Measuring Radioactivity From Waste Drums on the Sea Floor

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Summary and Introduction

South and west of the Farallon Islands, offshore from the Golden Gate and the San Francisco Bay region, is an area of sea floor commonly referred to as the "Farallon Islands Radioactive Waste Dump" (FIRWD) This area was where approximately 47,800 large containers, mostly 55-gallon (208 liter) drums, of low-level radioactive waste were dumped between 1946 and 1970. The containers were to be dumped at three designated sites, but they actually litter an area of sea floor of at least 1,400 km^2 (540 mi^2) in water depths ranging from about 90 m (300 ft) to more than 1,800 m (6,000 ft).

The Gulf of the Farallones and adjacent areas support a major commercial fishery and are also used extensively for sport fishing and other forms of recreation. Fears of radioactive contamination from leaking containers have in the past had an adverse impact on the fishery. However, the actual locations of the drums on the sea floor was unknown, and therefore evaluating potential hazards from radiation or contamination was nearly impossible.

In the early 1990's, the U.S. Geological Survey (USGS) and the Gulf of the Farallones National Marine Sanctuary surveyed part of the waste dump using sidescan sonar—a technique that uses sound waves to create images of large areas of the ocean floor (see chapter on Search for Containers of Radioactive Waste on the Sea Floor). By using new techniques to enhance the sonar images, USGS scientists were able to identify many objects that they believed to be radioactive-waste containers. These identifications were confirmed in 1994 using U.S. Navy submersibles.

In late 1994, discussions between the USGS and the British Geological Survey (BGS) led to a proposal to carry out a radioactivity survey of parts of the area where the drums had been mapped, using the BGS's proven towed seabed gamma-ray spectrometer system (figs. 1, 2). This system, called "EEL" because of its eel-like appearance, is towed along the sea floor and had to be modified to operate in the deeper waters found in the survey area. Previous attempts to measure radioactivity on the sea floor in FIRWD had been restricted to the analyses of samples of water, sediments, and marine animals and plants. Sediments from only a relatively small number of sites had been sampled, although in the mid-1970's some samples were collected from areas near drums found by chance using submersibles.

Using drum locations indicated on the USGS sidescan-sonar images, a survey was designed to investigate regional-scale levels of radioactivity in the sea floor sediments of the gulf. In 1998, the BGS EEL was used to make continuous measurements of sea-floor radioactivity in the gulf along several tracklines. These were mostly at depths between 90 and 900 m (300 and 3,000 ft), but some extended down to a maximum depth of about 1,800 m (6,000 ft). Samples of sea-floor sediment were collected on the basis of the EEL results and also were collected in areas where clusters of drums had been previously identified but where the seabed topography was too rugged for safe bottom towing of the EEL.

Both measurements made by the EEL on the sea floor and laboratory analyses of sediment samples indicate only very low levels of artificial radionuclides (radioactive atoms, such as cesium-137, that do not occur naturally but are produced by nuclear reactions) in the surveyed areas of FIRWD. These results are similar to those that had been reported in the limited previous studies.

The results of the EEL survey suggest some leakage from drums in FIRWD, but it appears that this has caused only a localized increase in radionuclides on the sea floor in the gulf. The data do not suggest any significant elevation of radionuclide levels on a regional scale. Most of the observed variations in sea-floor radioactivity are due to changes in natural radioactivity and show a good correlation to geological features, and some of the very low levels of artificial radionuclides detected in the area surveyed may simply be from fallout from atmospheric nuclear testing done during the Cold War.

It should be borne in mind that no data have yet been obtained for large areas of FIRWD. In particular, the deeper water areas where the majority of containers are believed to have been dumped remain virtually unstudied, both in terms of the radionuclide content of the sediments and the actual locations of the containers.

To date, container locations have only been mapped in 15 percent of FIRWD and radionuclide concentrations examined in only about 10 percent of the dump area. Although the areas studied are the shallower parts of the site most accessible to people and where contamination would be of most concern, further studies must be done to fully evaluate the possible hazards from radioactivity in FIRWD. This could be important because, as many fish stocks have declined in the shallow coastal areas of the Gulf of the Farallones, some fishermen have been forced to fish in the deeper waters of the Continental Slope to fill their nets (see chapter on Continental Slope Communities).

Background

Between 1946 and 1970, approximately 47,800 55-gallon drums, concrete blocks, and other containers of low-level radioactive waste were dumped at three sites on the Continental Shelf and Slope adjacent to the Farallon Islands offshore of San Francisco Bay (Waldichuk, 1960; Joseph and others, 1971; Noshkin and others, 1978; National Oceanic and Atmospheric Administration, 1990). Approximately 150 drums were deposited in a water depth of about 90 m (295 ft), 3,600 in a water depth of about 900 m (2,950 ft), and 44,000 in a nominal water depth of 1,800 m (5,900 ft). These sites are referred to here as the 90-m, 900-m, and 1,800-m sites, although the actual water depths at and around each site vary from the nominal values.

Many of the drums were probably not disposed of at the specific sites. It is more likely that they litter a 1,400-km^2 (540 mi^2) area of sea floor, FIRWD (Noshkin and others, 1978), defined by the irregular polygon shown on the index map (fig. 3).

Much of FIRWD lies within the boundaries of the Gulf of the Farallones National Marine Sanctuary, which was designated in 1981 (fig. 3). In 1990, the U.S. Geological Survey (USGS) and the Gulf of the Farallones National Marine Sanctuary jointly surveyed part of FIRWD with a sidescan-sonar system (see chapter on Search for Containers of Radioactive Waste on the Sea Floor). The results of this survey (Karl and others, 1994) led to the mapping of barrel locations over an area of 125 km^2 (50 m^2). The identification of the drums was verified during the initial survey using an underwater camera/video sled and subsequently using the manned U.S. Navy submersible *Sea Cliff* and the unmanned Advanced Tethered Vehicle. Visual observations showed the drums to be in all states ranging from completely intact to completely disintegrated.

The Gulf of the Farallones and adjacent areas support a major commercial fishery. The area is also used extensively for sport fishing (National Oceanic and Atmospheric Administration, 1990). Fears of radioactive contamination have previously had an adverse impact on the fishery.

Discussions between the USGS and the British Geological Survey (BGS) led to a proposal to carry out a radioactivity survey of parts of the area where drums had been mapped. This was carried out using the proven BGS towed seabed spectrometer system (called "EEL" because of its eel-like appearance), modified to operate in deeper water. Previous radioactivity measurements had been restricted to the analyses of samples of water, sediments, and biota (Noshkin, 1978; PneumoDynamics Corp., 1961; Dyer, 1976; Schell and Sugai, 1980; Suchanek and others, 1996). Sediments from only a relatively small number of sites had been sampled, although some samples were collected from areas adjacent to drums using submersibles (Dyer, 1976; Schell and Sugai, 1980).

The EEL survey was carried out in April and May 1998 and involved interagency collaboration among BGS, USGS, the U.S. Environmental Protection Agency (EPA), National Oceanographic and Atmospheric Administration (NOAA), and the Gulf of the Farallones National Marine Sanctuary. Work was concentrated in the shallower areas where commercial fishing occurs and where locations of drums had been mapped. A fuller account of this study is available (Jones and others, 2001).

Seabed Radioactivity Measurements

The BGS EEL system (Miller and others, 1977; Jones, 1994) was developed for Continental Shelf use and has mostly been operated at depths less than 200 m (660 ft). Significant modifications were made to the system for the Farallon survey to cope with the much greater depths involved. This entailed uprating the pressure vessel that houses the gamma-ray detector to a 3,000-m (9,800 ft) capability, switching to digital data transmission to allow signal transmission through 6 km (3.7 mi) of cable and completely updating the control electronics and data logging software. In addition, extra sensors were added to the seabed probe to give information on depth, temperature, and sea-floor roughness.

The detecting probe is towed on the sea floor, protected inside a 30-m (100 ft) length of plastic (PVC) hose (fig. 1). The full gamma-ray spectrum is measured, enabling contributions from natural and artificial radioactivity to be identified and quantified. Although originally developed for geological mapping and mineral exploration (Jones and others, 1988a; Ringis and others, 1993) the equipment has subsequently been used for a variety of environmental surveys, including the mapping of artificial radionuclides discharged from the Sellafield, England, nuclear plant in the sediments of the Irish Sea (Miller and others, 1982; Jones and others, 1988b).

Survey operations

The EEL was successfully deployed on the survey to a depth of 1,500 m (4,900 ft). Sets of lines were towed at both the 90-m and 900-m sites. Additional shorter tows were made through known barrel clusters at the 900-m site and lines extended from the 900-m site into deeper water adjacent to the 1,800-m site. Bottom sediment samples were also collected. The locations where the samples were taken were related both to the EEL towing and to clusters of drums, identified from USGS sidescan-sonar data, in areas too rugged for bottom towing.

