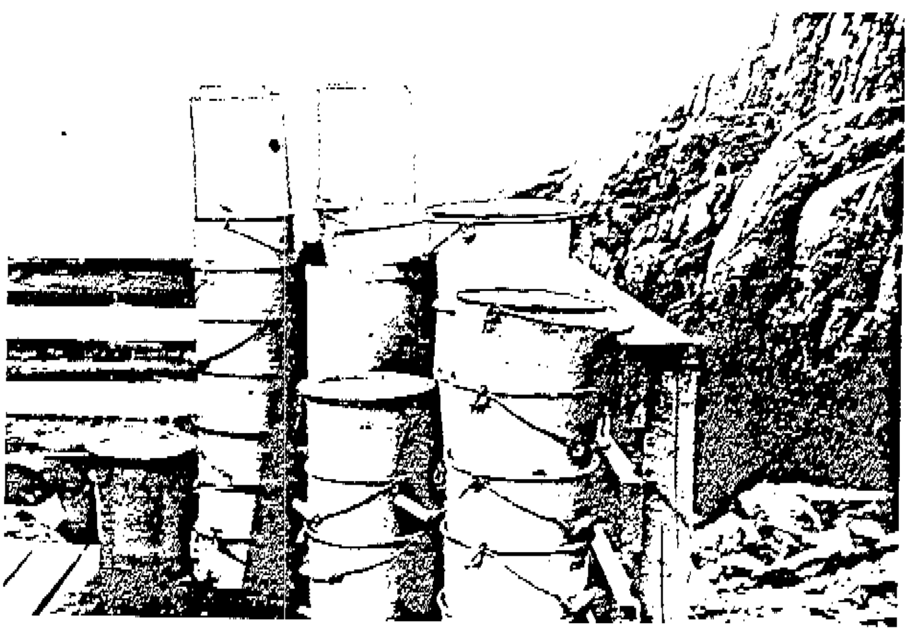


FIGURE 18

Figure 19 Storage tank disposal onto garbage dump a practice not to be recommended!

Another type of truck has a large holding tank which is equipped with a dumping drum with spikes on the inside of the drum. The full honeybag is placed in the drum by the driver and broken on the spikes by an upward hand motion. The contents flow, or are sucked, into the holding tank, and the ripped bag is placed in an oil drum for the purpose of storage before disposal (Figure 20). In a simpler case, honeybags are placed in oil drums on the back of a tractor-driven cart or pick-up truck. The drums with their contents are dumped at the disposal area and the drums reused. In Figure 21 is shown a system used in the southern part of Greenland.

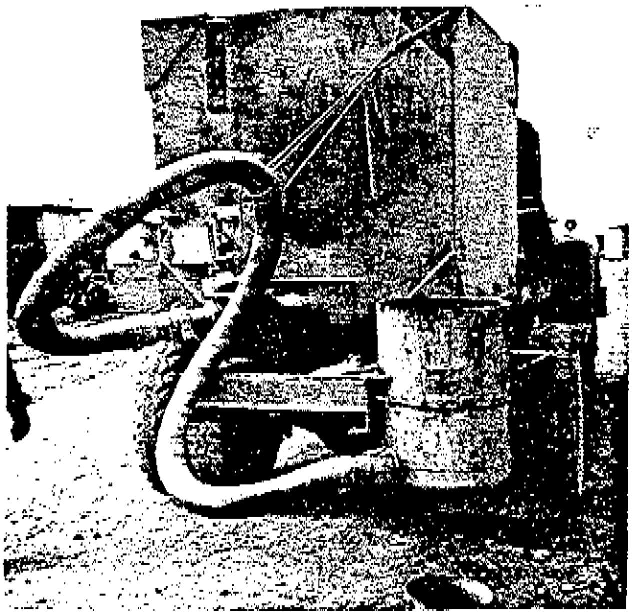
In some communities, homeowners must carry the bagged wastes to a disposal point. Normally, several disposal points are located in the village, and wastes are hauled from there by truck to the disposal site. Disposal points must be centrally located to all dwellings; otherwise the chance of being used regularly is low. The distance that individuals will haul wastes varies with many factors. Two of the more important considerations are training and education of the users and the ground conditions over which the wastes must be hauled. Experience indicates that the number of individuals who utilize a disposal point starts dropping off considerably when the distance exceeds 200 metres. People tend to haul longer distances in the winter because in most communities it is easier to get around and snowmobiles can be used. An extensive education programme is invaluable in promoting the use of a disposal point when individuals are hauling their own waste.

