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A NEW CONCEPT OF WASTE DISPOSAL

by M.A.J. Matich[*1] & W.F. Tao[*2]

INTRODUCTION

Concern for protection of the environment has increased considerably throughout the last 20 years and this has given rise to strenuous efforts to find safe methods for storing or disposing of hazardous wastes. This paper describes one step in the continuing effort to find new and improved disposal methods which involves development of a new concept for waste disposal referred to as the "Pervious Surround Method"*. This method was invented by the authors in the course of a search for the most effective means of disposal of low-level radioactive wastes in the form of uranium mill tailings and will be described by reference to its potential use in the formidable challenge of uranium tailings disposal. The concept is however also considered to have potential for disposal of other forms of hazardous wastes, and for other applications such as the permanent isolation of toxic substances already in the ground below the groundwater table.

Current technology of contaminant containment designed to minimize adverse impact on groundwater generally relies on the approach of providing some form of "impermeable" seepage barriers, and there are many examples in the published technical literature of designs based on such an approach, e.g. McWhorter & Nelson[1], Kays[2], Scarano & Linehan[3], to name a few.[1]

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Current technology of contaminant containment designed to minimize adverse impact on groundwater generally relies on the approach of providing some form of "impermeable" seepage barriers, and there are many examples in the published technical literature of designs based on such an approach, e.g. McWhorter & Nelson[1], Kays[2], Scarano & Linehan[3], to name a few.[1]

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The practical difficulties in constructing engineered barriers of this sort to achieve the required degree of containment and durability are well known. Natural barriers such as clay strata and massive bedrock are often difficult to find in reasonably close proximity to the sources of wastes to be disposed of. Positive verification of the flawlessness of such formations by investigative techniques is also difficult.

The Pervious Surround Method departs radically from the use of "impervious" seepage barriers and thus avoids the difficulties associated with the construction of such barriers. It is based in part on the same law governing physical seepage through porous media, i.e. Darcy's law, as in the current technologies. However, its approach is diametrically opposite to current methods in that instead of trying to resist seepage flow by use of low permeability materials, practical elimination of seepage potential is achieved by using highly permeable layer(s) surrounding the waste deposited below the natural groundwater table. The use of a pervious envelope to reduce the hydraulic gradients across the waste deposit to virtually zero also takes advantage of the phenomenon of non-Darcian flow under very low hydraulic gradients.

It is believed that the system (i) has the basic capability of virtually eliminating transport of contaminants from the waste by physical seepage, (ii) that it is relatively insensitive to hydrogeological details, and (iii) that it can perform satisfactorily within geological formations containing defects such as fault and/or fracture zones. The system is also believed capable of regulating by design, the rate of release of contaminants by diffusion/dispersion phenomena. It has gone through the conceptual development phase and has been accepted in principle by regulatory authorities for disposal of uranium tailings in Canada.

Detailed design for application of the system in a major uranium mining development is currently underway and initial construction is scheduled to begin in the summer of 1984.

The approach of controlled storage or disposal of toxic wastes below water level in open bodies of water, or below groundwater level in depleted open pit mines or special excavations for this purpose, has gained acceptance only comparatively recently in North America. For example, A.S.T.M. Subcommittee D18.14 in appraising what constitutes an acceptable hydrogeologic environment for a waste disposal site, conclude that "allowing wastes to be buried below the water table does not necessarily mean these wastes will be placed in an aquifer or that they will affect an aquifer."[4]

Coady and Henry[5] in describing principles, criteria and guidelines developed by The Atomic Energy Control Board of Canada (A.E.C.B.) for the management of uranium mill tailings, state that "the use of lakes, land-water, swamps and marshes will only be considered after it has been demonstrated that a suitable dry land area is not available and provided it can be established that the site is not a groundwater discharge area. The deposition of tailings in deep lakes, well below the water surface where chemical activity is expected to be limited by the absence of free oxygen, has not been ruled out; however, considerable supporting research will be required with respect to both short-term and long-term performance of this type of management before a decision by the A.E.C.B. could be made to licence such a facility."