Approximately 90 line-km (56 line-mi) of EEL data were towed on seven traverses at the 90 m site and nine sediment samples were collected (fig. 4). A further set of seven lines, totaling some 60 line-km (37 line-mi) was surveyed at the 900-m site (fig. 5) and two short traverses [about 5.5 line-km (about 3.4 line-mi)] were made through known barrel clusters (fig. 6). Six sediment samples were collected related to lines towed at the 900-m site and a further 10 samples were collected near barrel clusters that were not towed with the EEL (fig. 5). Two lines [about 18 line-km (11 line-mi)] were run from the 900-m site into deeper water adjacent to the 1,800-m site (fig. 7). These reached a maximum depth of more than 1,800 m (6,500 ft).

The radionuclide contents, grain size, and general geochemistry of the sediment samples were determined in BGS and USGS laboratories (Jones and others, 2001).

Results

Examination of the EEL data during the survey suggested only very low levels of gamma-emitting artificial radionuclides such as ^{137}Cs. The variations seen in sea-floor radioactivity were in natural isotopes attributable to geological features (fig. 8). The EEL data were reprocessed after the survey (see figs. 9-11). Overall, the data indicate very low ^{137}Cs contents across the survey area. There are no suggestions of any significant regional scale contamination of the sediments by ^{137}Cs, nor of any localized high concentrations of this radionuclide.

The reprocessed seabed data show lower levels of ^{137}Cs at the 90-m site compared to the 900-m and barrel cluster sites (figs. 9-11). There is some correspondence between higher seabed ^{137}Cs concentrations and proximity to the known locations of drums at the 900-m site (figs. 10, 11). There are also relatively high values where no drums have been located. This might be expected where drums are too degraded to produce a detectable sidescan-sonar response. It should be noted that the total number of targets identified using sidescan-sonar data represents only a small proportion of the total number of drums reportedly disposed of at the 900-m site. There are also relatively low ^{137}Cs levels around some barrel clusters. This again is to be expected—the drums could be intact, or at least have not suffered leakage, or there may not be any Cs present in those drums.

Laboratory sample analysis confirms the low levels of ^{137}Cs (<5 Bq/kg in the samples). ^{241}Am, $^{239/240}Pu$ and ^{238}Pu were also found in some samples at lower concentrations than 137Cs. The values of these radionuclides are comparable to those reported by earlier studies (Noshkin and others, 1978; National Oceanic and Atmospheric Administration, 1990; Dyer, 1976; Schell and Sugai, 1980). As much as 10 Bq/kg of ^{137}Cs and 20 Bq/kg of $^{239/240}Pu$ were recorded from the sediments. The concentrations of artificial radionuclides are well below the natural background levels of 40K (typically 400–600 Bq/kg) and generally below the concentrations of U(^{214}Bi) and Th(^{208}Tl), that mostly range from 15 to 50 and 15 to 30 Bq/kg, respectively. Whether the sediments are contaminated in excess of what would be expected from nuclear weapons fallout has been a matter of some controversy (National Oceanic and Atmospheric Administration, 1990). Much higher concentrations of ^{137}Cs, ^{241}Am, and Pu isotopes (as much as thousands of Bq/kg) are present in Irish Sea sediments (Jones and others, 1999; Kershaw and others, 1999). Those high concentrations are the result of authorized discharges from the Sellafield nuclear reprocessing plant. However, these higher levels do not give rise to doses in excess of annual limits either through direct exposure or via the food chain (Food Standards Agency/Scottish Environmental Protection Agency, 1999).

^{137}Cs was detected in all the 90-m site samples except for two with very high shell contents. Three of the 900-m site samples had no detectable ^{137}Cs. Slightly higher (albeit still low) levels of ^{137}Cs occur in samples taken near barrel clusters and some of these have detectable ^{241}Am.

Away from the cluster locations, ^{241}Am was only detected in one sample (from the 90-m site) at an extremely low level (0.2 Bq/kg). Similarly, Pu contents of the sediment samples are higher near to known drums than elsewhere at the 900-m site or the 90-m site. The differences in Cs, Am, and Pu levels between the cluster samples and other locations could be the result of inputs of radioactivity from the waste in the drums or the result of differential input/uptake of fallout radionuclides in sediments.

Barrel leakage is indicated by the coincidence of higher values of Cs, Am, and Pu with the barrel clusters and the generally similar levels of natural radioactivity in the samples. It is further supported by the poor condition of at least some drums. There have been differing interpretations made of previous sample analyses, but most authors conclude that there has been some input to the sediments from the drums (National Oceanic and Atmospheric Administration, 1990; Schell and Sugai, 1980). If barrel leakage has occurred, then there are no indications of any significant enhancement of radionuclide levels on a regional scale.

Alternative explanations are that the variations are the result of differences in fallout radionuclide input or uptake by sediments. The latter could be influenced by differences in sedimentation rate, with fallout particles being more efficiently scavenged from the water column or, conversely, diluted by higher rates of sediment build up.

Sample data do indicate clear differences between the shallow water sediments at the 90-m site and those from the much deeper 900-m site. The 900-m site has finer grained (muddier) sediments than the 90-m site. The geochemistry suggests a different mix of clay minerals at the sites, because Fe- and Mg-rich clays (for example, smectite), which have a great affinity for many trace elements, are more abundant in deeper water. This is supported by mineralogical studies of the area (Booth and others, 1989; Griggs and Hein, 1980).

Geochemically and texturally the sediments at cluster sites are very similar to those from the remainder of the 900-m site. This suggests that the slightly higher contents of radionuclides close to known drums are most likely the result of leakage from the drums. However, the differences in radionuclide contents between the 90-m and 900-m sites could in part be due to the greater capacity of the deeper-water, relatively smectite-rich sediments to take up radionuclide (Griggs and Hein, 1980).

U and Th concentrations in the bottom sediments are all well within normal ranges for sediments. As with Cs, there is no clear-cut relationship between U or Th content and known barrel locations. Some higher Th and (or) U areas coincide with drums, but other barrel locations are associated with lower Th and (or) U. The generally higher contents of U and Th in the sediments from cluster sites, when compared to elsewhere in the 900-m site, may indicate a slight enhancement due to input from the drums. U and Th are listed as being present in the wastes disposed at the FIRWD (Noshkin and others, 1978; National Oceanic and Atmospheric Administration, 1990).

Geochemical analyses of the sediment samples do not indicate any significant enhancement of other contaminants such as heavy metals or Be. Sn is the only element reported at levels that are appreciably above those expected for average fine-grained sediments or rocks. Concentrations of Sn are approximately twice average shale levels (about 6 ppm) in most samples from the cluster sites, and one sample (sample 13) from elsewhere at the 900-m site, which had a maximum of 31 ppm. Because Hg and organic contaminants were not measured in the samples, it is not possible to comment on the impact, if any, of the disposal of other types of waste in the area surveyed.

Implications and Conclusions

Both in situ measurements and laboratory analyses of sediment samples indicate only very low levels of artificial radionuclides in the surveyed areas of FIRWD. There appears to be some indication of leakage of radionuclides from the drums of waste, but this only seems to have slightly raised radionuclide levels in the sediments in the immediate vicinity of the drums. There is no evidence in the area surveyed of significant regional-scale contamination resulting from the disposal of containers of low-level radioactive waste. It should, however, be borne in mind that, at this stage, no data have been obtained for large areas of FIRWD. In particular, the 1,800-m site, where the majority of the containers were dumped, remains virtually unstudied, both in terms of the radionuclide content of the sediments and the actual locations of the containers. To date, container locations have only been mapped in 15 percent of FIRWD and radionuclide concentrations examined in only about 10 percent of FIRWD. On the other hand, the areas studied are the shallower parts of the site, most accessible to people and where contamination would be of most concern.

This study, along with earlier USGS work, shows the value of interagency cooperation and the merit of being able to target measurements and sampling on the basis of knowledge of container locations. This integrated approach could be extended to the deeper parts of this site and applied in other areas such as Boston Harbor, Beaufort's Dyke in the Irish Sea, and the Kara Sea in the Arctic. The data obtained by this type of study enable informed decisions to be made regarding the environmental management of the ocean.