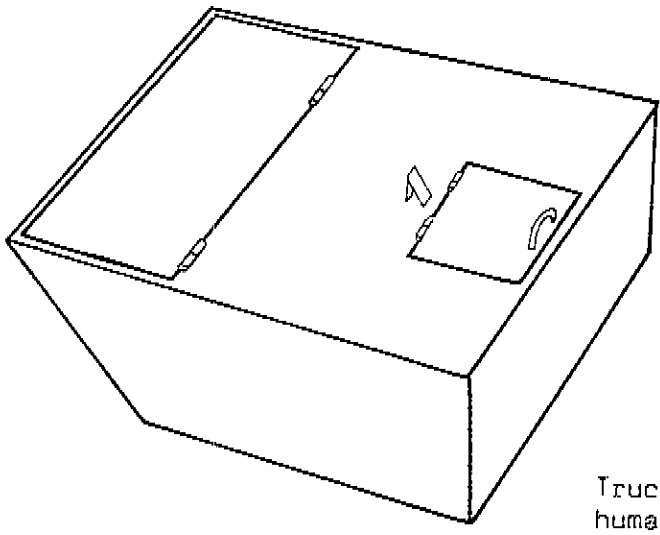
5.3 Disposal

Disposal of the contents of honeybags can be accomplished in several ways. They are: at a treatment plant or a lagoon treating sewage from a piped system; at a sludge pit-lagoon; at a disposal site next to the garbage dump; on the ice; and in the ocean.

The most satisfactory disposal method for honeybucket wastes would be at a central facility, such as a treatment plant where the wastes are a small part of the total waste load to the facility. A fly-tight closable box should be provided on the outside of the building which is convenient to use. It must be capable of being thoroughly washed down and cleaned daily. Above all, it must be aesthetically pleasing and easy to use; otherwise it will not be used. It must also be vandal-proof. This disposal method depends, of course, on the existence of a partial sewer system and treatment facility, where honeybags are used only by a portion of the community. If the wastes are deposited in a lagoon, a dumping point should be designed to prevent erosion of the lagoon dykes yet allow for easy access so the waste does not end up all over the dykes instead of in the lagoon. A platform with a hole cut out over the water seems to be satisfactory. A problem with lagoon disposal is the plastic bags which are often used as liners in honeybuckets. They are not biodegradable and should not be deposited in the lagoon. It will be necessary to empty their contents into the lagoon and then deposit the bags at a landfill or burn them. If honeybag wastes are dumped at a treatment facility this must be taken into account in their design. Although the hydraulic load is small the organic and solids loading is quite considerable (see Table 5). The waste may also contain a high concentration of deodorizers such as formaldehyde and pinesol, which could affect biological treatment processes.

Figure 20. rear view of honeybag suction vehicle





Truck mounted tank for
human wastes collected
in buckets.

