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# TECHNICAL REPORT
# TO THE
# CALIFORNIA COASTAL COMMISSION

## E. Metals and Radiation

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# SUMMARY

Operation of the condenser cooling systems at SONGS involves pumping large quantities of seawater through the generating station and returning the water to the local marine environment. Both radioactive and nonradioactive effluents are discharged into the cooling waters passing through the generating station, and metal containing structures within the generating station are exposed to erosion and corrosion via contact with sea water. Although the MRC did not sponsor its own long-term field research program to study the potential impacts of radionuclide and metal emissions, several studies of metal and radionuclide concentrations in the environment were done for the MRC, and other relevant information has been collected by Southern California Edison (as part of their required monitoring programs), as well as by other researchers. Because this report is a review of the available evidence coming from a number of disparate sources, its format differs from other MRC Technical Reports, most of which have emphasized the analysis of data collected by the MRC to answer the specific question at hand.

Our review of the available information indicates that the amounts of metals or radioactive materials released from SONGS are unlikely to cause substantial ecological impacts on the marine community. This conclusion is based upon information from MRC-sponsored studies of activity levels and metal concentrations in the tissues of sand crabs and mussels; measures of metal concentrations in mussels from the State Mussel Watch Program; reports to the Regional Water Quality Control Board on SONGS' discharges of metals; and various reports detailing activity levels in SONGS' effluents and selected marine organisms from the vicinity of SONGS.

The State Mussel Watch Program (SMW) has used mussels to monitor the quality of California coastal waters for over a decade. They established a station near the San Onofre discharges in 1985-1986. Metal concentrations reported from the San Onofre station by the SMW were quite similar to concentrations at several relatively "clean" Channel Island stations and to values at coastal reference stations. They were also lower than the concentrations in the source material collected at Bodega Head. Because the metal concentrations seen in the mussels transplanted near San Onofre were not high in comparison with other stations, SMW discontinued the San Onofre station after the 1985-1986 transplant. The MRC also transplanted mussels near San Onofre, twice during 1976-1977 and once in 1986. In general, the metal concentrations seen in these transplants were not especially high, and were lower than concentrations above which SMW flags a site for special attention. Our ability to compare the MRC results with SMW results is hampered to some degree, however, because most SMW transplants used the California mussel while the MRC used the bay mussel.

In the two MRC mussel studies, mussels were arrayed at varying distances from SONGS. Only in the 1986 study were stations located upcoast as well as downcoast of SONGS. The results of both studies indicated that metal (especially manganese) concentrations declined with increasing distance downcoast from SONGS. However, in 1986 metal concentrations continued to increase upcoast of SONGS, peaking in concentration about 4.5 km upcoast of SONGS, near the mouth of San Mateo Creek. The most striking result from the two transplants during 1976-1977 was that metal concentrations were much higher during the winter transplant than during the spring transplant. Possible explanations for the differences include (a) reductions in metal concentrations in response to the increase in gonad mass in the spring, (b) higher metal concentrations in response to higher sediment load during the winter, or (c) increase in metal concentration in response to the lower operating status (and thus more intermittent pumping) of SONGS Unit 1 during the spring period. Although all three of these factors may partially explain our results, we believe that only the first one can explain why the concentrations of all assayed metals were higher in the winter period. During all three transplants the growth rates of the mussels were lower at the sites nearest SONGS. This effect appears to be independent of metal concentrations in the mussels, and is probably caused by suspended sediments in SONGS' discharges interfering with the feeding of the mussels.

Data on metal concentrations in sand crabs come from a survey in 1982 by Dr. Adrian Wenner of the University of California, Santa Barbara, a former MRC contractor, and surveys by the MRC in 1983 and 1986. The one consistent result from these studies is that manganese concentrations tended to be higher in the general vicinity about SONGS in comparison with more distant beaches. This area of higher manganese concentrations may have extended as far as 30 km upcoast and downcoast from SONGS. Within this region there appear to be several local maxima, and the concentrations nearest SONGS were not the highest in the region. This result is in agreement with the mussel studies, where there was evidence for a local maxima in manganese concentration near the mouth of San Mateo Creek. In 1982 relatively high concentrations of nickel and zinc were seen at the beach 0.4 km north of SONGS, and the concentration of iron was relatively high at the beaches 0.4 and 1.5 km north of SONGS. In later surveys there was no indication of higher concentrations of either nickel or zinc near SONGS. Chromium and iron tissue concentrations were high at the beach 0.4 km north of SONGS in one of two category of crabs during one of the two surveys during 1983. However, similarly high concentrations were seen in the other category of crabs at a beach 12 km north of SONGS at the same time. On average chromium concentrations tended to be higher in the general area about SONGS during 1986. This higher average is due to the lack of beaches near SONGS at which relatively low concentrations were detected, rather than from exceptionally high concentrations at some of the beaches near the generating station.