Further Reading

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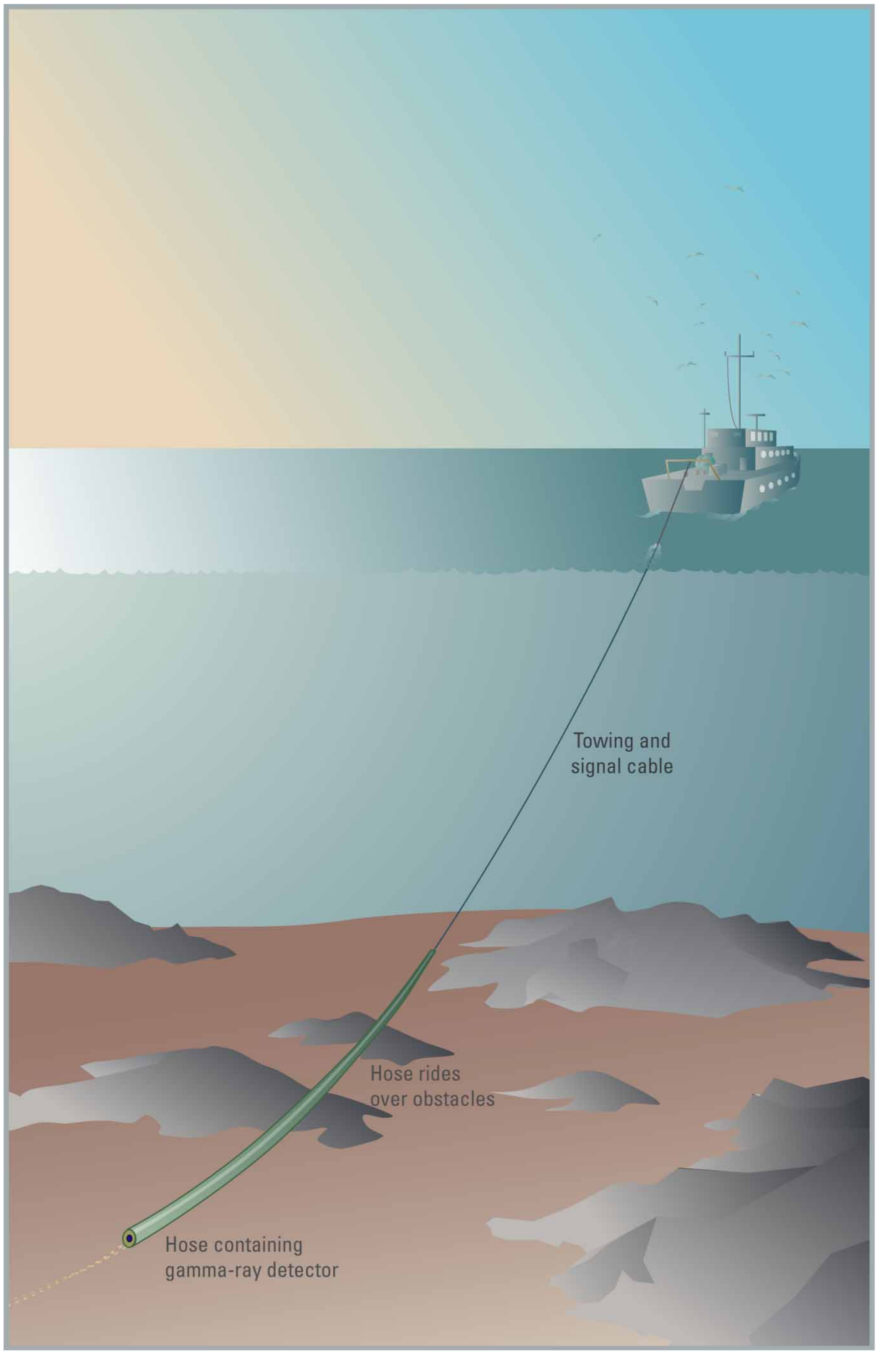

Figure 1. A seabed gamma-ray spectrometer belonging to and operated by the British Geological Survey, called the EEL because of its eel-like appearance, was used to measure the radioactivity of the sea floor in the Gulf of the Farallones. As shown in this diagram, the probe, housed in a protective hose (green), is towed along the sea floor. Data are sent up the towing cable to a shipboard computer and recorded continuously. The gamma-ray detector can measure both natural and artificial radioactivity in surficial sea-floor material to an effective maximum subbottom depth of about a foot.

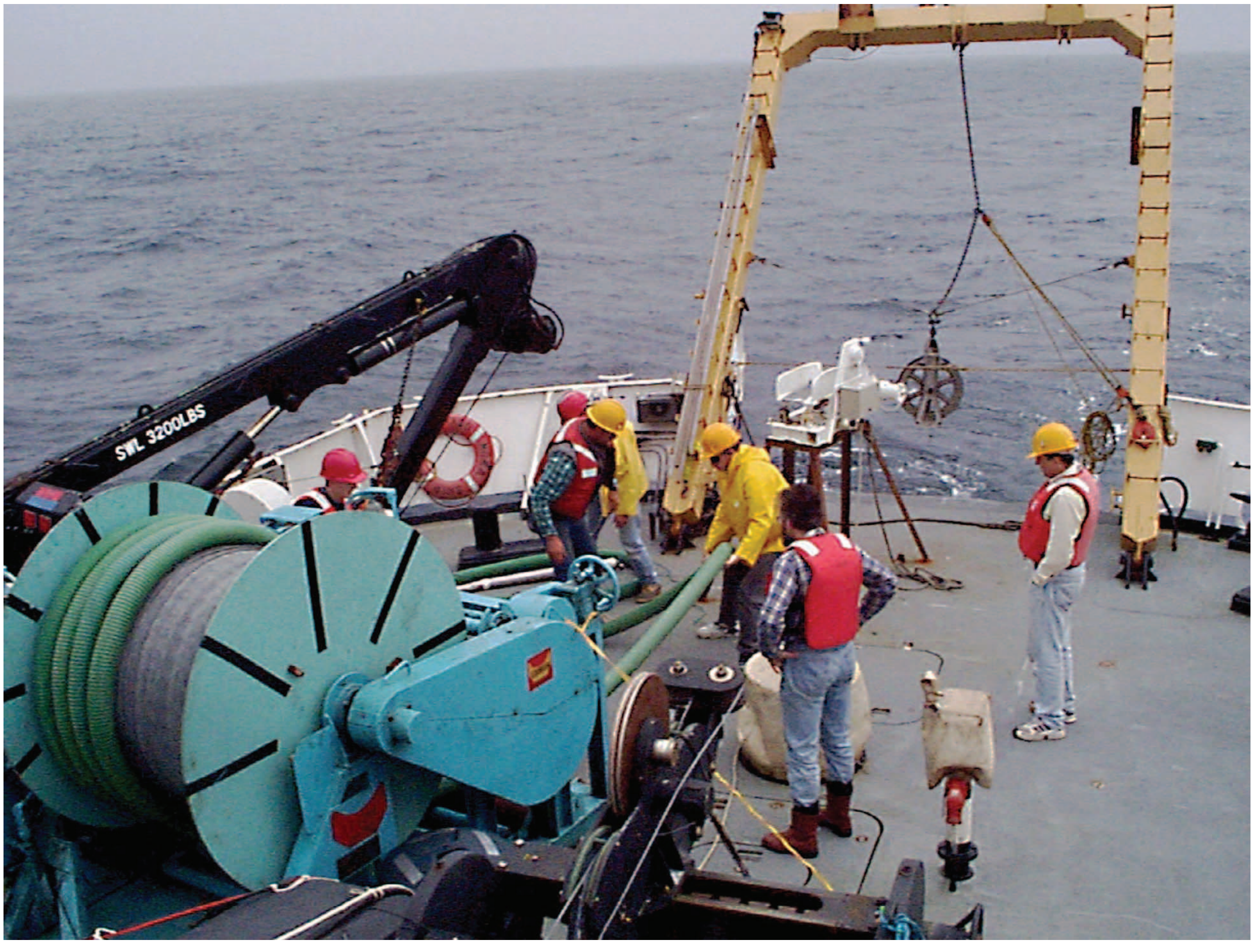

Figure 2. The British Geological Survey's EEL being prepared for deployment in the Gulf of the Farallones. Housed within the green hose of the EEL are several instruments, including a gamma-ray detector that measures radioactivity on the sea floor.