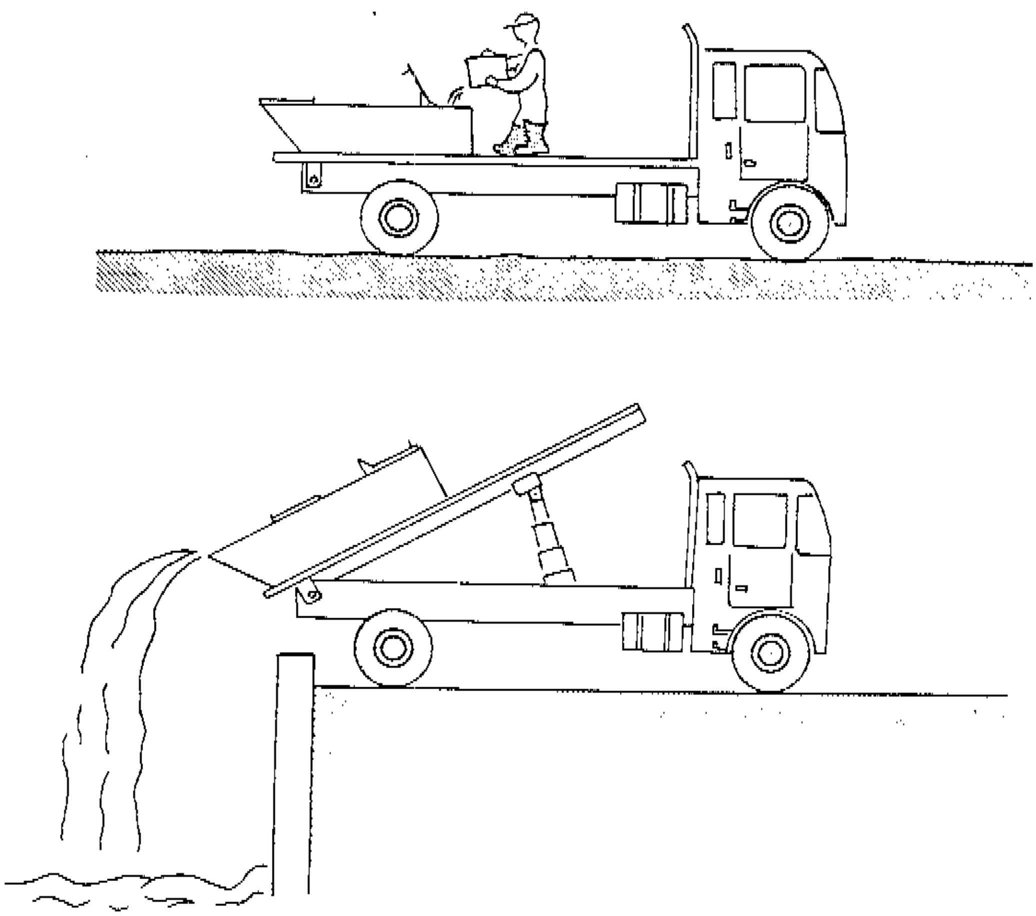


Figure 21 Oceandisposal af human wastes.

If the sewage treatment facility does not exist, the most satisfactory method is to build a sludge pit, lagoon or trench. It must be accessible for easy dumping of the contents of haulage tanks. One way would be to cover it with a platform which contains a disposal hole, covered with a fly-tight, hinged lid. The waste pit should be located on a site which will never be needed for other purposes, and as far as practical from the community and water supply source. It should be sized for about 0.55 m^3 per person per year, and covered after one year's operation and a new pit dug. If the community has a partial sewer system and a lagoon is used as the treatment method, a sludge pit should be constructed adjacent to the lagoon and liquid overflow directed to the lagoon. Some of the liquid portion of the wastes will seep out when the surrounding ground is thawed. As with privies, sludge pits are not a desirable form of waste disposal if the soil is frozen fine-grained silts or where there is a high groundwater table. If no other site is available, lining of the pit to prevent contamination of the groundwater may be required.

Disposal in a properly located, designed and operated waste pit or trench is not preferable to disposal in a garbage dump or in the ocean (see Figures 19 and 21). The two-year laboratory study, simulating waste pit in permafrost, showed that it acts as a holding tank only. No waste treatment occurs. Pathogens will remain viable in the pit for many years.

An improved method of handling and disposing of honeybags is practised in Greenland. Two communities (Holsteinsborg and Egedesminde) have changed from the 'bucket-toilet' system to a 'bag' system. Homeowners are provided with strong paper bags lined with plastic, and closing clips, which are placed inside the bucket. The bags are picked up and transported by a flat truck to a disposal station (see Figure 22). One man at the disposal station empties the bags into a discharge pipe (see Figure 23) leading to the ocean, below low water level. The paper bags are burned. This system is considered a big improvement in Egedesminde. In Holsteinsborg, plastic bags are used, rather than paper bags with plastic liners, and problems are experienced in burning the plastic bags. The cost of the disposal station could not be established but may be considerable, perhaps $150 000 (1973). It makes the solids handling more acceptable to the operators. The expense of such a disposal station is justified only where the honeybag system will continue to be used for many years.