PERVIOUS SURROUND CONCEPT

It is believed that an ideal waste disposal system will be required to meet the following main objectives:

i) effective isolation of the waste from the biosphere by positively controlling the rate of release of contaminants to an acceptable level, both in the short term during waste deposition and in the long term after decommissioning of the waste repository in a time frame which may be measured in thousands of years.

ii) capability of positive monitoring to verify the performance of the system during and immediately following completion of waste deposition, and also in the long term if required, and

iii) built-in capability of applying fallback contingency measures, if required at any time after decommissioning to ensure a failsafe system.

In the following sections, the basic conceptual arrangement of the system and method of operation are described, together with a general discussion on how the system aims at meeting the above objectives.

BASIC ARRANGEMENT AND METHOD OF OPERATION

Because the central philosophy is mitigation of potential for transport of contaminants, it follows that the single most important requirement of the system is that the waste deposit be located entirely below the natural groundwater table. This eliminates (i) the high, persistent potential heads associated with wastes deposited above the groundwater table, which tend to cause downward migration of pore fluids from the waste deposit, and (ii) mass transport due to frost action, capillary action, and vapour pressure gradients associated with unsaturated soils.

In its simplest form, the system is composed of the following elements:

i) a pit (of sufficient volume to contain the waste) below the natural groundwater table.

ii) a pit dewatering system to lower the groundwater level during the operating period, and for possible use in the post-decommissioning period if required, and

iii) a multi-layered pervious envelope totally surrounding the waste deposit.

Schematic presentations of these elements for two scenarios in which the waste deposit is located below a body of water or a land surface, respectively, are given on Figures 1a and 1b.

Operation of the system can, in a broad sense, be divided into three main periods as follows:

i) waste deposition
ii) transition
iii) post-decommissioning

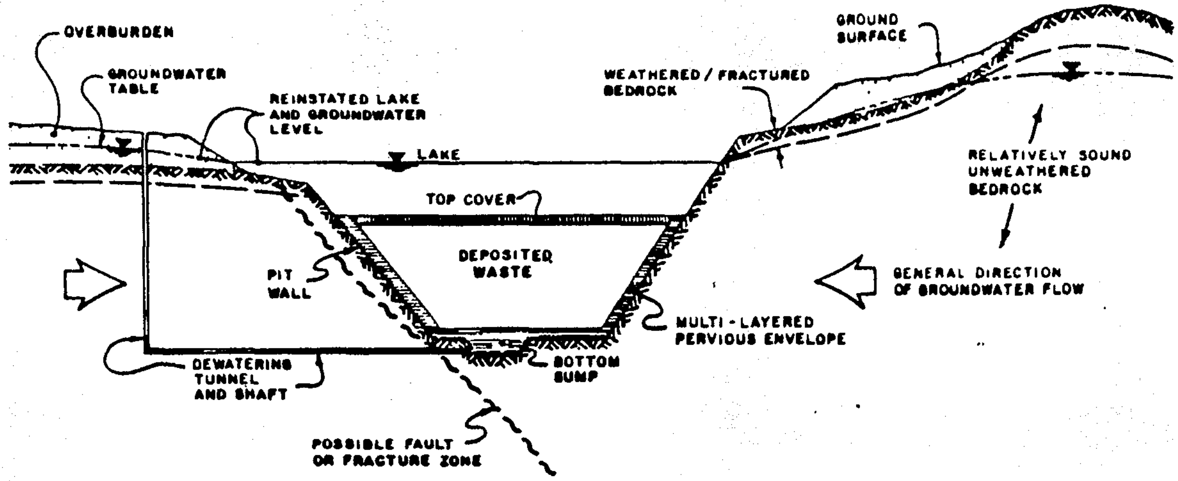

OVERBURDEN
GROUNDWATER TABLE
REINSTATED LAKE AND GROUNDWATER LEVEL
LAKE
TOP COVER
DEPOSITED WASTE
PIT WALL
GROUND SURFACE
WEATHERED / FRACTURED BEDROCK
RELATIVELY SOUND UNWEATHERED BEDROCK
GENERAL DIRECTION OF GROUNDWATER FLOW
MULTI-LAYERED PERVIOUS ENVELOPE
DEWATERING TUNNEL AND SHAFT
BOTTOM SUMP
POSSIBLE FAULT OR FRACTURE ZONE