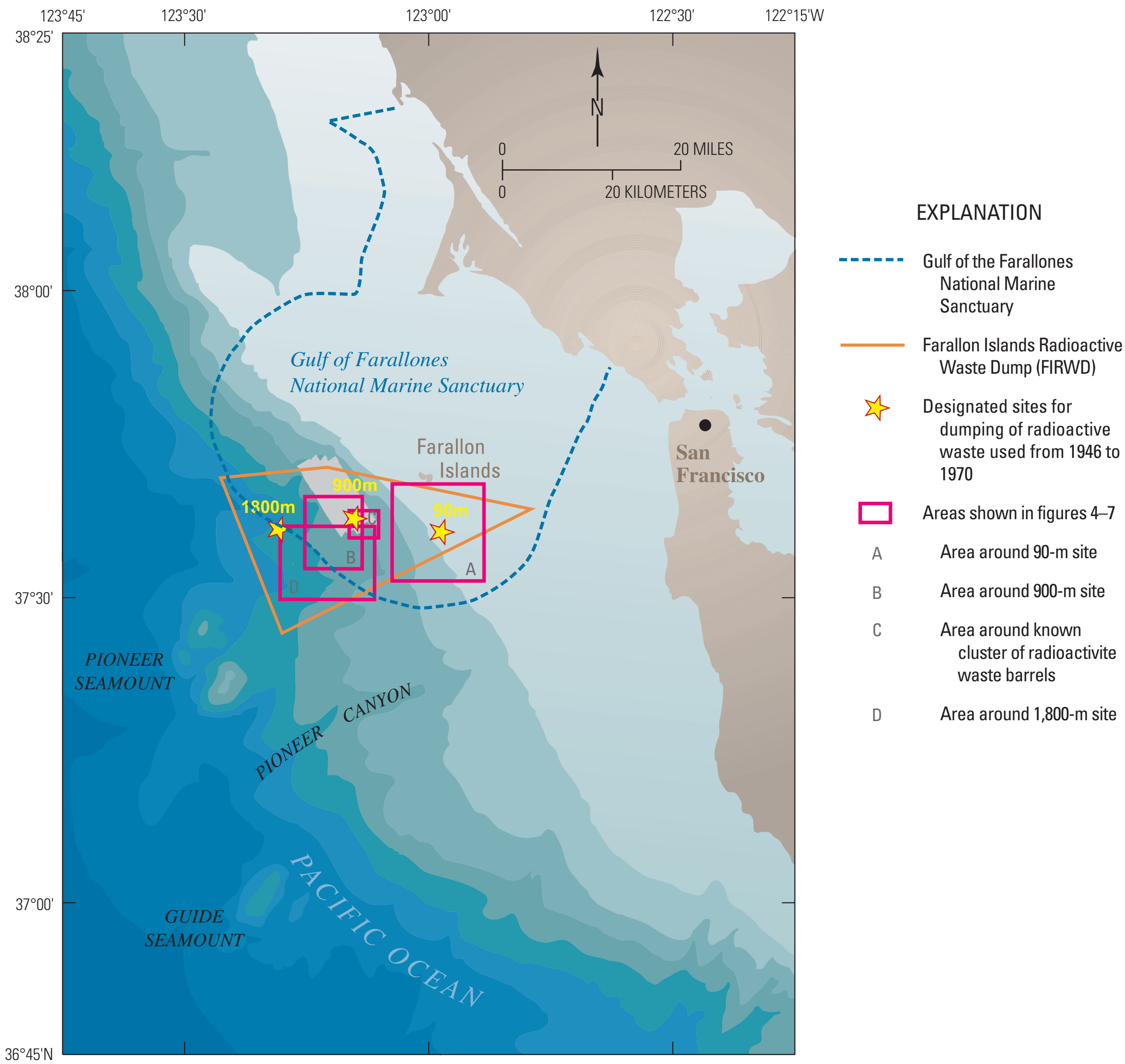

Figure. 3. Map showing areas of the Gulf of the Farallones where levels of sea-floor radioactivity were measured using the British Geological Survey EEL. Also shown is the approximate extent of the Farallon Islands Radioactive Waste Dump (FIRWD). This area was where approximately 47,800 large containers, mostly 55-gallon drums, of low-level radioactive waste were dumped between 1946 and 1970. The containers were to be dumped at three designated sites (informally referred to as the 90-m, 900-m, and 1,800-m dump sites), but they actually litter an area of sea floor of at least 1,400-km^2 (540 mi^2) in water depths ranging from about 90 m (295 ft) to 1,800 m (5,900 ft).

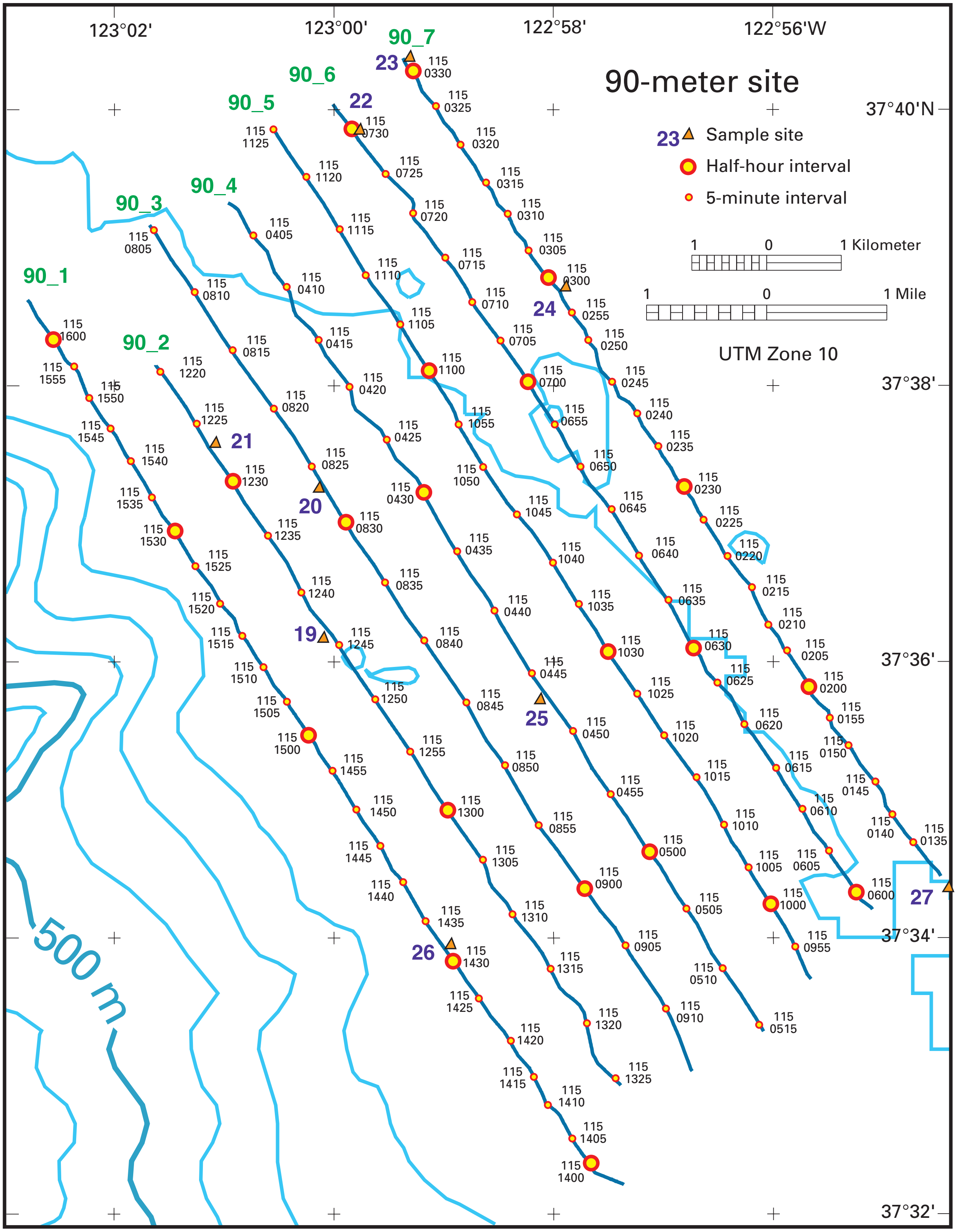

Figure. 4. Survey lines and sample locations for the radioactivity survey at 90-m site (for location see fig. 3).

