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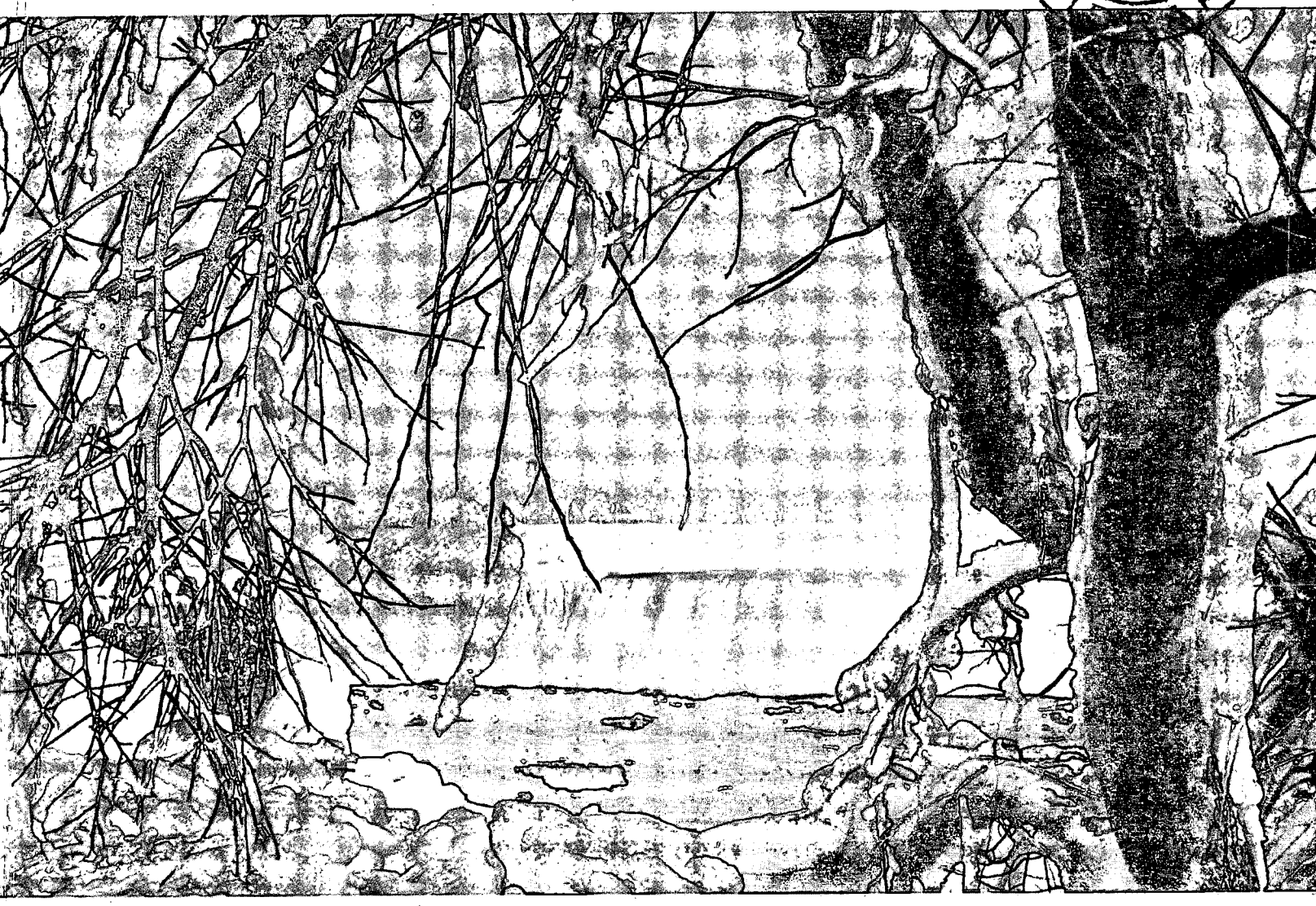
A Radiotracer Technique for Measuring Sediment Movement

R.W. Durham and R.J. Goble



SCIENTIFIC SERIES NO. 80
(Résumé en français)

INLAND WATERS DIRECTORATE,
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Abstract

A technique for measuring the direction of movement of sandy sediments by means of a radiotracer is described. An artificial sediment fabricated from glass containing a small percentage of arsenic is irradiated in a nuclear reactor to produce ^{76}As ($T_{\frac{1}{2}}$ = 26.4 hr). This material is then inserted into the particular sediment to be studied and its movement followed by monitoring the 560-keV γ-ray emission with a submersible NaI detector. A test of the method at Point Pelee on the north shore of Lake Erie with 140 g of artificial sediment containing 180 mCi of ^{76}As demonstrated that the redistribution of the radioactive material by the bottom current could be readily followed for at least three days after insertion.

Résumé

On décrit ici une technique de mesure du sens de déplacement des sédiments sableux au moyen d'un radiodétecteur. On irradie des sédiments formés artificiellement avec du verre à faible teneur en arsenic dans un réacteur nucléaire de manière à donner naissance à un matériau de formule ^{76}As ($T_{\frac{1}{2}}$ = 26.4 h). On l'introduit alors dans les sédiments que l'on doit étudier et on suit son déplacement en observant l'émission des rayons gamma 560 keV au moyen d'un détecteur à immersion NaI. On a mis cette méthode à l'essai à Pointe Pelée, sur la côte nord du lac Érié, en utilisant 140 g de sédiments artificiels contenant 180 mCi de ^{76}As; les résultats obtenus ont démontré que l'on pouvait aisément suivre, pendant au moins trois jours après introduction du matériau radioactif, sa nouvelle répartition due aux courants de fond.

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INTRODUCTION

The physical processes involved in the build-up and erosion of the sandy tip of Point Pelee on the north shore of Lake Erie were the subject of intensive study during the summer and fall of 1974 by scientists from the Canada Centre for Inland Waters (1). A part of that activity, described here, was the development of a radiotracer system for the determination of the prevailing direction of lake bottom sand movement.

Techniques for tracing sediment movement by radioactive means have been reviewed by Courtois (2) and Nelson and Coakley (3). These techniques involve inserting material into the sediment that is either tagged with a radioactive tracer for subsequent following with a γ-ray detector or tagged with a neutron activable element that can be followed by sampling the sediment around the insertion site. Irradiating the sediment samples in a nuclear reactor followed by γ-ray spectrometry determines the concentration of the tracer. This latter technique was used earlier in Lake Ontario (4) with satisfactory results but with excessive manpower requirements for sediment sampling and activation analysis.

In the present study a small quantity of radioactive artificial sediment was injected into the lake bottom, and the movement of the tracer was followed with a submersible γ-ray detector. Signals from this detector, consisting of a NaI crystal and photomultiplier, were routed to a γ-ray spectrometer on board the survey vessel. The artificial sediment was fabricated of glass containing 0.8% arsenic which produced the radioisotope ^{76}As, which emits a 560-keV γ-ray with a 26.4-hour half-life when irradiated in a nuclear reactor. This glass was manufactured by the Ontario Research Foundation using materials free from neutron absorbing impurities. The grain size distribution of the artificial sediment was matched to that prevailing in the experimental area so that the movement of the tracer would duplicate that of the sediment. The radioactivity measurements of the ^{76}As made in the field were related to mass of artificial sediment by calibrating the detector in a tank of water with an irradiated sample of known weight.