Fig. 1a

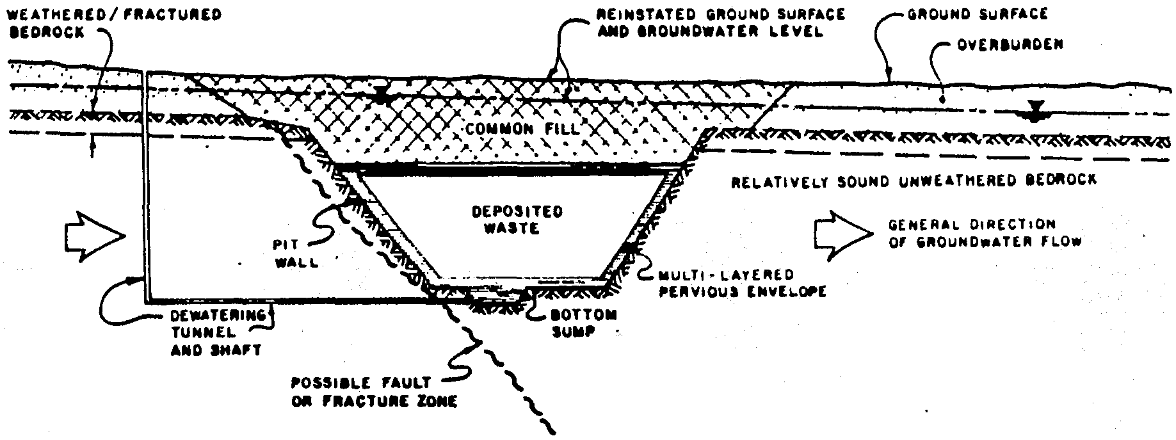

WEATHERED / FRACTURED BEDROCK
REINSTATED GROUND SURFACE AND GROUNDWATER LEVEL
GROUND SURFACE
OVERBURDEN
COMMON FILL
RELATIVELY SOUND UNWEATHERED BEDROCK
DEPOSITED WASTE
PIT WALL
GENERAL DIRECTION OF GROUNDWATER FLOW
MULTI-LAYERED PERVIOUS ENVELOPE
DEWATERING TUNNEL AND SHAFT
BOTTOM SUMP
POSSIBLE FAULT OR FRACTURE ZONE

Fig. 1b

The basic design requirements for the system and the manner in which it would perform during the various stages to achieve the required degree of contaminant containment are discussed below.

a) <u>Waste Deposition Period</u>

The pit dewatering system enables construction of the pervious envelope and waste deposition in the dry, and also performs two other very important functions.

Firstly, by creating a cone of drawdown in the groundwater table surrounding the pit, positive total containment of leachates or pore fluids from the waste is achieved due to the inward groundwater flow pattern so created. This is very significant because it provides a positive means for preventing any release of contaminants from the waste deposit into the groundwater throughout the operating life of the waste repository, which is not believed achievable to the same degree by conventional systems using engineered seepage barriers. There is thus no potential for release of contaminants from the waste deposit to the environment during the period until the groundwater table has fully recovered to its original natural position above the waste deposit, at which time the pervious envelope will become operative in controlling the rate of release of contaminants in the long term.

Secondly, the dewatering process creates an underdraining effect which preconsolidates the waste where necessary under its full bulk density and thus reduces the time required to achieve full consolidation of the waste relative to its eventual submerged condition after reinstatement of the natural groundwater table over it. This fully consolidated state is desirable to eliminate for all practical purposes, the potential for releasing pore fluids from the waste as a result of consolidation after decommissioning.

The dewatering system would handle maximum inflow into the pit during the operating period of waste deposition from (i) surface run-off, (ii) groundwater and (iii) excess pore water from the waste. Details are a matter of design. The system can also be incorporated into contingency measures for the post-decommissioning period, as discussed later.