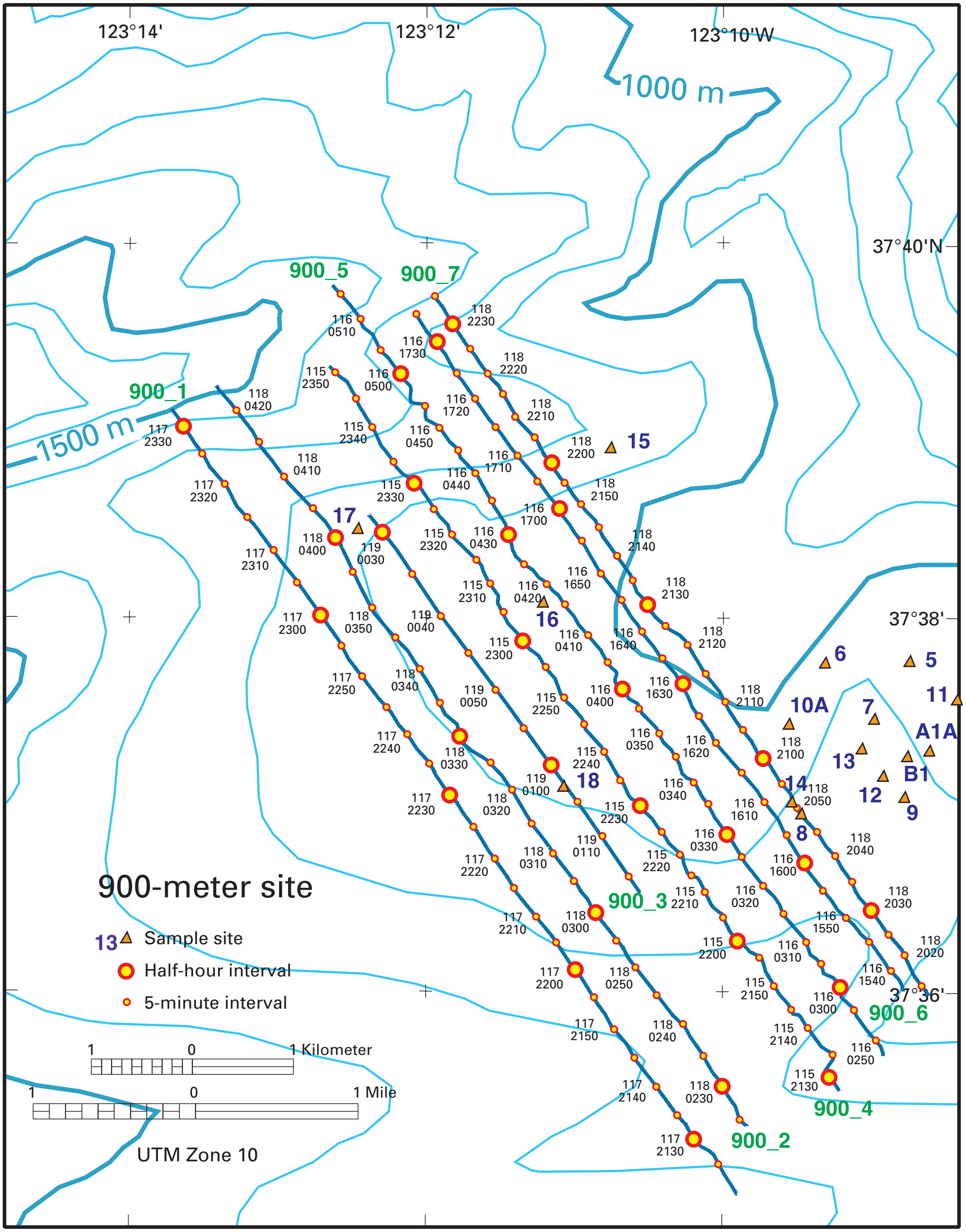

Figure 5. Survey lines and sample locations for the radioactivity survey at 900-m site (for location see fig. 3).

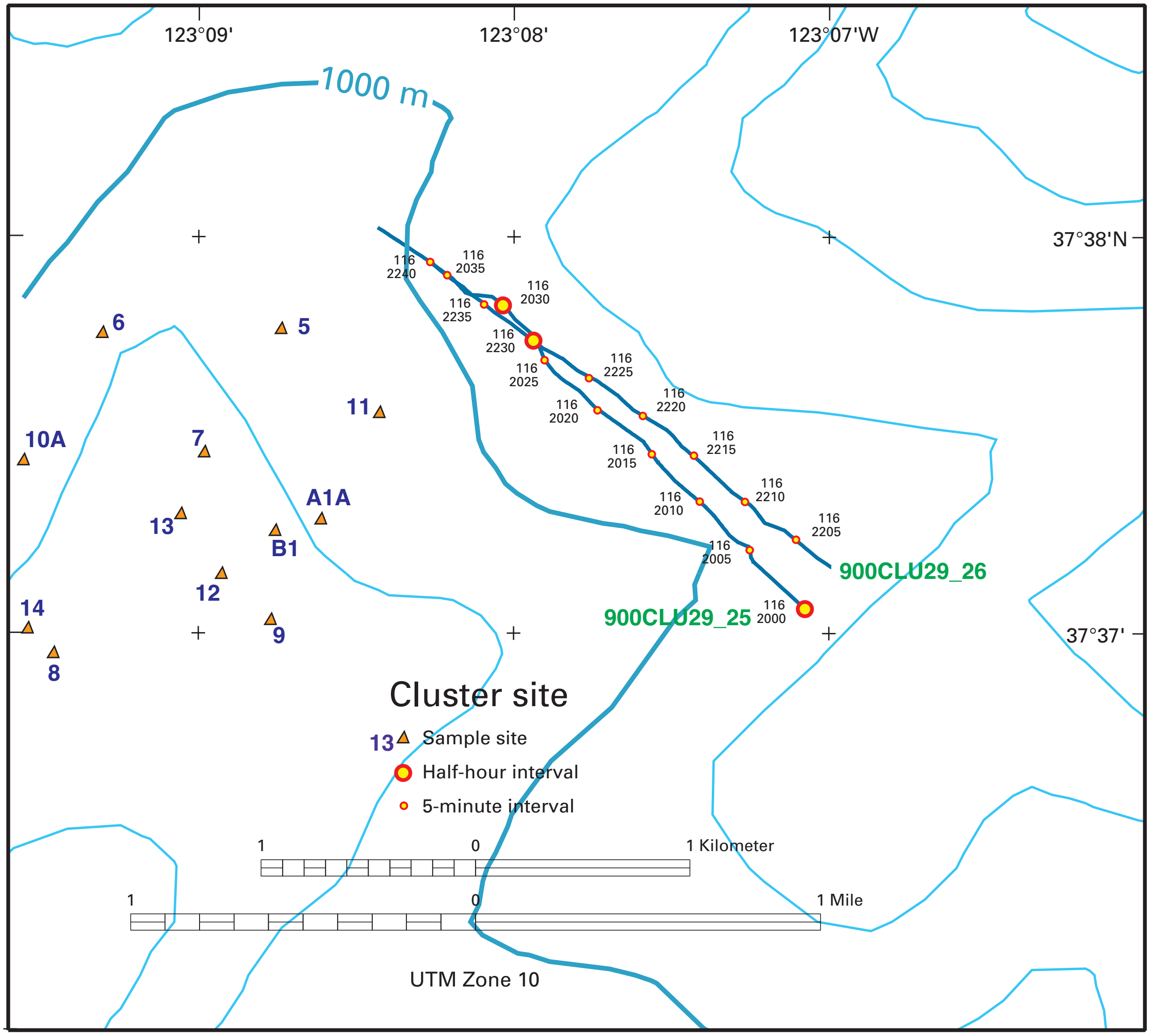

Figure. 6. Survey lines and sample locations for the radioactivity survey at the "cluster" site, an area of known barrel clusters near the 900-m site (for location see fig. 3).