Several preliminary field trials in the experimental area were necessary during the development of the equipment. Positioning the radioactive sediment accurately and safely required remotely operated equipment which was tested in the field using underwater television to observe the operation. The design of the γ-ray detector mounting and its handling underwent changes as a result of these trials.

A successful trial of the final system was accomplished at a site located about 200 m off the eastern shore. Figure 1 shows the relationship of the site to Point Pelee and the southeast shoal.

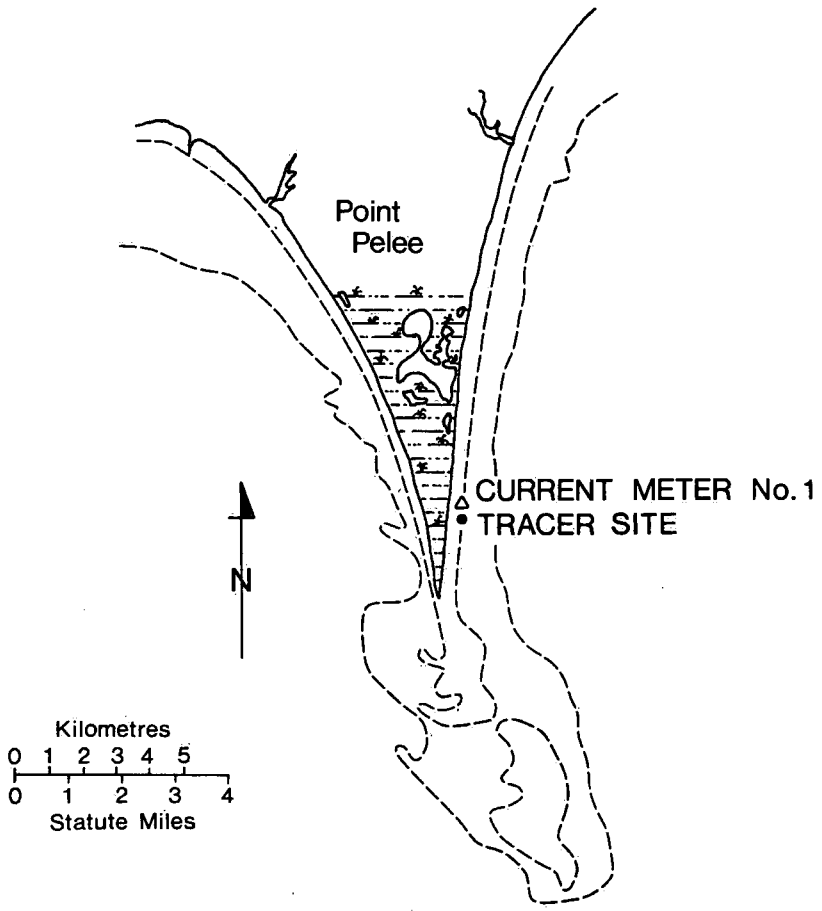


Figure 1. Point Pelee experimental site.

DEPOSITION CONTAINER AND SAMPLE TUBE

The radiotracer experiment required that a bulk sample of artificial sediment be neutron activated in the McMaster Nuclear Reactor in Hamilton, safely transported to the study area and injected into the lake bottom sediment.

Radioactive sample handling requirements placed stringent physical restrictions on the sample containers and deposition facilities.

The reactor core dimensions limit the sample container to a tube which can be placed in a core position of uniform activating flux. This sample tube (Fig. 2) is constructed of 0.89 mm wall-thickness 6061-T6 aluminum, 2.54 cm O.D. and 25 cm long. End caps were welded in place using tungsten-inert gas (after filling) and the tube was leak tested (10 min in a 70°C - 80°C water bath). A loop welded to one end allows transfer of the radioactive tube from the reactor pool to the transportation container.

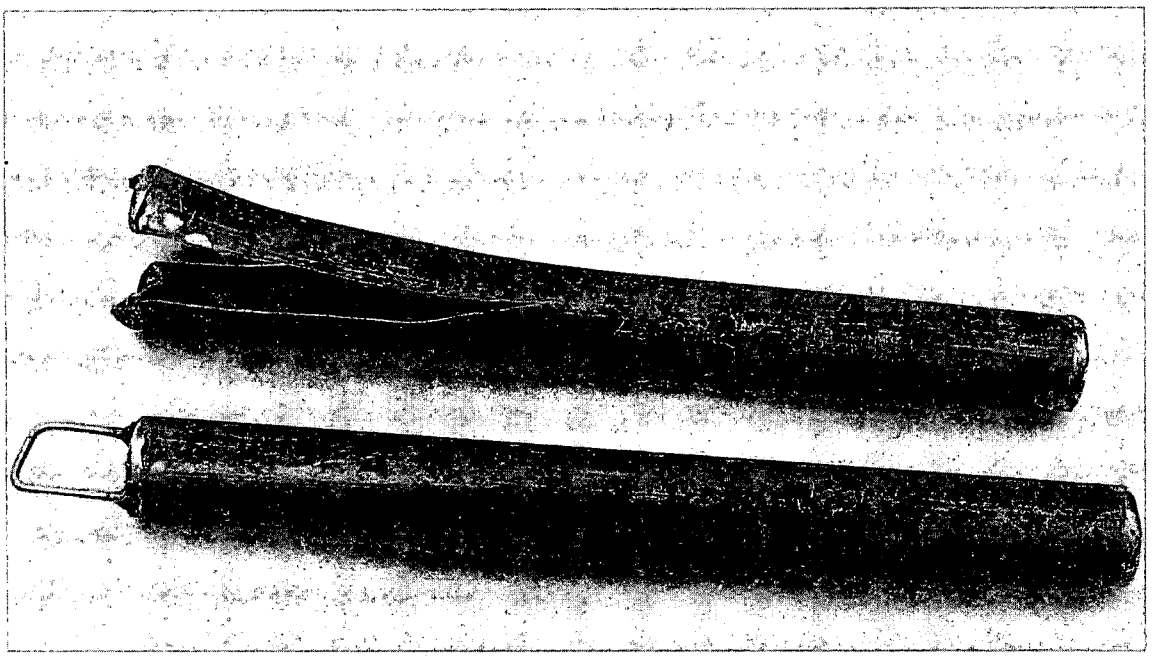


Figure 2. Artificial sediment irradiation tubes, before and after opening.