Concentrations of metals in the seawater and sediments near SONGS have been sampled by the Southern California Coastal Water Research Project and by Southern California Edison. The MRC sampled metal concentrations in sand. The results of these sampling programs suggest that metal concentrations in the vicinity of SONGS are relatively low in comparison with other sites in Southern California, and do not suggest that there has been a substantial increase in metal concentrations specific to sites near SONGS after Units 2 and 3 came on line. The evidence suggesting that there has been no increase in metal concentrations is stronger for sediment samples than for water column samples since the sediment concentrations were usually above detection limits and because we expect that sediment concentrations are, in some sense, an integrated measure of the sediment's exposure to metals over some time period in the past. Although we are less certain about whether SONGS has increased metal concentrations in the receiving waters, the concentrations observed at all times during the period after Units 2 and 3 began operating (1985 - 1987) were well below current conservative estimates of chronic toxicity.

Reviews of possible sources of metals (in particular chromium) within SONGS did not uncover sources large enough to lead to significant contamination of the receiving waters or to chronic violations of effluent limitations established in SONGS' permits. Review of the concentrations of metals in SONGS' combined discharges reported by SCE to the Regional Water Quality Control Board showed that SONGS was usually in compliance with discharge limitations. This is significant because the discharge limitations are based on estimates of the concentrations at which chronic exposure to each metal in the receiving waters would lead to adverse biological effects. Alone, neither the examination of possible sources of metals within SONGS, nor the review of metal concentrations reported in the combined discharges convincingly exonerate SONGS as a significant source of metals. Not all possible sources of metals were considered in the reviews (in particular corrosion and erosion of metallic surfaces and of surfaces painted with chromium-based paints were not included), and there were occasionally high concentrations of various metals in the combined discharges. Because the combined discharge is only sampled once every six months, we can not rule out the possibility that the occasionally higher concentrations represent high discharges over significant periods of time. We recommend that the current sampling program be augmented either by more frequent sampling or the placement of mussels in the discharge waters, following standard SMW procedures. However, the discharge monitoring and reviews of metal sources within SONGS certainly do not suggest that there is a problem with contamination of the marine environment with metals by SONGS, and the other sources of information on metal concentrations in the environment reviewed above indicate that such contamination has not occurred.

The concentration of radionuclides in beach sediments, effluents, subtidal sediments and organisms has been routinely monitored by SCE, and the results have been reported to the Nuclear Regulatory Commission. The MRC evaluated the concentration of radionuclides in sand crab tissues during one survey during 1986. Radionuclides are present in detectable quantities in organisms near SONGS, and in the MRC sand crab survey station-related radionuclides were detected in sand crabs at distances as far as 10 km from the plant. Nevertheless, the evidence strongly supports the view that the release of radioactive effluents from SONGS has not lead to measurable ecological effects on the local marine biota. This conclusion is based primarily on two observations: 1) maximum estimates of routine radiological releases from SONGS would result in exposures of local marine organisms to dose rates approximately 100 times lower than the lowest levels found to produce any sublethal effects in controlled laboratory experiments; and 2) measures in tissues of organisms collected near SONGS reveal that generally less than 10% of the total internal specific activity is due to artificial radionuclides released by the plant, the rest coming from natural sources of radiation.

# 1. GENERAL INTRODUCTION

Operation of the condenser cooling systems at SONGS involves pumping large quantities of seawater through the generating station, and then discharging the effluents into the local marine environment. Both radioactive and nonradioactive effluents are discharged into the seawater passing through the generating station, at various rates and durations. In this report we examine how such changes in the seawater concentrations of metals and radionuclides from SONGS might be impacting the local marine environment. SONGS certainly releases metals since virtually any structure containing metal and exposed to seawater will exhibit some corrosion or erosion. Chromium, copper, iron, nickel and titanium are the metals flagged for special monitoring by the Regional Water Quality Control Board. Manganese, nickel and zinc were reported to be in high concentrations in sand crabs collected at beaches near SONGS in 1982 (Wenner 1982a). More than 100 unstable radionuclides are probably released by SONGS (Final Environmental Statement for SONGS Unit 1, 1973) in radioactive effluents. The activity of 19 unstable radionuclides of particular concern are regularly monitored near SONGS in sediments, seawater, and the tissues of selected marine organisms.

The format of this technical report differs somewhat from other MRC reports because the MRC did not sponsor a long-term field research program to study the potential impacts of radionuclide and metal emissions on the marine environment. Such an investigation was not launched primarily because the MRC believed that routine operations of SONGS would not result in ecologically significant releases of metals or radionuclides into the marine environment (See

SCE & SDG&E 1971 for example).[1] Nevertheless, the MRC did a literature search for evidence of ecological effects of radionuclide releases on aquatic communities, and failed to find strong support for such effects, even when sources were releasing radioactive products at much higher rates than nuclear generating stations. In a majority report, the MRC concluded that radioactive emissions from SONGS were unlikely to result in measurable impacts on the local marine biota (MRC 1979, Doc. 79-04).