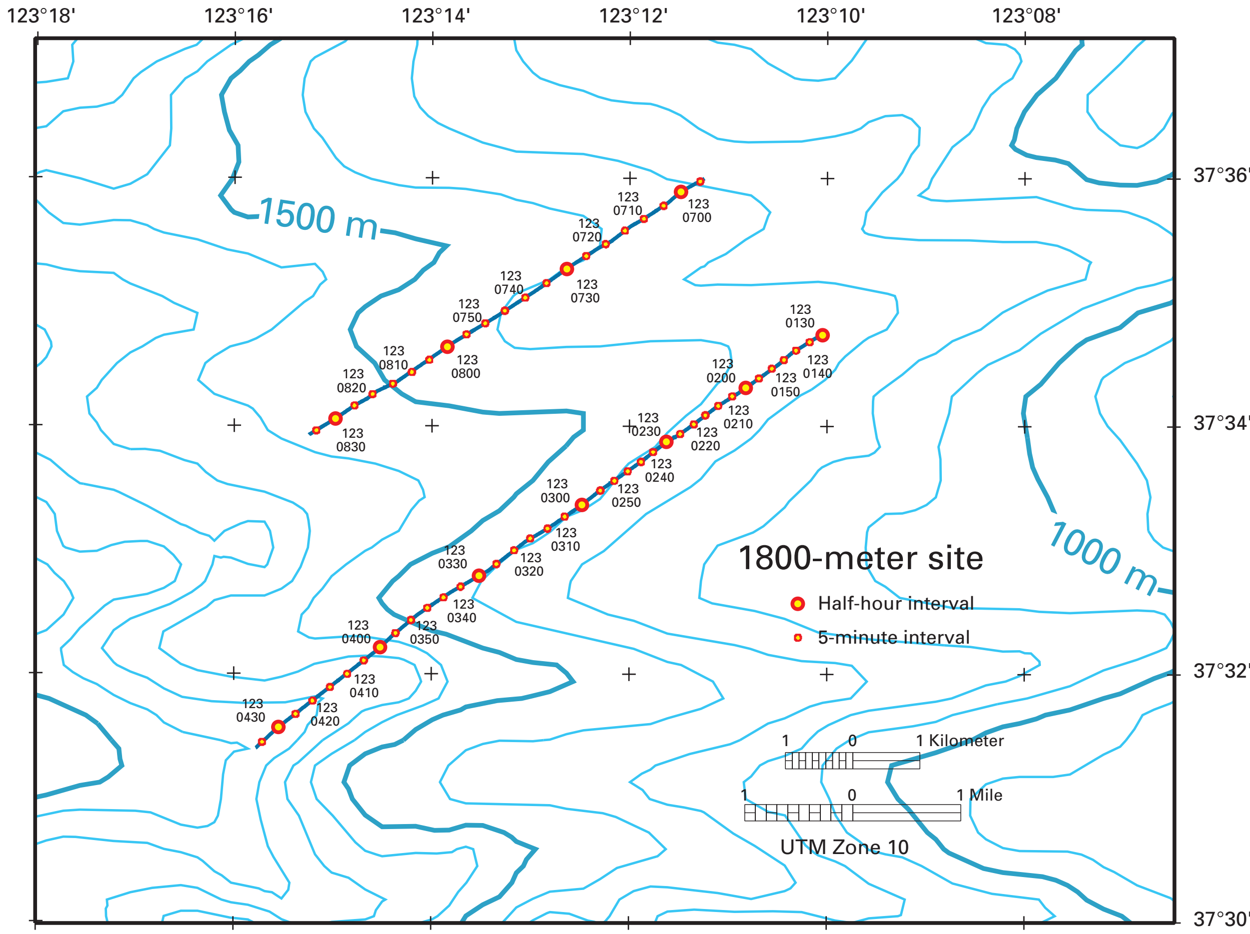

Figure. 7. Survey lines and sample locations for the radioactivity survey at 1,800-m site (for location see fig. 3).

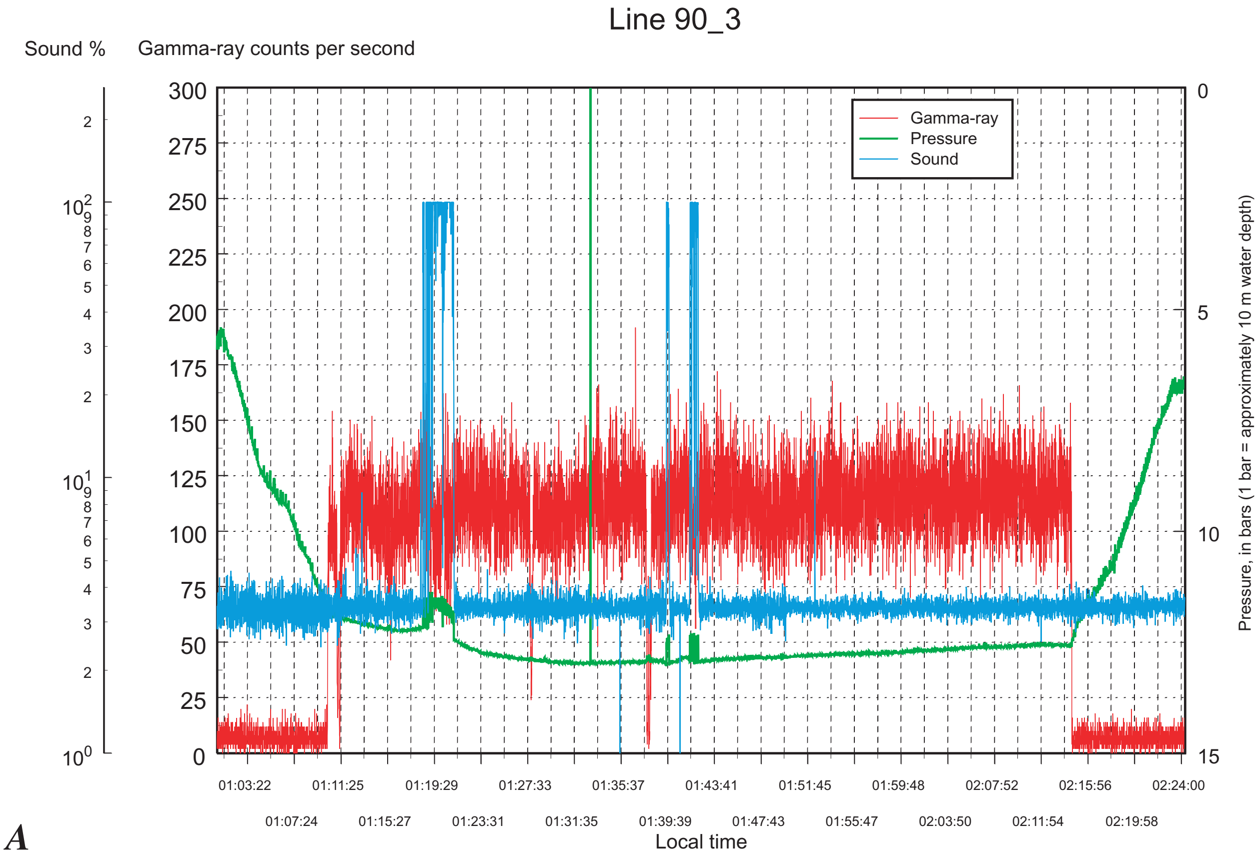

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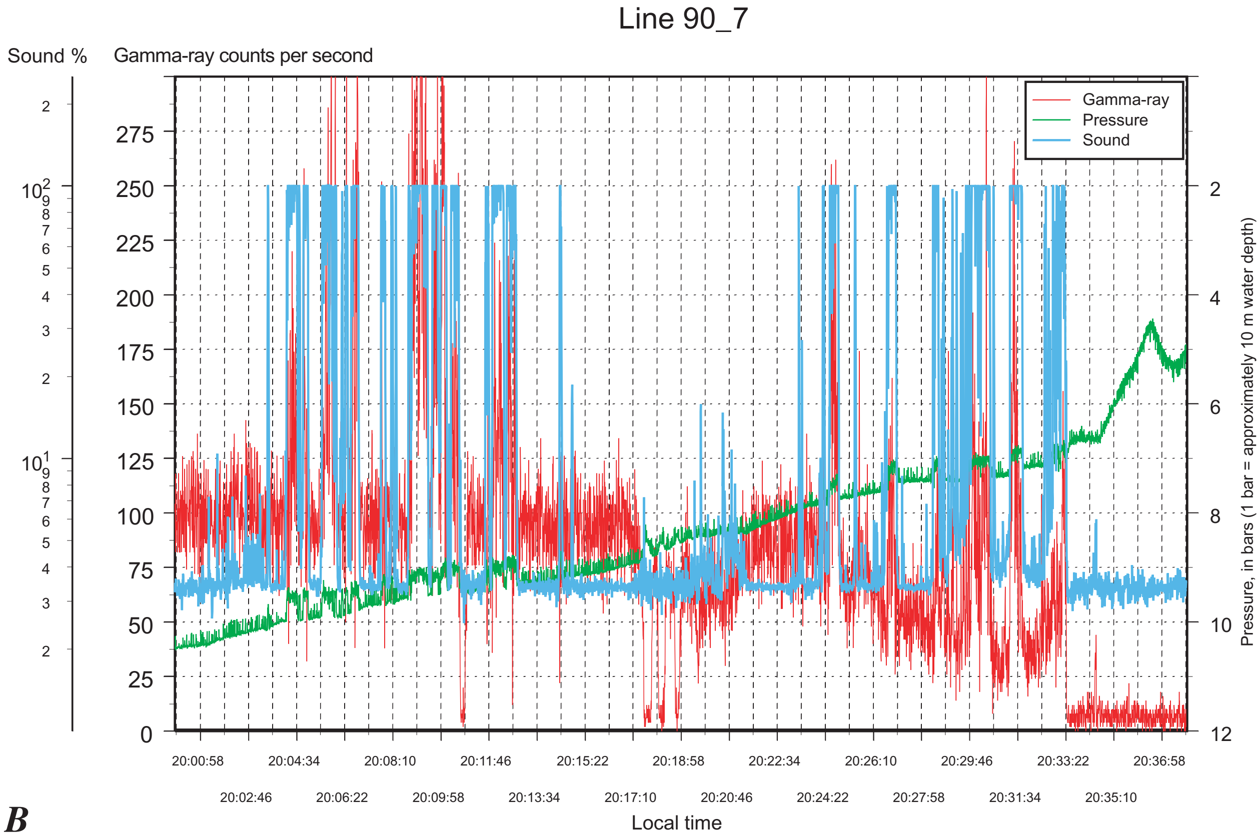
Figure 8. Examples of variation of gamma-ray spectrometer data along two survey lines in the area of the 90-m dump site. *A*, Line 90_3 (complete line) shows generally uniform total gamma-ray count over a smooth sediment-covered sea floor. Two small upstanding features on the seabed (seen on the pressure trace and as high noise features) match gravel waves seen clearly on the sidescan-sonar mosaic (see *C*). These features do not show any major difference in total gamma-ray count compared to the surrounding finer grained sediments. Very low total gamma-ray counts at the beginning and end of the line indicate times when EEL was not in contact with the sea bottom. *B*, Line 90_7 (part of line approximately northwest of sample site 24, see *C*). The rough areas of sea floor, seen on the sound and pressure traces, have a much higher total gamma-ray count than their surroundings. They match rock outcrops, seen on the sidescan-sonar mosaic (see *C*), which are probably granitic, like the nearby Farallon Islands. Changes in the total gamma radioactivity base level, from about 100 counts per second at the left end of the line to below 50 counts per second at the right, reflect a change from quartz sand to sand in large part made up of shell fragments. *C*, Survey lines for the 90-m dump site superimposed on the sidescan-sonar mosaic of area. Black areas are gravel waves.