In the field the activated sample tube is remotely opened underwater by driving it with a piston system against a knife-edge cutter. The system is illustrated in Figures 3 and 4. The piston driving force was originally generated from a compressed air tank, but was later adapted to an air-over-water drive (see below). To reduce the radiation hazard arising during sample transfer at the injection site, the sample tube opening system was designed into the transport shielding as the inner core. Pressure lines were installed in the pneumatic cylinder (minimizing radiation path lengths along pressure line routes) which was welded inside an outer steel pipe. The void was filled with molten lead giving an effective lead shielding

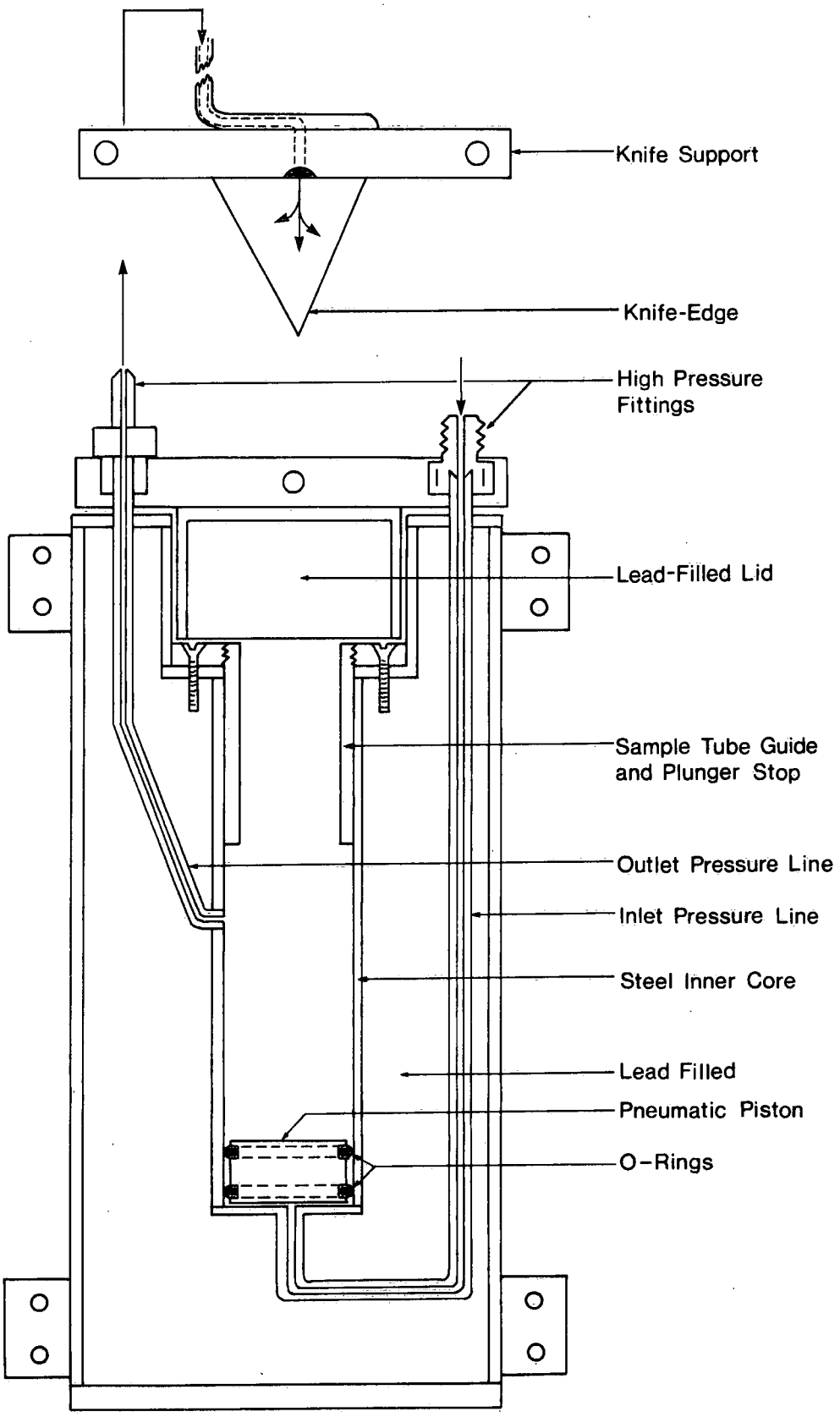


Figure 3. Schematic diagram of deposition container.

thickness of 6 cm. This lead-filled deposition container was suspended in a larger open frame (aluminum) providing stability to the container, mounting locations for the deposition peripherals (e.g., television camera and underwater light) and standoff from the site floor for deposition purposes.

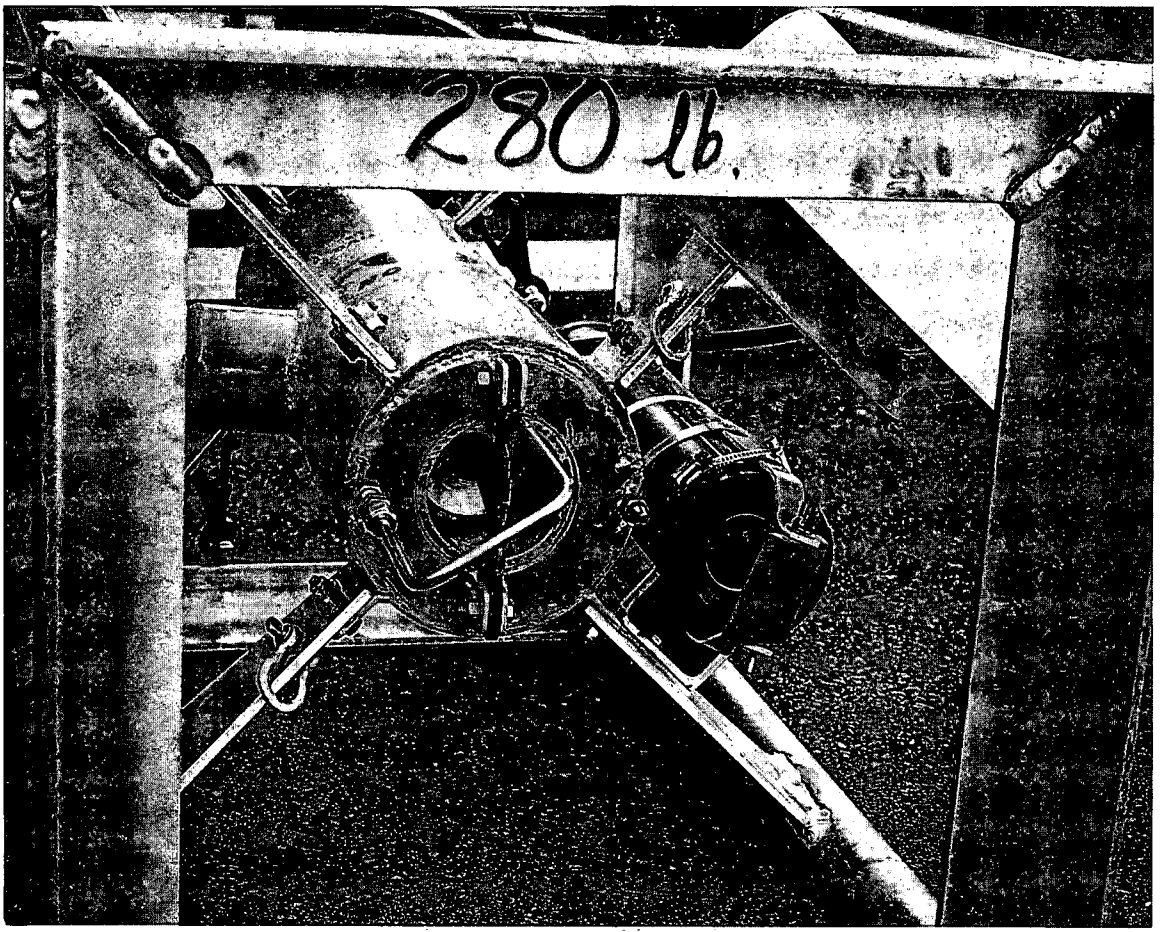


Figure 4. Deposition container with knife-edge opener in position.