The MRC also chose not to launch a comprehensive investigation of potential impacts from substances in SONGS emissions, due to the underlying philosophy of their analytical approach. Rather than attempting to identify and then quantify all possible causes of adverse ecological effects, which may or may not actually be producing impacts, the MRC adopted the program of attempting to first identify ecological effects, and then seeking to identify their specific causes. However, concern over metal releases from SONGS was renewed after a study suggested that reproductive patterns in sand crab populations near the station might be influenced by metallic releases from corrosion within the plant (Wenner 1982a; Siegel and Wenner 1984; see Final Technical Report A: Sand Crabs).

We report on information obtained from a number of sources, which fall into three broad categories: (1) metal concentrations and radionuclide activity levels in marine organisms collected near SONGS; (2) metal concentrations and

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[1] On June 28-30, 1976, the Marine Review Committee, at the suggestion of J. Mihursky, the representative for the environmental groups at that time, held a meeting where a panel of experts on the environmental effects of nuclear power discussed the "metals issue". The joint opinion of this panel was that SONGS was unlikely to be a significant source of metals with the possible exception of copper. It was recommended that copper not be used in the cooling system at SONGS. If this recommendation were followed, it was thought that the program should not attempt to detect and follow such materials coming from the plant (*personal communication* from J. Mihursky to W.W. Murdoch on 6/14/89).

radionuclide activity levels in SONGS' effluents, and in seawater and sediments near the plant; and (3) estimates of potential releases of metals in SONGS' effluents, incorporating knowledge of plant structure and chemical inputs. We first describe the relevant findings from tissue concentrations of metals in mussels and sand crabs. Metal concentrations reported in the large baseline set of data collected by the State Mussel Watch Program are examined, and contrasted with the values from MRC studies of metals in mussel tissues (Section 2). We then examine in detail the MRC studies of metals in mussel tissues (Section 3). Section 4 gives the results of MRC-sponsored studies on the concentrations of metals and radionuclides in the tissues of sand crabs. In that section we also consider independent reports on metal concentrations in sand crab tissues near SONGS, provided by Dr. A. Wenner, a former MRC contractor.

Researchers have been monitoring metal concentrations in seawater and sediments at locations throughout the Southern California Bight for a number of years, and some of these studies collected samples in the region of San Onofre. Using these data, and seawater and sediment samples collected by SCE near the generating station, we examine the extent to which SONGS appears to influence metal concentrations in the local environment, and whether these concentrations pose a potential threat to marine organisms (Section 5). In Section 6, we examine measurements of metal concentrations in SONGS' effluents, and evaluate engineering estimates of potential sources of chromium discharges from SONGS.

Finally, we focus on the possibility that radionuclide releases from SONGS might produce adverse ecological effects (Section 7). We examine reports by SCE to the Nuclear Regulatory Commission on radiological releases from SONGS, and survey the literature for further information regarding the effects of releases of artificial radionuclides into the marine environment.

# 2. STATE MUSSEL WATCH'S MEASUREMENTS OF METAL CONCENTRATIONS IN MUSSEL TISSUES

## 2.1 Summary

The State Mussel Watch Program (SMW) has been using mussels to monitor the quality of California coastal, bay and estuarine waters for over a decade. They established a station near the San Onofre discharges in 1985-1986, providing an ideal opportunity to contrast the values recorded there with the extensive and analytically consistent SMW data base. In addition, we compared metal concentrations detected in the MRC-sponsored mussel studies of 1976-1977 and 1986 with those reported in the SMW data base.

Metal concentrations reported from the San Onofre site by the State Mussel Watch were quite similar to concentrations at several relatively "clean" Channel Island stations and to values at coastal reference stations. Mussels from San Onofre had lower levels for eight of the nine metals assessed, compared with the neighboring Oceanside site, which is a coastal reference station specifically located "away from known sources of pollution". Additionally, none of the metal levels detected at San Onofre by SMW in 1985-1986 were close to the 85th percentile for the total SMW data collected from 1977-1986. This percentile is the level at which State Mussel Watch flags a site as relatively polluted, and begins tracking that site more closely.

The values reported in the two MRC-sponsored studies were in general agreement with those detected near San Onofre by the State Mussel Watch. Interestingly, some of the chromium values from the 1976-1977 MRC study were lower than any ever recorded by SMW. The 1986 MRC study showed somewhat high values for manganese, but the SMW data base reveals that, during roughly the same time period, even higher levels of this element were present at stations both to the immediate north and south of San Onofre. It is thus unlikely that the generating station is the primary source for elevated levels of manganese. In addition, high concentrations of Mn in the tissues of mussels can result when they are exposed to high levels of particulates, even when Mn is not particularly elevated in the environment.