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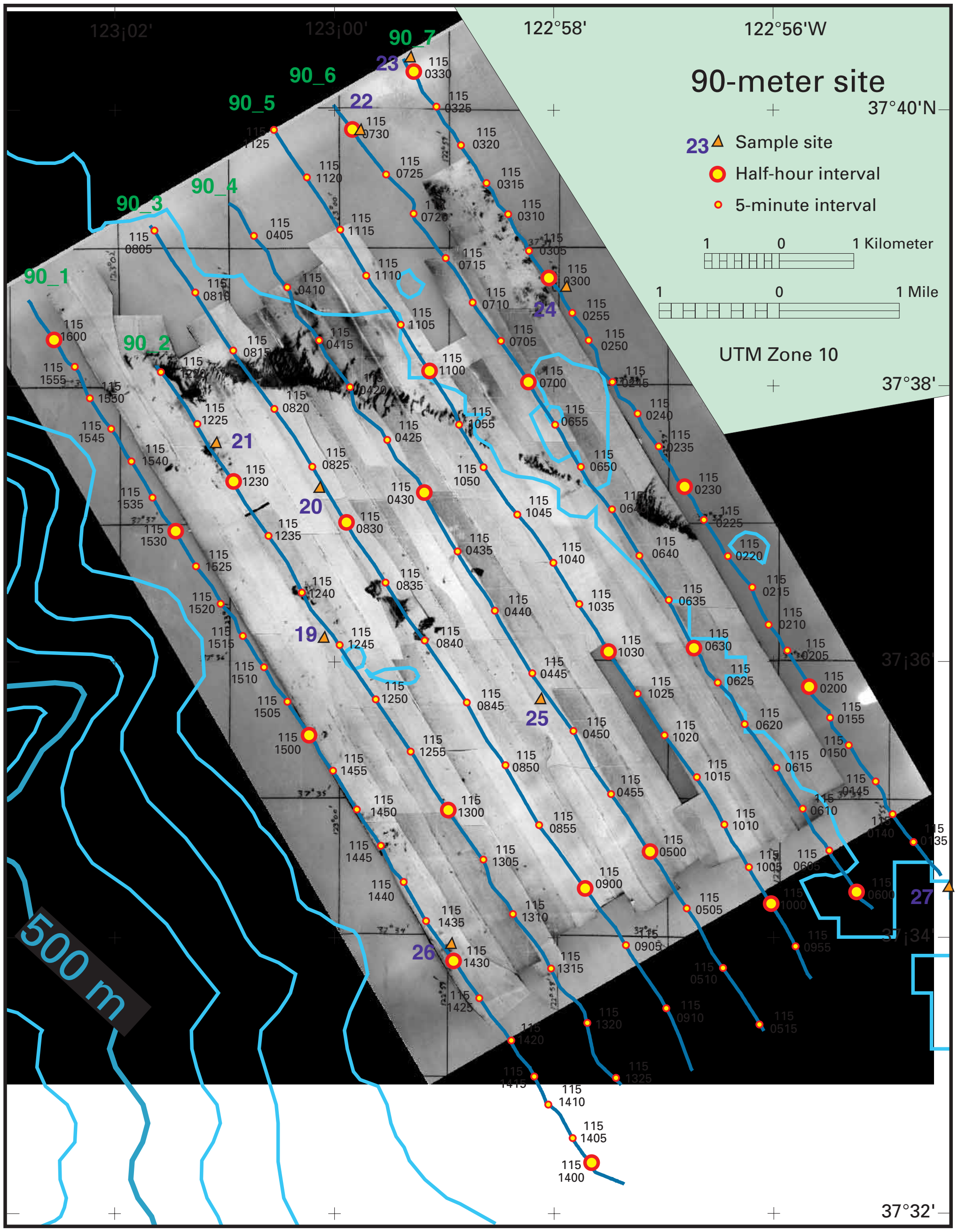

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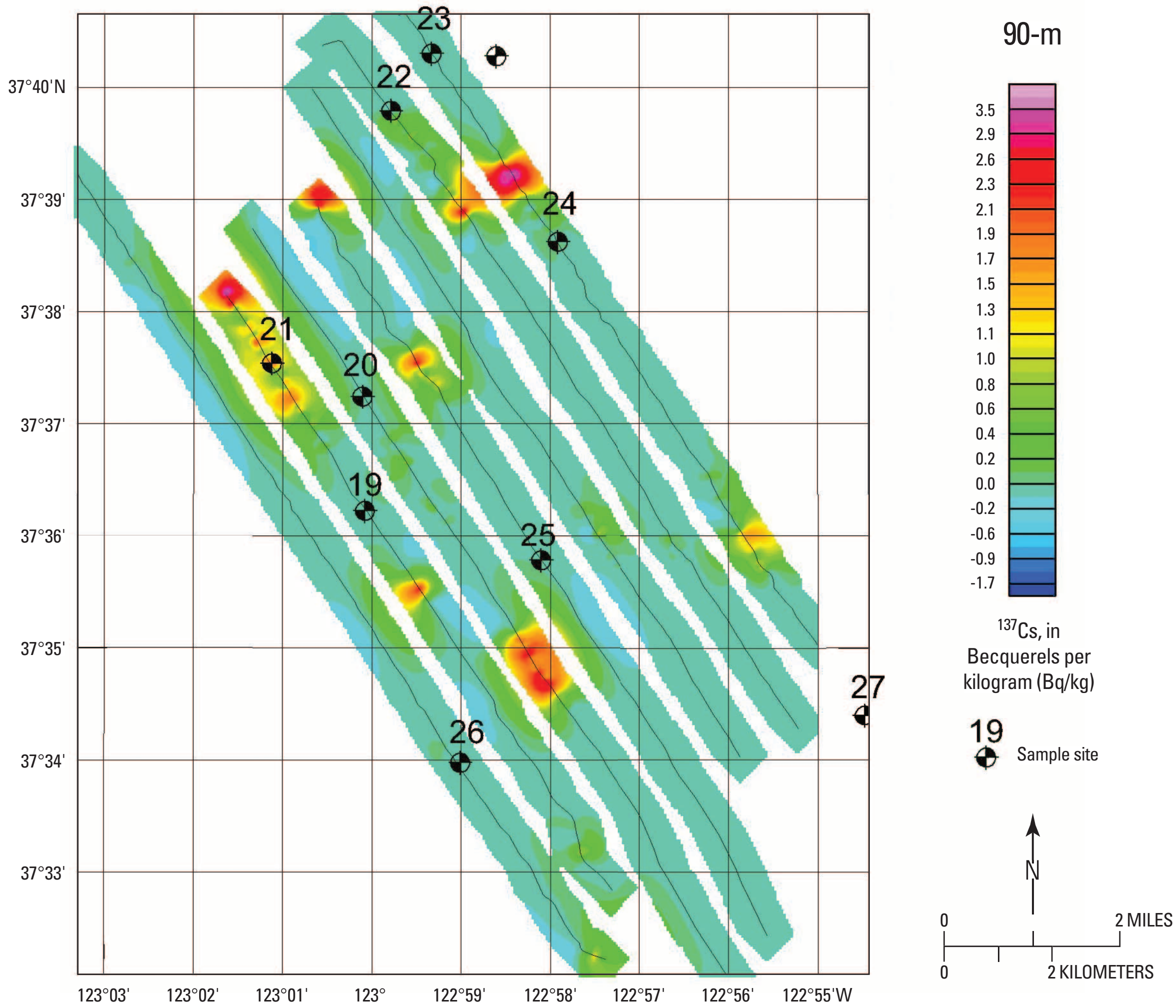

Figure 9. Distribution of measured ^{137}Cs radioactivity for the survey of the 90-m dump site (for location see fig. 3).