In underwater laboratory tests of the air-only system, the knife-edge sliced about 10 cm into the longitudinal axis of the aluminum sample tubes (Fig. 2) and the contents were deposited cleanly onto the floor of the test tank. Monitoring the deposition in the field with an underwater television camera indicated when sample deposition was complete and thus prevented excessive use of the compressed gas, which might have caused excessive turbulence and distorted the sample distribution.

Problems with the television system (suspected RF interference from the electrical system of the research vessel) on the second field trial, however, prevented observation of the sample deposition resulting in excess gas release and possible site disturbance. The piston drive system was therefore changed to air-over-water whereby compressed air forced water into the drive cylinder containing a small amount of detergent (6 ml Kodak Photo-Flo). Proper opening of the sample tube and thorough rinsing of the artificial sediment were ensured by monitoring the delivery line pressure gauges. Sudden pressure fluctuations (at 650-750 psi) indicated the entire volume of water-detergent mixture had flushed through the sliced sample tube and the delivery valve was closed immediately. Observations of the water drive system in the test tank indicated that the sample would deposit cleanly in a thin layer of approximately 20 cm in diameter.

Although the television monitoring system was retained, electrical interference on board rendered it inoperative. Monitoring the delivery gauges, however, allowed satisfactory sample deposition with minimum turbulence as indicated by a minimum amount of escaped air, a clean sample tube, and low background on the retrieved container.

A second shielded container was built, less the drive mechanism, with a larger internal bore and smaller external frame for transporting the empty sample tubes after deposition. This facilitated the on site decontamination of the primary deposition container. Decontamination problems were encountered on the first field trial from active material becoming trapped on adhesive surfaces of warning labels, creating a potential radiation hazard. Special handling tools and related equipment were fabricated to allow manipulation of the deposition container and sampling tubes with minimum exposure during preparation and retrieval operations.

UNDERWATER DETECTOR SUB-SYSTEM

The NaI (Tl) detector requires a 1-kV power supply and protection against thermal and mechanical shock. The detector output signal must be processed by a preamplifier (amplification and pulse shaping) and a main amplifier before being accepted by the analyzing equipment. Signal degradation becomes a serious problem because of the long cable length for the signal to traverse from the lakebed to the analyzer on board the research vessel. This problem is best overcome by preamplifying the signal at the detector-photomultiplier before sending it to the surface.

The NaI detector and photomultiplier assembly was separately housed in a watertight aluminum can which was pressure tested to 60 m. The can was coated

with phenolic micro-balloon cellular insulating material. This was bonded with polyester and coated with Fiberglas reinforced polyester resin for both thermal and abrasive protection.

The electronic support system was separately housed in a large battery can connected to the detector housing by a large-diameter Tygon tube providing a cable feed-through. This package housed the preamplifier with its associated power supply and regulator and a 1-kV battery for the detector power.

The preamplifier-regulated power supply maintained the power requirements at manufacturer's specifications for several months of average use despite battery voltage drift owing to temperature variations and power drain.

The photomultiplier tube was powered directly from batteries. Voltage decay curves performed on two Mallory type 497 photoflash batteries (510 V), which were connected in series with a simulated detector load, showed an initial sharp drop to 900 V, then an extended voltage plateau dropping to 800 V after 32 days at 2°C. These characteristics were considered suitable for the photomultiplier power supply.

The detector and electronics package were mounted initially on an aluminum sled, 2.5 m long by 1.2 m wide (Fig. 5), which was towed behind the research vessel. The detector was slung beneath a sled cross-member 5 cm above the bottom. A fin mounted in front of the detector protruded to within 1 cm of the bottom to lift the sled over any solid obstruction and protect the detector face.

The sled was lowered from a stern A-frame by winch cable and towed about 30 m behind the research vessel at a mean depth of 8 m. Problems, however, occurred during the positioning of the sled. The bottom depths varied and hence the distance of the sled behind the vessel changed; the sled was slow to centre itself behind the vessel after a turn; and the vessel was required to make wide turns to prevent side-stepping of the sled. Also, noise was generated in the detector and electronics on turning, probably from the sled runners bumping sideways.

To overcome these problems the detector and electronics were remounted on a one-metre square carriage which could be lowered vertically to the lakebed, thus improving on the detector positioning and eliminating microphonics. This unit, containing in the electronics package a 1000-V dry battery, preamplifier and associated battery power supply, was lowered by winch cable from the stern A-frame.

The electronics system as originally designed worked exceptionally well with very good signal quality at the surface. On the other hand, vertical handling

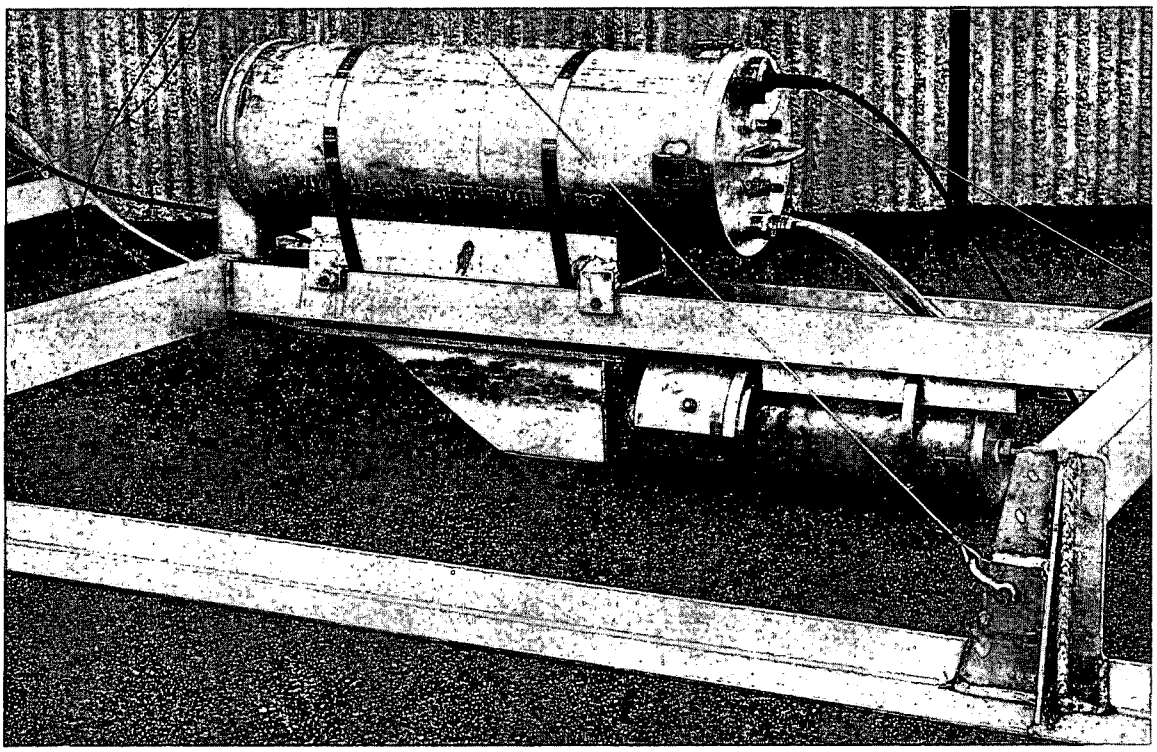


Figure 5. Sled with γ-ray detector and electronics package containing HV batteries, preamplifier and power supply.