The State Mussel Watch data from 1985-1986 indicated that metal concentrations in mussels at the San Onofre site were not high relative to other sites that are monitored, so subsequent monitoring of this station was discontinued. Although we concur with the finding that the San Onofre region appears relatively "clean" with respect to metal concentrations in 1985, continued use of mussels as bio-indicators at this site could provide valuable information regarding the potential impact of discharges by SONGS on the marine environment, and especially of how they might change through time.

## 2.2 Background

The State Mussel Watch Program measured metal concentrations in mussels outplanted at San Onofre in 1985-1986, and has been measuring tissue metal concentrations in mussels collected at numerous other stations along the entire California coastline for over ten years. This data base permits us to compare concentrations of trace metals recorded at stations near SONGS with tissue concentrations measured elsewhere, and to contrast the concentrations recorded by the Mussel Watch Program with those collected in the MRC-sponsored outplants described in Section 3.

Mussels are widely used as bio-indicators because they are a cost-effective means for monitoring pollutant concentrations in the aquatic environment (Goldberg *et al.* 1978; Hayes and Phillips 1987). They are well-suited for use as a bioassay as they are long-lived, and efficient accumulators of toxic substances in their environment (Stephenson *et al.* 1980). The sessile habit of mussels also makes them ideal for transplanting to sites where no resident populations are present. Outplants can be established in areas suspected of having high pollutant concentrations regardless of whether the appropriate hard substrate for mussels is naturally available (Hayes and Phillips 1985).

The State Water Resources Control Board (SWRCB) established the California State Mussel Watch (SMW) as a long-term program for monitoring water quality in California coastal waters, bays and estuaries. SMW has been routinely assessing the concentrations of 9 potentially toxic trace metals in mussel tissues from numerous sites along the California coast since 1977. Currently SMW takes two types of measurements. The first are taken at a set of coastal reference sites and resident *M. californianus* are used in most cases. The second type are taken at "hot-spots" in areas of suspected contamination using transplanted *M. californianus*. Thirty-one stations were initially established in areas thought at that time to be distant from point sources of pollutant discharges. Regular monitoring of these 31 stations was discontinued in 1978, but in conjunction with five coastal references stations, also located away from known sources of pollution and still monitored on an annual basis, these sites provide a broad baseline of trace metal concentrations in mussels.

The SMW uses a standardized methodology in handling and analyzing pollutant concentrations in its samples (Hayes and Phillips 1985; Hayes and Phillips 1987). This is a distinct advantage in assessing spatial or temporal trends in the data, since estimates from different laboratories can differ substantially, probably due to the use of differing analytical techniques (Hayes and Phillips 1986). Details of the methods employed in the SMW program can be found in their annual reports (e.g. Hayes and Phillips 1985; Hayes and Phillips 1987). Values reported here are all in μg/g dry weight.

Two aspects of the studies examined here should be mentioned. SMW transplants and the majority of the resident population data are tissue concentrations from *Mytilus californianus*, the California mussel, while the MRC outplants were *Mytilus edulis*, the bay mussel. This raises the possibility that differences in metal concentrations between the two studies may arise simply from intra-specific variability in tissue affinities for the various metals. We address this potential confound below (see Stephenson *et al.* 1980 for a detailed analysis).

A second consideration involves the duration over which transplanted mussels were deployed in the field. Metal uptake rates can vary widely, a two month period being adequate for assessing the environmental concentrations of some metals, while an outplant duration of six months or more may be necessary for complete tissue equilibrium to occur for metals such as silver, copper or lead (Hayes and Phillips 1985). The SMW uses outplants of four to six months, which should be adequate for most metals. They left mussels at the San Onofre station for 4.9 months.

We contrast metal concentrations from six SMW stations with the concentrations detected by SMW in 1985-1986 at San Onofre, and with concentrations measured by the MRC in its 1976-1977 and 1986 outplant studies (Tables 1 and 3). The SMW stations examined here include the two coastal reference stations within the southern California bight (Royal Palms Beach and Oceanside), which were located by SMW in order to provide a long term baseline set of metal concentrations from regions distant from known sources of pollution. (In spite of this goal, the Royal Palms Beach station is located within several km of the White's Point sewage outfall.) The two Channel Island sites are presented because they presumably exhibit metal concentrations indicative of relatively pristine ocean waters. The station at La Jolla is listed because it is situated near an MRC sampling location for sand crabs. Data from the Bodega Head site are included because this was the source site for mussels transplanted to San Onofre. The individual stations monitored by the MRC in 1976-1977 and 1986 are described in Section 3, but all were located within 15 km of SONGS.

## 2.3 Results

We first examine data collected by the State Mussel Watch Program, comparing concentrations from the San Onofre station with the program's extensive data base of metal concentrations from other stations in southern California. We then contrast the results of the MRC-sponsored mussel outplants with those of the SMW program.

### 2.3.1 State Mussel Watch Results

Nine metals were assessed in tissues of mussels outplanted at San Onofre by the State Mussel Watch Program during 1985-1986 (Table 1). None of the metal concentrations at the San Onofre station were elevated relative to the other five sites. In fact, for chromium, lead, mercury, silver, and zinc, concentrations at the San Onofre station were the lowest, compared with the mean concentrations from the other stations (Table 1).