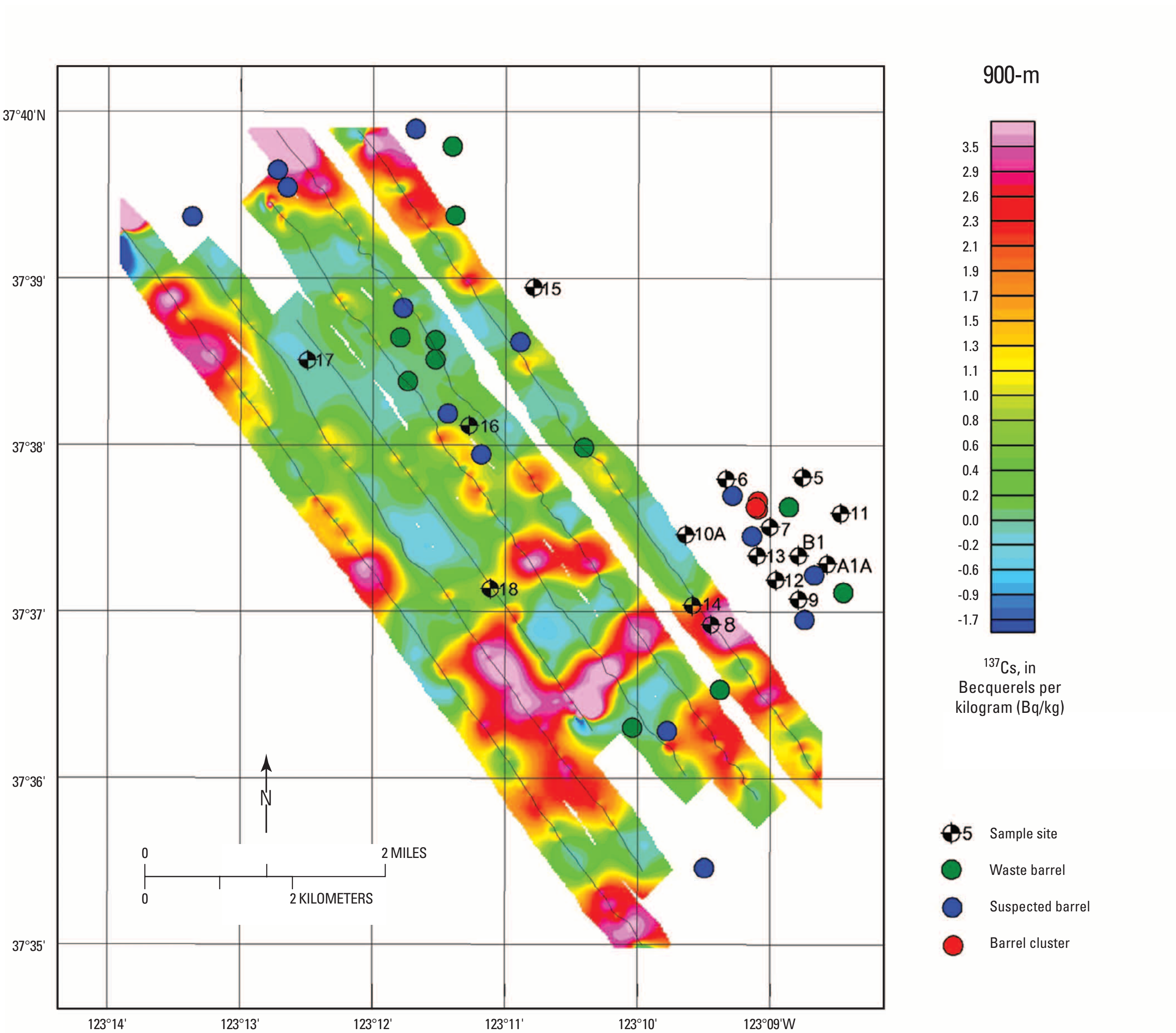

Figure. 10. Distribution of measured ^{137}Cs radioactivity for the survey of the 900-m dump site (for location see fig. 3).

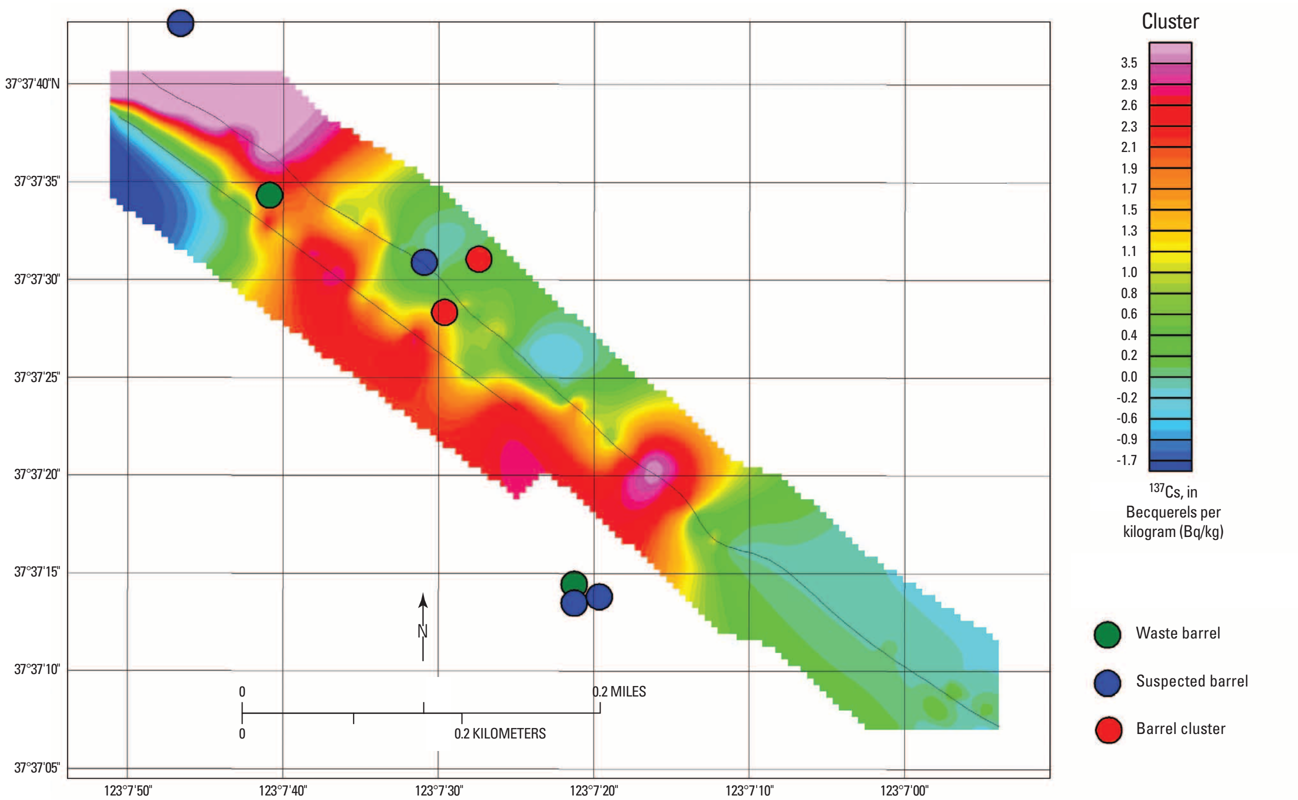

Figure 11. Distribution of measured ^{137}Cs radioactivity for the survey of the "cluster" site, an area of known barrel clusters near the 900-m site (for location see fig. 3).