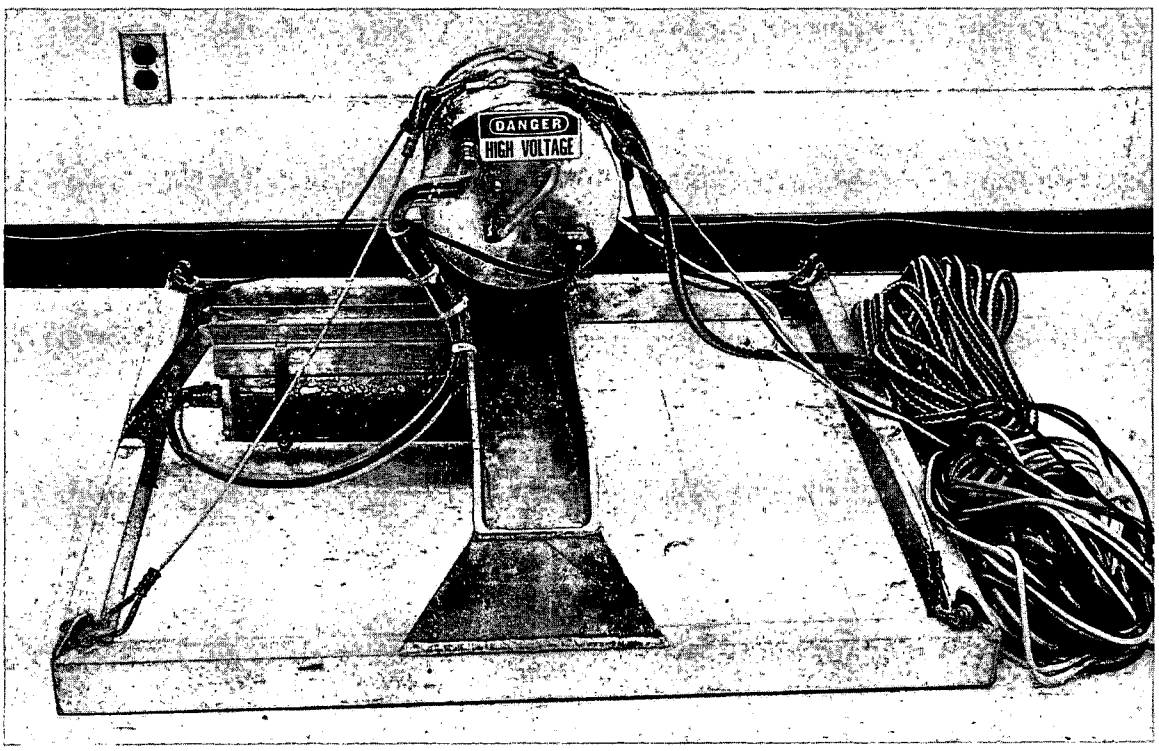


Figure 6. Carriage with γ-ray detector and HV batteries.

proved awkward over the vessel sides. Significant weight reduction, resulting however in a corresponding degradation of signal, was accomplished by modifying the electronics package to a small battery can (Fig. 6) containing only the 1-kV battery. The preamplifier was placed on board the vessel and powered from the main amplifier supply. The photomultiplier output signal was routed directly to the preamplifier through the underwater coaxial cable.

The resultant much lighter assembly was more easily managed on site, and when immersed could be raised and lowered from the lake bottom by one man without the aid of a winch. Without the preamplifier, however, the signal from the photomultiplier was sharply degraded by the underwater coaxial cable (impedance attenuation is high compared with standard RG-59 U coaxial). At maximum photomultiplier gain a signal pulse can traverse only 15 m of underwater coaxial cable, limiting the depth capability at present to 15 m in calm weather and 11 m under adverse surface conditions. The final operating version of the system is shown in Figure 7.

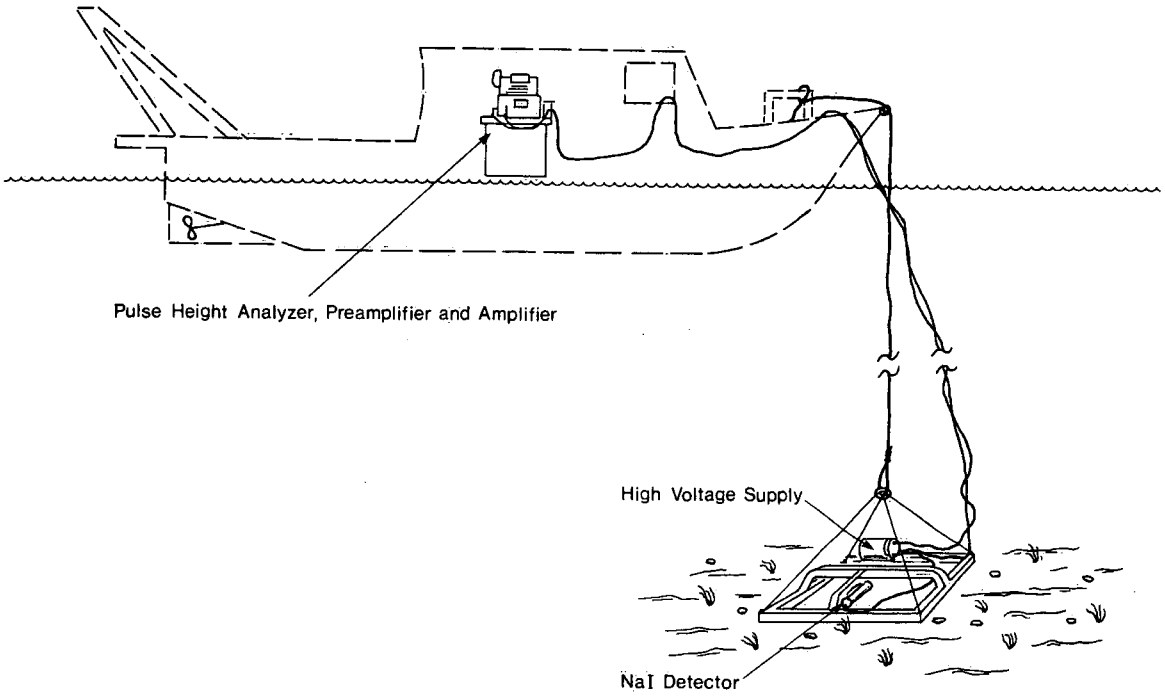


Figure 7. Radioactive sediment tracer detection system.

DETECTOR CALIBRATION

The γ-ray detection efficiency of the underwater detection system was determined by empirical measurements with supportive theoretical calculations.