Closer comparison of the San Onofre data with other Mussel Watch stations reveals some interesting points. The Oceanside site is a coastal reference station, specifically chosen to be distant from known sources of pollution (Hayes and Phillips 1987). Yet, all of the mean metal concentrations in mussels from Oceanside were higher than those at San Onofre, with the exception of cadmium. For cadmium, the San Onofre concentration was well within the range observed at Oceanside (Table 1).

The two Channel Island stations were chosen to represent relatively pristine conditions distant from industrial and urban influences. Concentrations of chromium, copper, and mercury from San Miguel and Santa Barbara Islands were quite similar to those found at the San Onofre station (Table 1). This indicates that for many metals, the concentrations in waters near the generating station were indeed similar to those found in areas with minimal anthropogenic input. High cadmium concentrations detected at the island stations probably reflect greater influxes of more northern waters, which tend to exhibit elevated cadmium concentrations due to strong upwelling of mid-depth water (Hayes and Phillips 1987). The aluminum concentration at San Onofre appeared elevated with respect to the island stations, but was well within the range found at the three other mainland stations, and substantially lower than the mean concentration at Oceanside Beach (Table 1). Manganese also appeared slightly higher at San Onofre than at the islands, but the concentration was *below* the *lowest* concentrations found at two of the mainland stations (Oceanside Beach and Royal Palms Beach), and roughly equal to the mean concentration from La Jolla Beach (Table 1). The higher concentrations of aluminum and manganese at mainland sites in comparison with sites at the islands may well be due to the higher particulate load in mainland coastal waters (Hayes and Phillips 1985).

The State Mussel Watch Program keeps a running tally of metal concentrations measured at all the stations along the California coast. "Elevated data levels" (EDL's) are calculated from this extensive data base, and represent the concentration, for each metal, which equals or exceeds the 85 or 95th percentile of all measurements collected in organisms of that species and exposure type (Table 2; Hayes and Phillips 1987). The concentrations for the EDL's in the SMW Transplanted populations tend to be higher than for the Resident populations (Table 2), probably because transplants are usually located in areas suspected of high pollutant concentrations. Metal concentrations in California mussels deployed at San Onofre, however, were far lower than the 85% EDL for every metal measured, using either the Resident or Transplanted California population EDL's for comparison (Tables 1 and 2). Since the Mussel Watch data come from a variety of sites over a broad range of conditions, the fact that the San Onofre concentrations do not exceed the 85th percentile of these observations indicates that the San Onofre station is probably less exposed to metallic pollutants than many other SMW stations. Although metallic pollution could still be impinging on the San Onofre area, the results presented above suggest that anomalous biological conditions seen near SONGS, in comparison with other areas, are probably due to factors other than unusually high metal concentrations in the environment there. Further evidence that San Onofre is a fairly "clean" area in terms of metal concentrations comes from a comparison of the concentrations seen by SMW in mussels transplanted there, with the concentration of metals in mussels at Bodega Head, the source site, at the time that mussels were being collected for transplantation to San Onofre. The concentrations seen at San Onofre were generally about the same or less than those seen at Bodega Head (Table 1). The exception was aluminum, which was higher at San Onofre, but higher concentrations of aluminum were seen at the other nearby sites in Southern California (Table 1).

### 2.3.2 Comparison of the State Mussel Watch results with the MRC-sponsored studies

We examine in detail the evidence for spatial patterns in metal concentrations from two MRC-sponsored mussel outplants in Section 3. Here we contrast the data from those studies with concentrations reported by the State Mussel Watch Program. The MRC outplants used the bay mussel, *M. edulis* as the study organism, and metal concentrations in resident bay mussels are generally higher than those in Resident California mussels (Table 3). For this reason we believe that when we are forced to make inter-specific comparisons, they tend to be environmentally conservative ones.

The concentrations reported for individual metals in the three studies--the 1976-1977 and 1986 MRC outplants, and the 1985-1986 SMW outplant-- were generally similar, exhibiting a range of concentrations for each metal that could occur due to natural temporal fluctuations at a station, even when we ignore the fact that the 1985 Mussel Watch outplant used *M. californianus* (Table 3). Values from the MRC outplants for most of the metals were within the range of concentrations reported by the SMW from the Channel Island and coastal reference stations (Tables 1 and 3).