The pervious envelope serves as a drainage blanket surrounding the waste during the operating period, enabling run-off and excess pore fluid from the waste to be collected and returned via the pit dewatering system for recycling as process water, or to be suitably treated prior to discharging to a receiving stream. To fulfil this short term function, the pervious envelope will be required to meet the normal design criteria for drainage blankets. However, the principal function of the pervious envelope, which is to provide a means for mitigation of contaminant release from the waste deposit in the long term governs its design. Further comments on the pervious envelope are thus made later in connection with the post-decommissioning long term aspects of the system.

b) <u>Transition Period</u>

After completion of waste deposition, pumping and treatment of water from the dewatering system would be continued over a suitable interval as required for consolidation of the waste to a fully-consolidated or over-consolidated state with respect to the final fully submerged condition. If necessary, special measures could also be applied to accelerate the consolidation process.

After the desired degree of consolidation has been achieved, pumping from the dewatering system would be terminated, allowing the groundwater to regain its natural level over the top of the waste.

Depending on post-decommissioning water quality requirements, the pervious envelope could be flushed to remove any residual contaminants of significance which may remain in it from the pore water drained from the waste during the final stages of the consolidation process. This can be achieved by intermittent pumping from the dewatering system to produce a limited cone of depression sufficient to cause flow of natural groundwater through the pervious envelope without initiating further consolidation of the waste deposit. Periodic checks on the quality of the pump discharge or direct sampling of water from within the pervious envelope would provide information for judging the duration of the flushing operation.