The dumping of honeybags at a landfill site, on the ice or in the ocean should not be encouraged, the main problem being the plastic bag. If honeybags are deposited at a landfill site, this should be separate from the garbage. Daily covering with at least minimal material will prevent animals and birds from getting into it. This is important to prevent disease transmission.

5.4 Cost and Charges

Presented in Table 6 are the actual costs involved for the honeybag collection system in some northern communities (25). These costs are either given as a set charge per pick-up and/or as the actual annual cost per person. This includes labour, material, vehicle O & M, and overhead and profit costs for service provided by a contractor.

Figure 22 disposal station for human waste at Egedesminde, Greenland
Figure 23 view of inside of disposal station, Egedesminde, Greenland

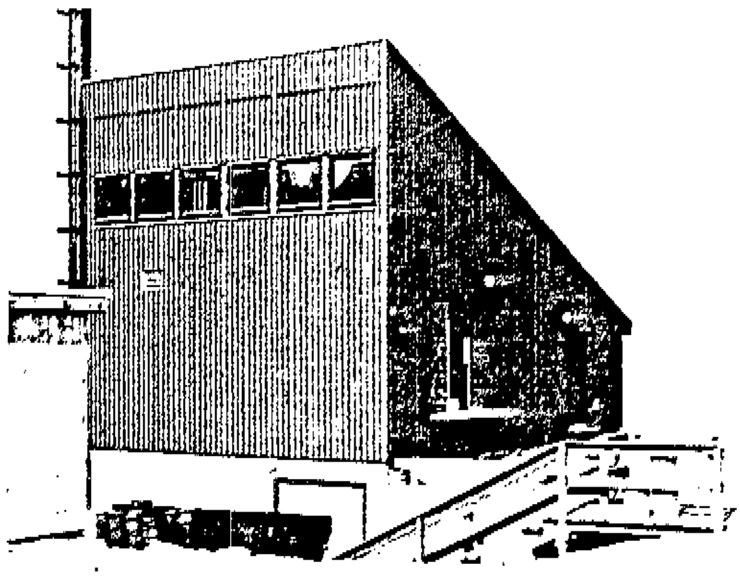


FIGURE 22

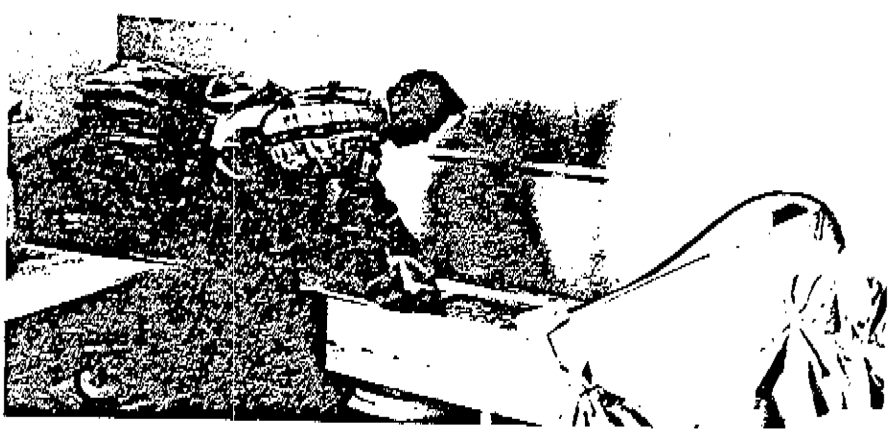


FIGURE 23

TABLE 6

Honeybag Collection Costs

Community	Year of Survey	Population Serviced	Costs	
Coppermine	1976	758	$1.20/pick-up	$32/person/yr
Gjoa Haven	1976	420	$2.15/pick-up	$50/person/yr
Fort Good Hope	1977	443	$1.85/pick up	
Fort McPherson	1976	710	$1.50/pick-up	$32.10/person/yr
Paulatuk[1]	1977	145	$1.15/pick-up	
Chesterfield Inlet[1]	1976	243		$56.80/person/yr

[1] Labour and materials only

6. Treatment Plant Sludges

Some water and all wastewater treatment processes result in sludge which must be disposed of, usually to the land.