The concentration of two metals from the 1976-1977 MRC study appeared to differ somewhat from the concentrations recorded by the SMW at San Onofre during 1985-1986: chromium concentrations were quite low, and copper concentrations somewhat high in the MRC outplants relative to the SMW concentrations (Table 3). Indeed, two of the six chromium concentrations reported in the 1976-1977 MRC study were lower than any found by the SMW in *Mytilus californianus* or *M. edulis* tissues from 125 stations measured over a ten year period (Hayes and Phillips 1987). The three highest copper concentrations were measured near SONGS in 1976-1977 (Table 3) at a time when copper was still a component of that system's cooling system (Section 3). However, these concentrations were all below the 85% EDL for Resident bay mussels set by the State Mussel Watch (Tables 2 and 3). Such high copper concentrations were not obtained by SMW in 1985-1986 or in the 1986 MRC study (Table 3), perhaps because copper conduits in the station had been replaced with titanium and concrete by mid-1981. Possible explanations for the generally higher metal concentrations seen during the "off" than during the "on" 1976-1977 outplants are discussed in Section 3.

The 1986 MRC outplants were slightly elevated in cadmium, copper, manganese and zinc, relative to the 1985-1986 SMW data from San Onofre (Table 3). None of these differences were substantial, however, and the concentrations for copper, and zinc from the 1986 MRC data closely matched the concentrations from the Oceanside reference station (Tables 1 and 3). None of the concentrations for any of these metals exceeded the 85% EDL for Resident bay mussels (Tables 2 and 3). Although several of the manganese measures in *bay mussels* from the 1986 MRC outplant at San Onofre exceeded the SMW's 85% EDL for *resident California mussels*, even higher concentrations of manganese were detected by SMW in California mussels from relatively nearby sites. For example, in 1985-1986, the State Mussel Watch detected 25.77 μg/g of manganese in Oceanside Harbor, 11.44 μg/g at Oceanside, and only 6.30 μg/g at San Onofre. SMW stations to the north of San Onofre also showed manganese concentrations higher than 10 μg/g that year (Hayes and Phillips 1987).

## 2.4 Conclusion

The concentrations of nine metals reported by the State Mussel Watch Program in mussels outplanted at the San Onofre discharges indicated that the area is relatively clean with respect to metallic pollution. Comparisons of the SMW concentrations with concentrations recorded from MRC-sponsored outplants also indicate that the San Onofre region has relatively low concentrations of metals.

# 3. MUSSEL STUDIES AT SONGS AND METALS

## 3.1 Introduction

The MRC funded two mussel studies, one during 1976-1977 and a second during 1986. In the first study, mussels were outplanted at varying distances from the outfall at Unit 1. In the second study, mussels were outplanted at varying distances from the diffusers of Units 2 and 3. Only in the 1986 study were stations located upcoast as well as downcoast of SONGS. Listings of the programs and data bases used in these analyses can be found in Appendix A.

The results of the initial study indicated that mussels grew at a slower rate in the immediate vicinity of Unit 1's outfall (Kastendiek *et al.* 1981). The mechanisms for this reduction in growth rate were not certain (Kastendiek *et al.* 1981); a similar reduction in growth was seen when Unit 1 was classified as "off" as well as during "on" periods. Mussel samples from the longest "on" and "off" outplants were frozen pending potential metal analyses. At the time of the initial studies, the MRC considered the release of metals a very unlikely mechanism for impacts on mussels or other organisms. Consequently, the samples remained frozen until release of metals from SONGS was suggested as a possible mechanism of impact on sand crabs. Because of the focus on metals in relation to studies of sand crabs, in 1986 the MRC authorized metal analyses on these stored samples. In addition, a second study of mussels was undertaken in 1986, and mussel samples associated with this study were analyzed for metal concentrations.

In this section we examine spatial patterns in metal concentration in relation to proximity to SONGS, and examine relationships between mussel growth or gonad weight, and tissue metal concentrations. In Section 2, we compared the tissue metal concentrations seen in the MRC studies with those reported from other sites by the State Mussel Watch program.

## 3.2 Methods and Study Design

Field methods for both the 1976-1977 and 1986 studies follow those described in Kastendiek *et al.*, 1981. The 1976-1977 outplants were done before State Mussel Watch had determined their standard size range for transplanted mussels. Consequently, a wide range of initial mussel lengths (30-60 mm) was used in that study. To avoid confounding the influence of initial size with location, each individual mussel at a station was matched in size with a mussel at each of the other stations. During the 1986-1987 study, mussels in a narrower size range (45-60 mm) were used. The bay mussel, *Mytilus edulis*, was used in the MRC studies. In our statistical analyses of metal concentrations we do not use size as a covariate. This is because metal concentrations are only available for a composite at each station or site, not for each individual mussel, and the average sizes used at each site or station were standardized.

Table 4 provides a description of the two MRC outplant studies. For the 1976-1977 study, tissue metal data are available from one "on" and one "off" period, each lasting approximately four months. During each period, mussels from four distances downcoast from the outfall of Unit 1 (25, 50, 1600, and 12,800 m) were analyzed (Fig. 1). For each outplant period, composite samples consisted of approximately 15 mussels coming from a single bag. Thus, for a given period and distance from the diffusers there is no replication.