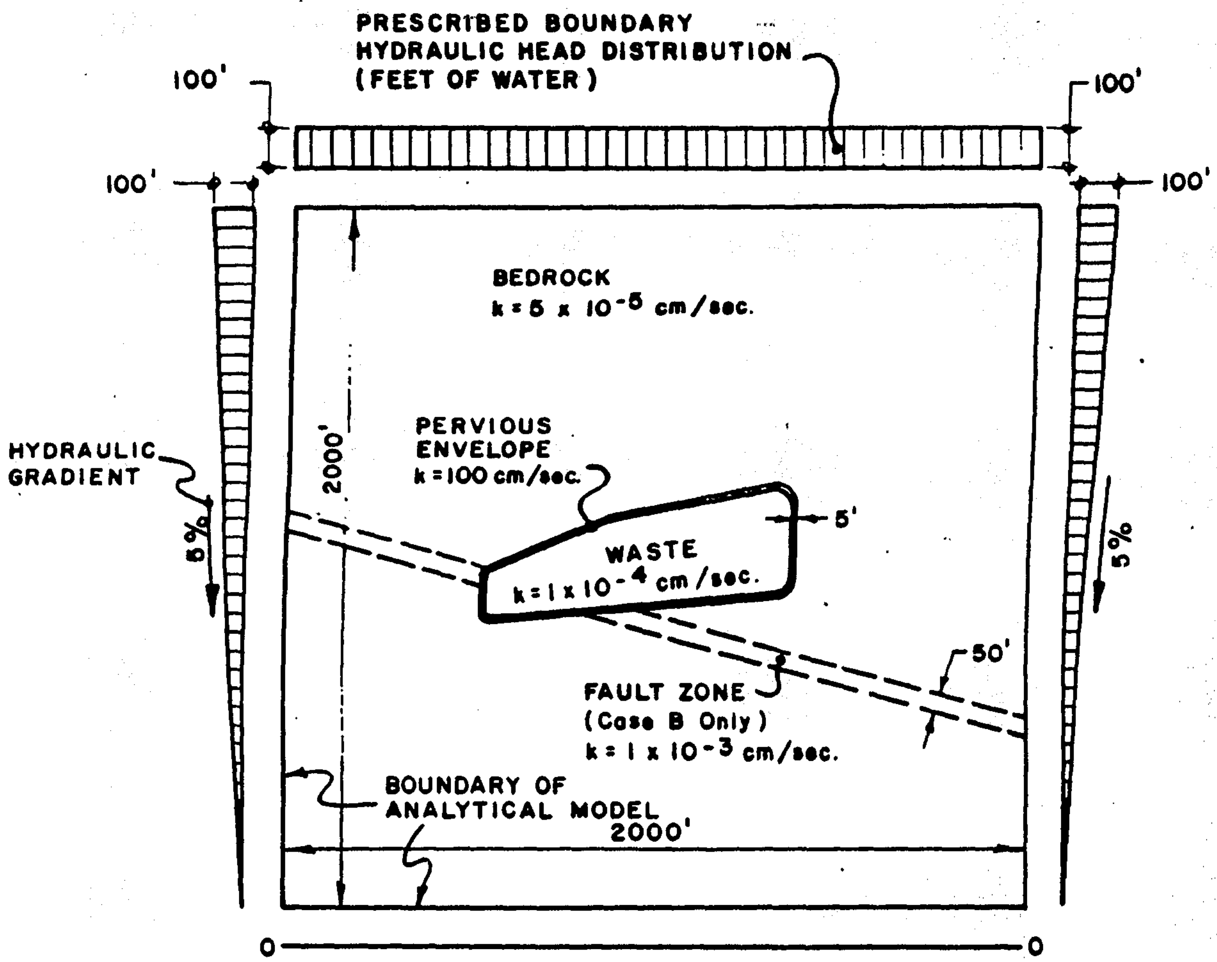
c) Post-Decommissioning Period

As already mentioned, the primary function of the pervious envelope is to mitigate the rate of release of contaminants in the long term after decommissioning of the waste repository. With the waste located permanently below the groundwater table and provision for full consolidation of the waste (relative to its submerged state) prior to decommissioning, the remaining driving forces or potentials for transporting contaminants away from the waste deposit would be:

i) hydraulic gradients of the natural groundwater system across the waste repository
ii) geochemical gradients between the waste and the surrounding groundwater.

Groundwater systems generally have low hydraulic gradients except of course in cases such as mountainous regions or areas where artesian conditions exist. Thus, sites with low natural groundwater gradients favourable for application of the Pervious Surround Method are common. Within such a groundwater environment, with appropriate design the originally low hydraulic gradients (typically less than 10 percent) can be readily further reduced by several orders of magnitude by introducing a zone of highly pervious material totally enveloping the waste deposit, such that for all practical purposes, no groundwater seepage will occur through the waste.

The effectiveness of such a system is illustrated by an example shown in Figure 2 in which the results of finite element seepage modelling are summarized. The model represents a near horizontal one foot deep section along a plane of natural groundwater flow, across a pit in which uranium tailings has been deposited. The tailings are assigned an average coefficient of permeability of 1×10^{-4} cm/sec. and are assumed to be surrounded by a 5 foot thick layer of rock fill with an average permeability of 100 cm/sec. For the sake of simplicity, the filter zone/s required between the rock fill and the tailings have not been included in the model. The surrounding bedrock is assumed to be uniform in one analysis (Case A) with an assigned average permeability of 5×10^{-5} cm/sec. In another analysis, Case B, a fault intersecting the pit is also modelled as a 50 foot wide zone with an average permeability of 1×10^{-3} cm/sec. Boundary hydraulic head distribution is prescribed in both analyses to simulate a 5 percent hydraulic gradient across the model.



	CASE A (WITHOUT FAULT ZONE)	CASE B (WITH FAULT ZONE)
Flow through pervious envelope, Qp (cu. ft/day)	9.6	10.9
Flow through Waste Deposit, Qw (cu. ft/day)	0.0018	0.0020
Flow Ratio, Qp:Qw	5330:1	5450:1
Max. hydraulic gradient in Waste Deposit	7.6×10^{-6}	9.7×10^{-6}
Max. Darcy velocity in pervious envelope (ft/day)	0.98	1.07
Max. Darcy velocity in Waste Deposit (ft/day)	2.2×10^{-6}	2.7×10^{-6}

Fig. 2

The significant points brought out by the results of the analyses are as follows:

i) Seepage through the tailings is negligible for all practical purposes, even assuming Darcian flow conditions to apply.

ii) A very high ratio of flow through the pervious envelope to flow through the tailings can ensure dilution of contaminant concentrations to innocuous levels even within the pervious envelope itself. It is evident that this flow ratio would also be practically independent of changes in the hydraulic gradient across the model and thus the system has the significant advantage of being insensitive to groundwater level fluctuations.

iii) The maximum computed hydraulic gradient in the tailings is several orders of magnitude lower than the minimum measurable values in controlled laboratory research experiments such as those reported by Law and Lee[6], carried out to examine non-Darcian flow behaviour of fine-grained soils. Preliminary test work on uranium tailings also shows positive evidence of non-Darcian flow behaviour starting at hydraulic gradients several orders of magnitude higher than the maximum computed hydraulic gradient in the tailings from the modelling analyses shown herein. Thus it is believed that if there is any seepage through the tailings at all, it would be much less than the computed values shown on Figure 2.

iv) The increase in computed seepage through the tailings resulting from the presence of the fault zone in Case B compared to Case A is insignificant, demonstrating the insensitivity of the system to hydrogeological details.

v) Seepage velocities through the pervious zone are extremely low and thus blockage of it in the long term due to transport and sedimentation of solid particles is not of concern.