6.1 Water Treatment

Few water treatment facilities in cold regions produce sludge. The sludge produced is from coagulation processes normally limited to open river water periods, and softening which may be a year-round operation. The sludge produced will have characteristics similar to that produced by southern facilities. Disposal may be back to the water course although this is not generally recommended. Discharge of the sludge to a lagoon where it can undergo freeze dewatering appears viable.

6.2 Wastewater Treatment

Different wastewater treatment processes produce different types and amounts of sludge. Lagoons are the most widely used wastewater treatment system in cold climates. The sludge accumulates in the cells for a few years prior to removal. Data suggest that colder environments or more northern locations result in greater sludge accumulation rates. This is probably due to lower rates of anaerobic decomposition caused by the lower annual average wastewater temperature.

Sludge removal options are limited to two methods as described below.

- Dry sludge removal: the removal of sludge using earth-moving equipment is carried out after the cell has been isolated and the liquid portion of the sewage has been pumped into the remaining cells. This operation can be undertaken in either summer or winter. In summer, precautions should be taken to ensure that the equipment does not sink into the sludge; in winter, the sludge has to be broken into small pieces prior to removal. If the lagoon liner is exposed, care should be taken not to tear it by covering the exposed part with sand to allow for the movement of equipment.

- Liquid sludge pumping: the second method consists of liquefying the sludge so that it can be pumped to a disposal area. The bottom sludge usually has a solid content of approximately 20 per cent which is too thick to be handled by pumps (limit approximately 10 per cent). To enable pumping of the sludge, the water level overlying the sludge, in the cell to be cleaned, is lowered to a point above the top of the sludge approximately equal to the sludge depth. Then the remaining water is mixed with the bottom sludge using a centrifugal pump to stir up and reduce the percentage of solid content. Finally, the watered down sludge is pumped out of the cell and onto a drying bed. The surface area of the drying bed should be approximately equal to the surface area of the cell to be cleaned and with a depth approximately twice the anticipated sludge depth accumulated between cleanings. The drying bed should be equipped with underdrain pipes embedded in sand and gravel and discharging into a sump. The collected liquid is pumped back into the remaining lagoon cells. After the sludge has dried, it can be hauled to the landfill or used on suitable limited access land areas to enhance vegetation growth. This procedure is commonly used for cleaning lagoons.

Sludge from activated sludge and rotating biological contactors should be concentrated and allowed to freeze dewater. Indefinite lagoon storage either before or after digestion has been used. Also incineration of waste sludge has been practised at some industrial sites.

7. References

1. Heinke, G.W. 1984. Public Health Effects of Municipal Services in the Northwest Territories. Department of Local Government, Government of the Northwest Territories, Yellowknife, 45p.

2. Alter, A.J. 1969. Solid Waste Management in Cold Regions. Scientific Research Data and Reports, Department of Health and Welfare, State of Alaska, College, Alaska, 90p.

3. Heinke, G.W. 1973. Solid Waste Management in the Canadian North. Department of Civil Engineering, University of Toronto, Ontario, 145p.

4. Heinke, G.W. 1974. Report on Municipal Services in Communities of the Northwest Territories. Information Canada No. R72-12874, Department of Indian and Northern Affairs No. QS-1323-000-EE-A1, 165p.

5. EPEC Consulting Western Ltd. 1981. Community Water and Sanitation Services, Northwest Territories. Department of Local Government, Government of the Northwest Territories, Yellowknife, 352p.

6. Kelton, K. 1975. Comprehensive Plan for Solid Waste Management. Alaska Department of Environmental Conservation, Juneau.

7. Cameron, J.J., J. Dusseault & B. Elkin. 1982. Community Water and Sanitation Services: Inuvik Region, Fort Smith Region and Kitkmeot Region, Northwest Territories. Community Planning Division, Department of Local Government, Yellowknife, N.W.T.

8. Associated Engineering Services Ltd. 1974. Report on Tuktoyaktuk Water Supply and Waste Disposal. Government of the Northwest Territories, Yellowknife.

9. Canadian-British Engineering Consultants (1971) Ltd. 1975. Study of Solid Waste Management of Indian Settlements in Northern Ontario. Federal Activities Branch, Environment Canada, Ottawa, Ontario.