During 1986, a bag of thirty mussels was outplanted at each of three replicate sites within each of six "general areas" arrayed from approximately 5 km upcoast to approximately 5 km downcoast of SONGS (Fig. 1). These areas were (in order from upcoast to downcoast): the upcoast portion of San Mateo Kelp Bed (SMKU), the downcoast portion of San Mateo Kelp Bed (SMKD), the "north bed", a small kelp bed immediately upcoast of Unit 2 and 3's diffusers (SOKN), the region in the immediate vicinity of SONGS' diffusers (Diffuser area), the upcoast portion of the main San Onofre Kelp bed (SOKU), and Pendleton Artificial Reef (PAR). Mussels were outplanted on September 4, 1986. Half the mussels (15) from each bag were removed from the field on December 31, 1986 and 10 of these mussels from each bag formed a composite sample analyzed for metal concentrations. The values based on these composite samples from each bag at a site were treated as replicate observations within each of the six areas. Thus, there were three replicate samples from each general area, each collected from one of three separate sites located within a few hundred meters of one another.

Metal concentrations in the composite samples of the mussels were assayed by SAIC blindly (i.e. without knowledge of the outplant locations). Samples were analyzed by atomic absorption spectrophotometry, using both flame and graphite techniques. Accuracy of instrumentation was checked by estimating the concentration of metals in certified reference material (lobster hepatopancreas tissue) provided by the National Research Council of Canada. Precision of concentration estimates was evaluated by analysis of three or four separate aliquots from a mussel sample and from reference materials. Replicate aliquots were analyzed for one 1976 mussel sample, one 1986 mussel sample and for the reference material used to determine accuracy for both these sets of samples. Additional details on the methods, and the precision and accuracy of these methods is in SAIC (1987a and b), which are reproduced here as Appendix B.

## 3.3 Results

### 3.3.1 1976-1977 Study

During the "off" period, power production was low, and water flow averaged about half of its maximum capacity (Table 4). During the "on" period, power production was high, and water flow through the cooling system averaged approximately 80% higher than during the "off" period (Table 4). During the "on" period, the current was predominantly in the downcoast direction (Table 4). Current measurements were first made by the MRC in February 1977, so no data are available for the initial part of the "off" period. For the portion of the "off" period beginning in February 1977, currents were upcoast and downcoast about an equal number of the days for which data were available, with the average current only slightly in the downcoast direction (Table 4).

The mean growth rates and metal concentrations from the outplants at the stations are in Table 5. Spatial patterns in metal concentrations were analyzed by regression against distance from the Unit 1 outfall, with dummy variables included to allow different means and slopes in the two periods (i.e. ANCOVA, see Table 6). In no case were the slopes significantly different between periods. Metal concentrations were log transformed. By using log transformations we have invoked a model assuming an exponential decline in concentration with distance from the outfall.

The most striking pattern in the results is that metal concentrations were significantly higher during the "off" period than during the "on" period for six of the eight metals (the exceptions were Cd and Zn, Table 6). For five metals, there were no significant or nearly significant trends with distance from the outfall (Cd, Cu, Ni, Pb, Zn; Table 6). For three metals (Cr, Fe, Mn), concentrations declined significantly (Fe) ($p < 0.05$) or nearly significantly (Mn, Cr) ($p < 0.10$) with increasing distance from the outfall (Table 6). These results suggest (assuming tissue metal concentration reflects environmental concentration, see Discussion) that there is a source of these metals at, or upcoast of the outfall, and perhaps, that more metals were released from that source during the "off" period than during the "on" period. Since no metal data were collected from upcoast of the outfall during 1976-1977, it is not possible to distinguish between releases from a source at the outfall or upcoast of the outfall. Although copper showed no statistically significant trend with distance from the outfall, and concentrations were similar at all sites, the two highest concentrations during both periods were at the two stations closest to the outfall (within 50 meters; Table 5).

Relationships between mussel growth and metal concentration were analyzed by ANCOVA using metal concentration as a covariate and period ("on" or "off") as the class variable. A preliminary analysis indicated that slopes were homogeneous across periods. (No analyses are reported for gonad mass or gonad index for 1976-1977 because the estimates of gonad mass are unreliable due to deterioration of the samples during their long storage.)

Growth rate was significantly and negatively related to tissue copper concentration, but not to the concentrations of any of the other metals (Table 7). In these analyses, the effect of Period was also significant only for the analysis against copper. This effect indicates that for a given copper concentration, growth rate was different in the two periods. This results from the fact that growth rate did not vary much between the periods while copper concentration did.

### 3.3.2 1986 Study

During this study, all three units averaged substantially greater than 50% of capacity in both flow through their cooling systems and in power production, and the current was predominantly in the downcoast direction (Table 4).

Because there was replication within general areas during 1986 these data were analyzed by ANOVA, followed by *a posteriori* comparisons using the Tukey-Kramer method. This contrasts with our analysis of spatial patterns for the 1976 outplant, which we analyzed by regression, using a dummy variable for period (see above).