When seepage rates through the tailings are as low as the computed values described above, mass transport from the tailings becomes mainly a function of geochemical gradients. Seepage velocity of groundwater surrounding the tailings deposit is a factor influencing the rate of mass transport in terms of the dependence of longitudinal and transverse dispersivity values on the velocity of groundwater flow. However, Harleman and Rumer[7] show that molecular diffusion becomes predominant relative to mechanical dispersion for seepage velocities below a value corresponding to a Reynolds number of 10^{-3}.

In the Pervious Surround system, the graded filter layer/s within the pervious envelope will necessarily have permeabilities intermediate between the rock fill and the tailings. Thus, seepage velocities in the filter layer/s would range between those of the rock fill layer and the tailings deposit. These limiting velocities as indicated in the example discussed earlier, are of very low orders of magnitude. Extensions of the analyses by including the filter layer/s of select granular materials indicate that seepage velocities in the innermost filter layer could readily be reduced to the point that the corresponding Reynolds numbers would be at least two orders of magnitude lower than the value referred to above. This condition ensures that transport of contaminants from the tailings across the innermost filter layer would be controlled by molecular diffusion only, for all practical purposes.

The rate of molecular diffusion is governed by Fick's first and second laws[8]. With constant flushing by groundwater flow through the pervious rock fill layer, a steady-state condition will be established in the long term in which concentration gradients become uniform within each filter layer. The rate of molecular diffusion through the innermost filter layer in this case can be computed by applying Fick's first law. Thus it is a matter of design to provide a sufficient thickness to the innermost filter layer to control the final rate of release of contaminants by molecular diffusion in the long term.

OTHER ADVANTAGES

In addition to the control on the rate of release of contaminants from the system throughout the operating life of the disposal repository and in the long term after its decommissioning, the Pervious Surround system has a number of other advantages, as described below.

i) Because the pervious envelope is constructed of natural inert materials and will be permanently submerged below the groundwater table, it should not be susceptible to deterioration of consequence in the long term.

ii) Compared to a seepage barrier, the performance of a pervious envelope is considered significantly less sensitive to local imperfections which may result from either unavoidable flaws (which perhaps escape detection even with the most thorough quality control practices), or, in the long term, from human activities or natural events.

iii) The performance of the Pervious Surround system is readily amenable to monitoring by installation of conventional piezometers within it. As already mentioned, its performance is not sensitive to hydrogeological details of the surrounding ground, such as fault or fracture zones.

iv) The pit dewatering system, although not required in the long term, provides a convenient fall back measure, which can be reactivated in the unlikely event that this is required. Initiation of drawdown not only provides immediate total containment of contaminants, but also generates a flushing action by reversing the direction of groundwater flow particularly along the more prominent pathways through which contaminant transport may have been occurring.

CLOSURE

The authors believe that the Pervious Surround Method provides a system that meets the main objectives of an ideal system for disposal of solid wastes particularly in large quantities such as uranium mill tailings. They also believe that the basic concept of the system can be adapted to other applications such as the isolation of wastes which may exist in-ground from events such as in-situ extraction processes. The system cannot by itself deal with some of the particular problems associated with special waste forms such as high level nuclear wastes, hazardous liquid industrial wastes, organic or gas generating wastes, and the like. However, a predominant common objective in planning disposal facilities for such wastes has always been to eliminate the potential transport of contaminants through the groundwater system. In this regard, the authors are encouraged to believe that the Pervious Surround Method can be adapted as an enhancement measure to some such waste management systems, by creating a region of stagnant groundwater around them, thereby achieving the same desired effect which near perfect "impervious" geological media or engineered barriers would produce.

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