10. Leskiw, G. 1981. Elements of Engineering Design for a Sanitary Landfill. Water Management Branch, Publ. No. 4, Alberta Environment, Edmonton Alberta, 54p.

11. Hansen, J.A. 1982. Danish Research and Development on Solid Wastes. Elmia Waste Management, 6th International Conference, Jönköping, Sweden.

12. Dorogovtsev, V.A. 1969. Garbage Disposal in the Far North. Gig. Sanit, (trans. Hygiene and Sanitation), 34, 9.

13. Vesilind, P.A. & A.E. Rimer. 1981. Unit Operations in Resource Recovery Engineering: Prentice-Hall, Inc. Englewood Cliffs, New Jersey, 452p.

14. O'Connell, T.J. & S.A. Zaidi. 1979. Open Pit Incinerator. Technology Demonstration Project. Environmental Protection Service, Northwest Region Rep. No. EPS 4-NW-79-2, Edmonton, Alberta, 61p.

15. National Center for Resource Recovery. 1973. Municipal Solid Waste: Its Volume, Composition and Value. NCCR Bulletin, 3, 2, 4+.

16. Heuchert, K.R. 1974. Refuse Sack Collection System Study. Arctic Waste Disposal, Social Program, Task Force on Northern Oil Development Rep. No. 74-10. Department of Indian and Northern Affairs, Ottawa, Ontario, pp. 1-22.

17. Cameron, J.J. 1981. Guidelines for the Preparation and Administration of Municipal Water and Sanitation Trucked Service Contracts. Water and Sanitation Section, Dept. of Local Government, Government of the Northwest Territories, 120p.

18. Greenland Technical Organization. 1984. Guidelines for Housing and Human Settlement Planning and Design Criteria in Cold Climates: Greenland. Regional Office for Europe, World Health Organization, Copenhagen, Denmark, 167p.

19. Forgie, D.J.L. 1976. Shredded Solid Waste Disposal. Some Problems of Solid and Liquid Waste Disposal in the Northern Environment. Environmental Protection Service Rep. No. EPS-4-NW-76-2, Edmonton, Alberta, pp. 43-85.

20. Tilsworth, T. 1982. Solid Waste Management in Remote Alaskan Communities. In: Utilities Delivery in Cold Regions. Environmental Protection Service Rep. No. EPS 3-WP-82-6. Ottawa, Ontario, pp. 329-344.

21. Smith, D.W. & R.O. Straughn. 1971. Refuse Incineration at Murphy Dome Air Force Station. Arctic Health Research Centre, Fairbanks, Alaska, 27p.

22. Cohen, J.B. 1973. Solid Waste Disposal in Permafrost Areas. Permafrost: North American Contribution, Second International Conference, National Academy of Sciences, Washington, D.C., pp. 590-598.

23. Rylander, H. Swedish Association of Public Cleansing and Solid Waste Management. Elmia Waste Management, 6th International Conference, Jönköping, Sweden.

24. Gamble, D.J. & C.T. Janssen. 1974. Evaluating Alternative Levels of Water and Sanitation Services for Communities in the Northwest Territories. Can. Journ. of Civil. Eng., 1, 116-128.

25. Doulton, B. 1978. Water and Sanitation Operation and Maintenance Costs - A Consolidation of Historic Information. Department of Local Government. Government of the Northwest Territories, Yellowknife, 143p.

26. U.S. Army Corps of Engineers. 1972. Technical Evaluation Study, Solid Waste Disposal, Fort Greely, Alaska. Office of the District Engineer, Anchorage.

27. Grunwaldt, J.J., T. Tilsworth & S.E. Clark. 1975. Solid Waste Disposal in Alaska. In: Proceedings, Environmental Standards for Northern Regions. Institute of Water Resources Rep. No. IWR No. 62, University of Alaska, Fairbanks, pp. 331-356.

28. W.O. Wardrop & Associates Ltd. 1978. Burning Practices in the Northwest Territories. Environmental Protection Service, Edmonton, Alberta.

29. Orr, R.C. & D.W. Smith. 1977. A Review of Self-Contained Toilet Systems with Emphasis on Recent Developments. Proceedings, Utilities Delivery in Arctic Regions. Environmental Protection Service Rep. No. EPS 3-WP-77-1, Ottawa, Ontario, pp. 266-305.