Artificial sediment was irradiated at the McMaster Nuclear Reactor under activation conditions equivalent to the field trials. The radioactive glass (1.1 g) was quantitatively transferred to a clean quartz vial and flame sealed.

Before acquiring calibration data the detector system was stabilized for temperature and voltage in a test tank, 1.3 m by 1.3 m by 1.0 m deep. A radial grid was located beneath the aluminum underwater frame and geometrically centred on the NaI (Tl) detector. This grid allowed systematic positioning of the calibration source over a hypothetical lake floor. The source was counted at 16 circumferential positions at a 5-cm radius from the centre line of the detector and at similar positions at 10-cm radial increments out to 50 cm. Calibration spectra were acquired to reasonable statistics and the ^{76}As photopeaks were analyzed using background at 560 keV from a spectrum acquired with the source removed. All peak intensities were corrected for radioactive decay to time zero of the irradiation.

Corrected peak intensities indicated a lobed efficiency distribution at distances greater than 20 cm, with maxima along the cylindrical axis of the NaI (Tl) crystal. In actual field operations, however, no preferred axis orientation could be maintained with respect to field coordinates. It was therefore necessary to average the circumferential counting rates at each radial increment. These results produced the radial distribution of detection efficiency and integration of this radial distribution over a circle 56 cm in radius yielded an effective efficiency for a source spread over one square metre. The efficiency was determined as $8.3 \pm 0.9 \times 10^3$ counts per second per gram artificial sediment per square metre. This value is dependent on the specific reactor activation conditions and, as such, is proportional to neutron flux and activation time.

To test the validity of the measured efficiency distribution, a theoretical calculation based on the geometry for a point source not on the detector axis (5) was computed for ideal detector geometry. The resulting activity was corrected for absorption in water and normalized at one point on the efficiency curve, resulting in good agreement with the measured values.

The efficiency distribution as measured is for an ideal source and lake floor, i.e., a homogeneous distribution of activity of zero thickness over the surface of a plane. No estimates were made for partially buried active sediment or irregular surfaces. The active region of detection was delineated by the aluminum frame on which were mounted the underwater detector and power supply.

TRACER EXPERIMENTS

Three preliminary field trials were carried out in the nearshore zone of Point Pelee in September 1974 during which the deficiencies in the design of the original equipment were rectified. The final tracer experiment started on October 15 with the injection of the radioactive artificial sediment at the site shown in Figure 1. This was followed by three days of surveying the lake bottom in the vicinity of the injection with the underwater detector system.

An irradiation container filled with 140 g of artificial sediment was irradiated for 29 min in the McMaster Nuclear Reactor producing an estimated 180 mCi of ^{76}As. This was placed in the deposition flask, transported by truck to Wheatley Harbour, and then transferred to the research vessel. The vessel was a 14-m launch equipped with 110-V ac power for the multichannel analyzer and a winch capable of lifting the 130-kg deposition flask over the stern. A Motorola Range Positioning System was used to navigate the vessel to the drop site while an Atlas sounder recorded bottom depth. The injection point was at a depth of 4 m, and a bottom sample taken with a Shipek sediment sampler confirmed that the sand particle size distribution was as expected.

The deposition flask was lowered to the bottom and its location marked with a securely anchored float. The sample container was then opened by turning on the compressed air, which in turn forced water into the container cylinder pushing the sample container against the opener and flushing the sediment out onto the lake bottom. The deposition flask was hauled back on board, the empty sample container was transferred to the shipping flask, and the deposition flask was monitored for possible contamination.

The extent of the radioactive plume was determined one day later, October 16, by lowering the detector over the bow of the vessel and surveying on a radial grid pattern around the injection point, taking 100-second measurements of the γ-spectrum between 0 and 1500 keV. A representative spectrum with the ^{76}As photopeak at 560 keV clearly outlined is shown in Figure 8. The total number of counts in the ^{76}As photopeak channels for the 100-second interval was recorded on the Teletype for each surveyed point on the grid. A background spectrum was measured away from the plume and the number of counts per 100 s integrated over the same channels that would include the ^{76}As photopeak were recorded. This background was subtracted from each radioactivity measurement, and the resultant activities were extrapolated back to zero time. These radioactivity results were converted to amounts of irradiated artificial sediment by dividing by the average efficiency of the detector determined in the laboratory as described in the section on "Detector Calibration."

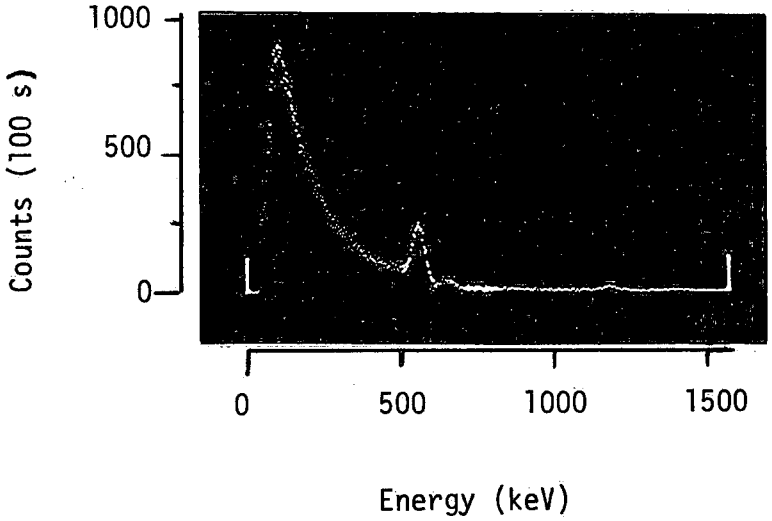
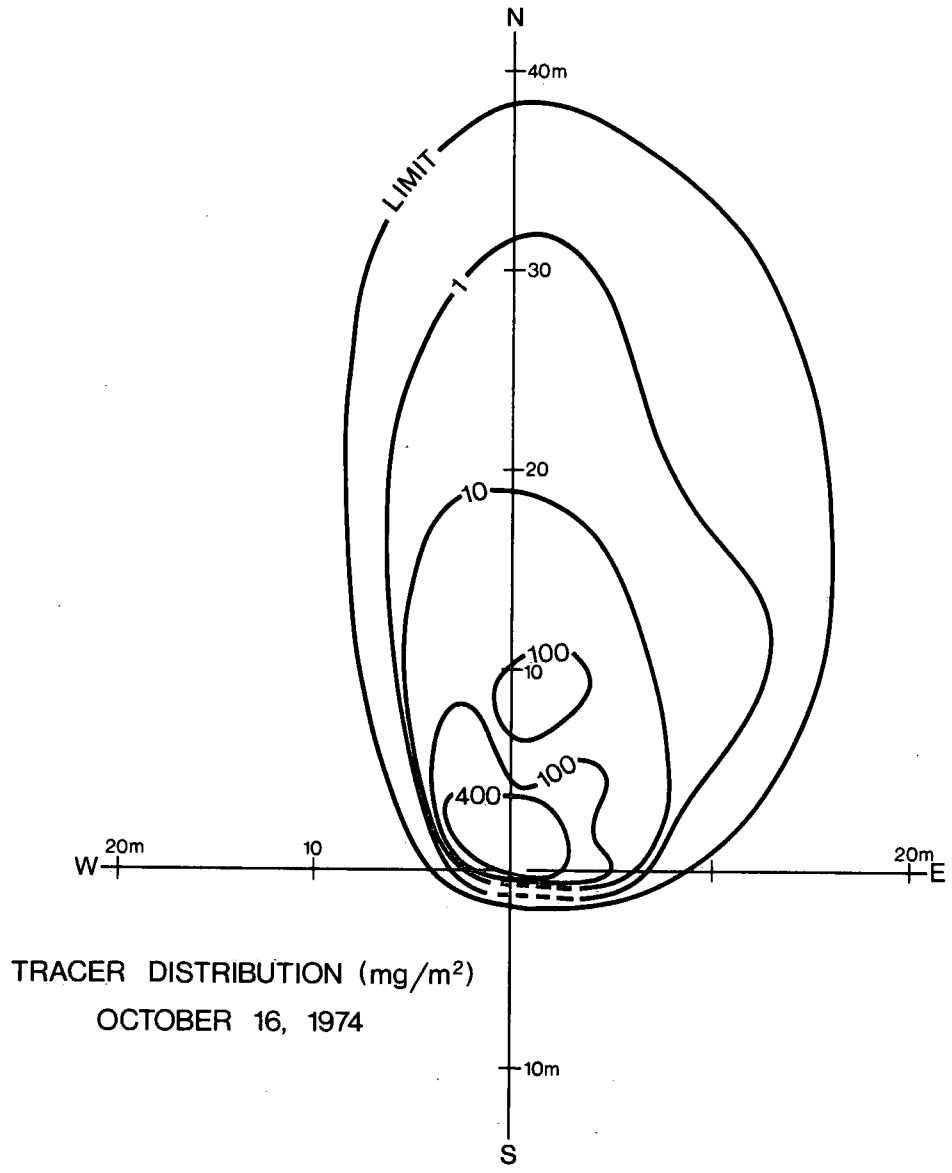
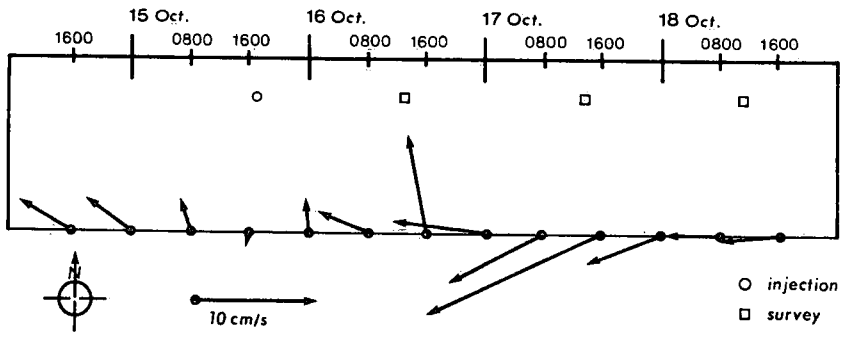