30. Heinke, G.W. & D. Prasad. 1980. Anaerobic Treatment of Human Waste in Northern Communities. Can. Journ. of Civil Eng., 7, 156-164.

31. Cadario, P.M. & G.W. Heinke. 1972. Manual for Trucking Operations for Municipal Services in Communities of the Northwest Territories. Department of Civil Engineering, Univ. of Toronto, Ontario.

8. Bibliography

Associated Engineering Services Ltd. 1973. Solid Waste Management in the Canadian North, Environmental Protection Service, Ottawa, Ontario.

Associated Engineering Services Ltd. 1974. Report on Tuktoyaktuk Water Supply and Waste Disposal. Government of the Northwest Territories, Yellowknife N.W.T.

Associated Engineering Services Ltd. 1978. Waste Management for Northern Work Camps, Environmental Protection Service, Northern Technology Centre, Edmonton, Alberta.

Cadario, P.M. & G.W. Heinke. 1972. Manual for Trucking Operations for Municipal Services in Communities of the Northwest Territories, Publication, Department of Civil Engineering, University of Toronto, Ontario.

Grainge, J.W. 1969. Study of Environmental Engineering in Greenland and Iceland, Manuscript Report No. NR-69-5, Division of Public Health Engineering, Canada Department of National Health and Welfare, Ottawa, Ontario.

Grainge, J.E., R. Edwards, K.R. Heuchert & J.W. Shaw. 1973. Management of Waste from Arctic and Subarctic Work Camps, Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development, Government of Canada, Ottawa, Ontario.

Heinke, G.W. 1973. Report on Environmental Engineering in Greenland and Northern Scandinavia, Department of Civil Engineering Publication No. 73-05, University of Toronto, Ontario.

MacLaren Plansearch Services Ltd. 1984. Study to Develop a Uniform Strategy for Handling Solid Wastes in the Beaufort Region. Environmental Protection Service, Yellowknife, Northwest Territories.

Miller, R.E. & O.E. Dickason. 1982. Management of Solid Waste in Cold Regions: Resource Recovery Potential. In: Utilities Delivery in Cold Regions. Environmental Protection Service Rep. No. EPS 3-WP-82-6, Ottawa, Ontario, pp. 345-357.

Ryan, W.L. 1975. Village Sanitary Problems, Environmental Standards for Northern Regions, Institute of Water Resources, Rep. No. IWR 62, University of Alaska, pp. 315-320.

Schindler, J.F. 1983. Solid Waste Disposal National Petroleum Reserve in Alaska. Proceedings, Permafrost, Fourth International Conference, National Academy Press, Washington, D.C., pp. 1111-1116.

Stanley Associates Engineering. 1973. Solid Waste Management in the Canadian North, Environmental Protection Service, Ottawa, Ontario.

Stanley Associates Engineering. 1974. Final Report on Community Services Improvement Program, Yukon Territory. Department of Local Government, Government of the Yukon Territory, Whitehorse, 292p.

Stanley Associates Engineering Ltd. 1974. Baling for Solid Waste Management at Baker Lake, N.W.T., Northwest Region, Environmental Protection Service, Edmonton, Alberta, 55p.

Straughn, R.O. 1972. The Sanitary Landfill in the Subarctic. Journ. of the Arctic Institute, 25, 1.

Underwood McLellan & Assoc. Ltd. 1974. Report on Study of Pollution Control Systems, Resolute, N.W.T. Government of the Northwest Territories and Environmental Protection Service, Edmonton, Alberta.

Underwood McLellan Ltd. 1982. Identification and Verification of Active and Inactive Land Disposal Sites in the Northwest Territories. Environmental Protection Service, Yellowknife, Northwest Territories.

Watmore, T.G. 1975. Problems of Waste Disposal in the Arctic Environment, Industrial Wastes, 21, (4), 24.

Zenone, C., D.E. Donaldson & J.J. Grunwaldt, 1975. Groundwater Quality Beneath Solid Waste Disposal Sites at Anchorage, Alaska, Groundwater, 13, (2) 180-190.