Figure 8. Characteristic γ-ray spectrum showing 560-keV photopeak of ^{76}As site at age two days; equivalent to 22 mg/m^2 of artificial sediment.

The results of the plume survey are plotted in Figure 9, which delineates a well-defined area of detectability, 40 m by 20 m, having its major axis lying in a northerly direction. The majority of the radioactive sediment was still within 3 m of the point of insertion, but a discrete second activity peak appeared about 8 m due north of the main peak. Bottom current measurements recorded near the experimental site show that, in fact, the net current direction during the period was toward the north with a mean velocity of about 5 cm/s. The results of a similar survey on October 17 (Fig. 10) show a slight broadening of the overall pattern with development of the main peak toward the southwest. The current meter data for this period indicate a net west-by-southwest direction with an average velocity of 10.5 cm/s. A final survey was carried out on October 18, and the plot of the results (Fig. 11) depicts further movement of the artificial sediment toward the southwest. The net direction of the bottom current was to the west with an average velocity of 5 cm/s.

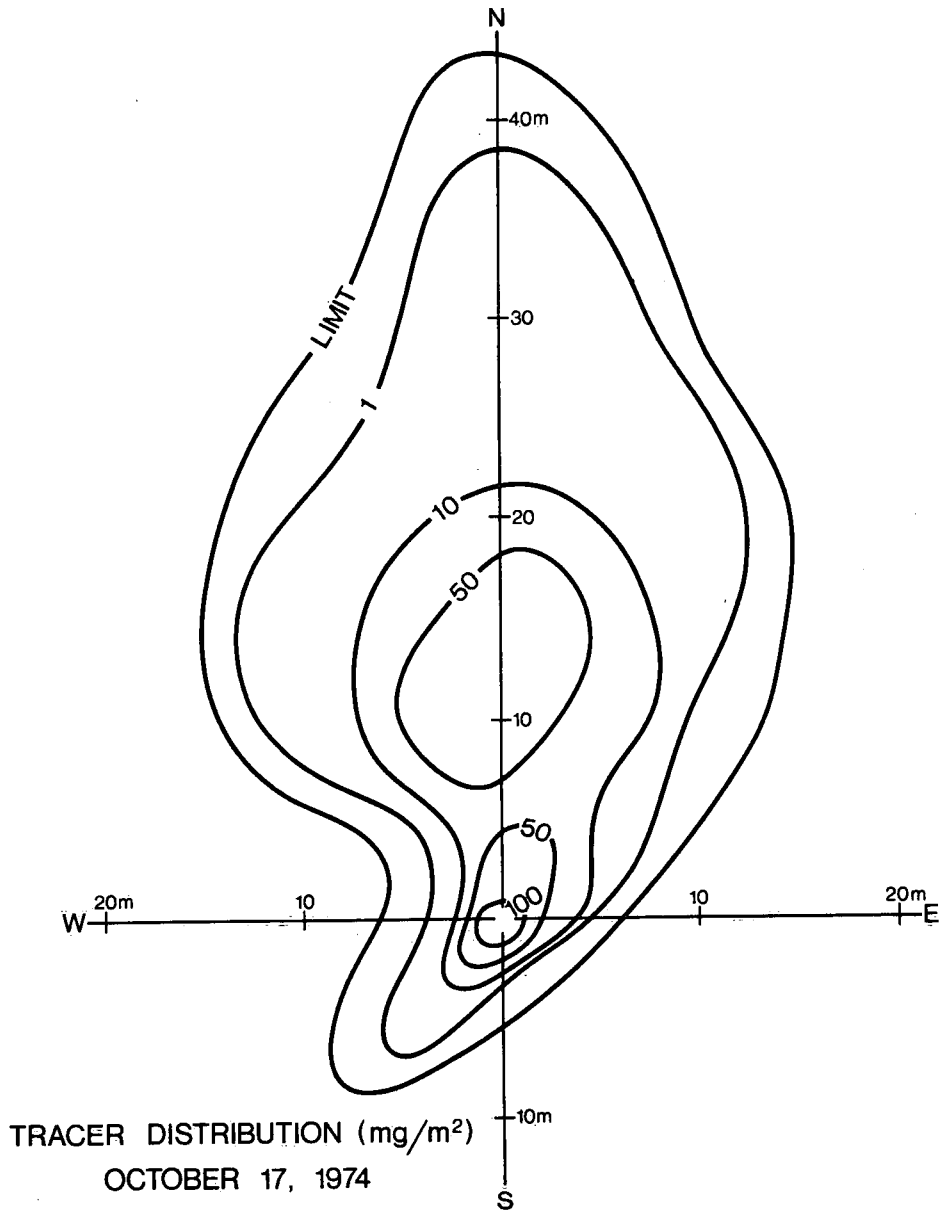
The results of this experiment were thus quite successful in showing that sediment transport direction could be measured in the field over a three-day period using a relatively small quantity of a short-lived radioisotope which emitted a readily identifiable γ-ray. The 26.4-hour half-life of ^{76}As ensured that no long-term radiological hazard was introduced into the environment.

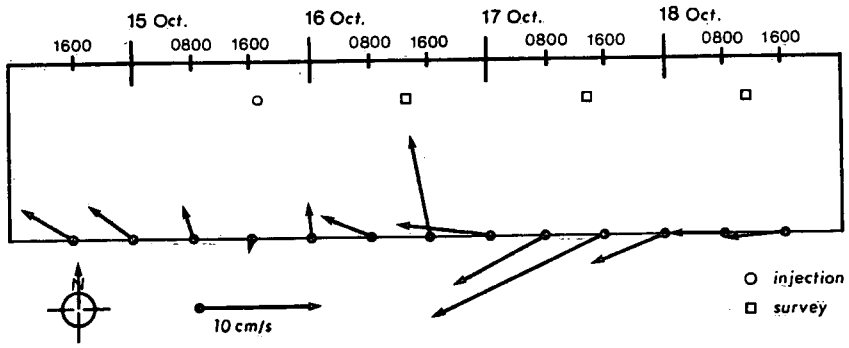




Current Record, Meter No. 1, Point Pelee, October 1974

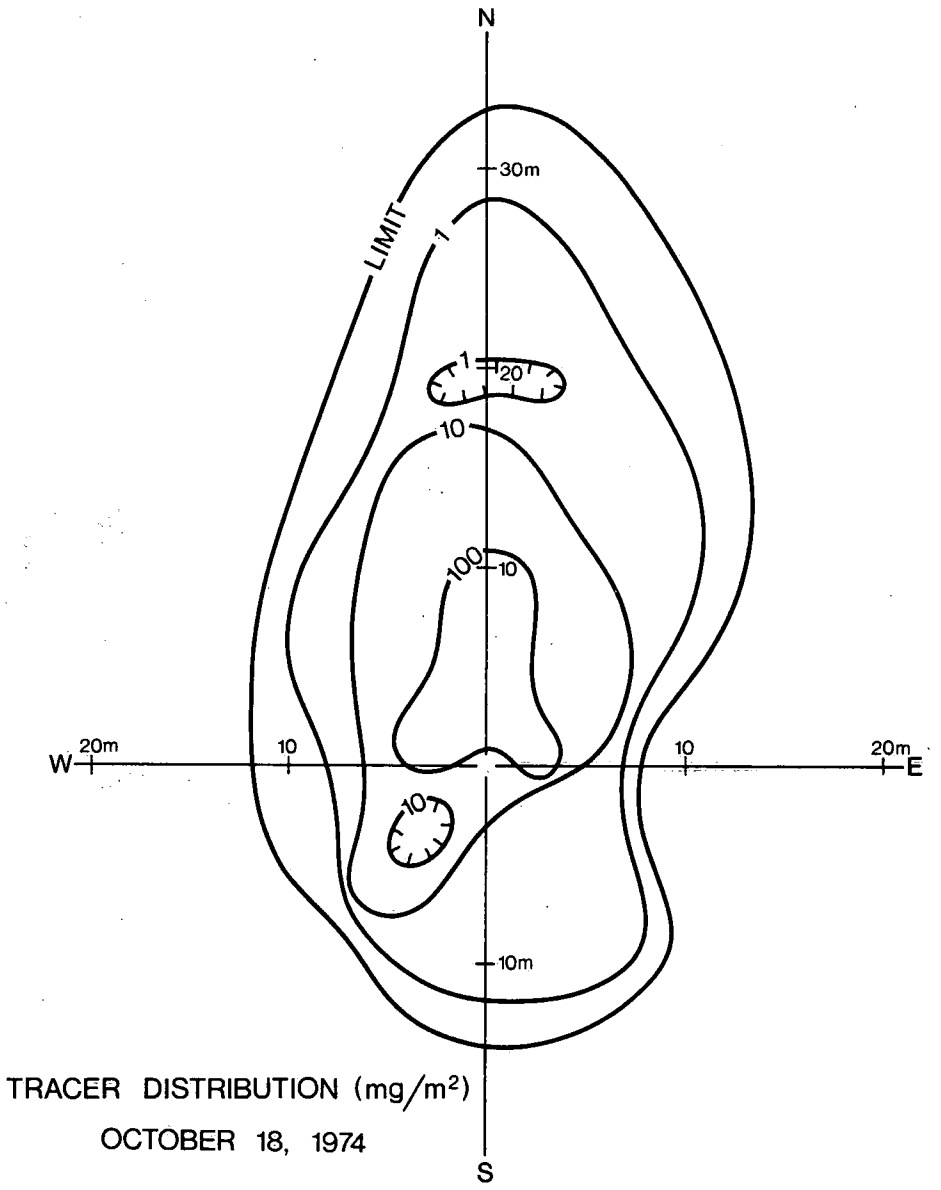
Figure 9. Distribution of artificial sediment after one day.

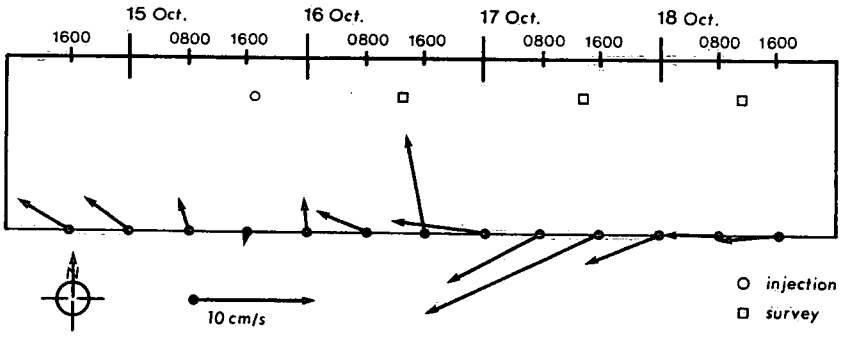




Current Record, Meter No. 1, Point Pelee, October 1974

Figure 10. Distribution of artificial sediment after two days.





Current Record, Meter No. 1, Point Pelee, October 1974

Figure 11. Distribution of artificial sediment after three days.

ACKNOWLEDGMENTS

The help provided by J.P. Coakley in defining texture and size distribution of the Point Pelee sediments and in procuring current meter data is gratefully acknowledged. The design and construction of the radioactive sediment deposition system by H. Savile and the electronics package by C. Goldie of the Engineering Services Section were significant contributions to the success of the project, as was the production of the artificial sediment at the Ontario Research Foundation under the direction of Dr. I.H. Joyce.

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