There was significant variation among general areas in growth rate, gonad weight, gonad index (gonad weight/total weight), and the tissue concentration of all metals except zinc (the concentration of nickel was always below detection limits, and will not be considered further). Note that there can be significant variation among means even though we cannot distinguish between any two means using pairwise comparisons.

Growth rate was lowest at the diffusers and the site immediately (approximately 0.5 km) downcoast from the diffusers (SOKU) (Table 8). Growth rate did not differ significantly between these two sites, but was significantly less at each of these sites than at the other four sites. Growth rates at these other four sites were not distinguishable from one another (Table 8). Gonad weight only differed significantly between SMKD and SOKN (Table 8). No pairs of sites could be distinguished in gonad index (Table 8).

There was a general pattern for metal concentrations to be highest in the downcoast portion of San Mateo Kelp bed (SMKD), approximately 4.5 km upcoast of SONGS, and to decline with increasing distance downcoast (Table 8). This pattern was especially marked for Cr, Fe, Mn, and Pb. Concentrations at the furthest upcoast site, SMKU, were lower than at SMKD for most metals, and intermediate in value in comparison with the other downcoast stations (Table 8). For two metals (Cd and Zn), no pairs of stations could be distinguished statistically (Table 8). For each of the other five metals, at least one station had significantly lower concentrations than a station upcoast of it (Table 8). Considering SMKD and stations further downcoast, there was no case where a downcoast station had significantly higher concentrations than a station further upcoast. However, only for Mn was it possible to statistically distinguish concentrations at SMKD from those at the diffusers (DIFF). The other metals showing the most distinct differences among stations were Cr and Fe (Table 8).

The biological variables were generally not highly or significantly correlated with the concentrations of metals in tissues (Table 9). The one exception was the negative correlation between growth rate and tissue concentration of Cd (Table 9).

## 3.4 Discussion

In its early consideration of the "metals issue", the MRC reached the conclusion that release of metals by SONGS was not a mechanism by which the plant was likely to cause ecological impacts. The MRC's more recent concern regarding metals stemmed largely from an informal report (Wenner 1982a; also see Wenner 1988) that concentrations of some metals were higher in sand crabs near SONGS, and that these higher concentrations might have adverse effects on the crabs. The MRC has been particularly concerned with the concentrations of manganese, iron, and especially chromium, because these are the metals for which the MRC studies found some indication of higher concentrations near SONGS in sand crab tissues (Final Technical Report A. Sand Crabs).

The results of the MRC mussel studies suggest that there may be a source of manganese, and perhaps iron and chromium, near, but upcoast of SONGS. As demonstrated in the previous section (Section 2), however, the metal concentrations found in mussels at the sites most proximate to SONGS are generally low in comparison with other sites in southern California.

Results from the MRC studies during 1976-1977 and 1986 are consistent. In both studies, mussel growth was lower in the vicinity of the SONGS outfall or diffusers. Also, in both studies there was a tendency for the concentration of Mn, Cr, and Fe to decline with distance downcoast from the SONGS area. The results from 1986 suggest that the source of metals creating this gradient is likely to lie in the vicinity of SMKD and downcoast of SMKU, rather than at or in the very near vicinity of the SONGS outfall or diffusers. The SMKD station is located almost immediately offshore of the outlet for San Mateo Creek (Fig. 1), and Mn is associated with stream runoff (Hayes and Phillips 1985), while high concentrations of Fe are known to be associated with high sediment loads. Thus, San Mateo Creek is the most likely cause of the observed longshore gradient in metal concentration in tissues from outplanted mussels. This possibility could be tested by sampling the water in the creek to determine if Mn concentration is high there.

Stream runoff may also explain differences in concentrations of metals in mussel tissues between the "on" and "off" periods during 1976-1977. The "off" period, when higher concentrations of metals were seen in mussels, was in the winter, during a period of higher rainfall and stream runoff than in the subsequent "on" period (Dixon *et al.* 1988). An alternative explanation regarding differences in metal concentrations between the "off" and "on" periods is that metal concentrations declined from winter to spring in association with the beginning of the reproductive season for mussels (Simpson 1979, but see Brown *et al.* 1982). A third possibility is that SONGS Unit 1 released more metals during the "off" period than during the "on" period. Although higher releases of copper were seen at the Diablo Canyon power plant following a prolonged period when there was no pumping (Harrison *et al.* 1980), it seems unlikely that all the metals assayed would respond in this way, as they would need to, to explain the 1976-1977 results.

The concentration of copper in mussel tissues was higher in the "off" period of 1976-1977 than during either the "on" period from that study, or in mussels outplanted near SONGS' outfalls during later studies. Although no significant trend with distance was detected in the 1976-1977 study, mussels from the two stations closest to the diffusers had the highest concentrations of copper during both the "on" and "off" periods. In Section 2 we noted that these concentrations during the "off" period were also high in comparison to reference stations away from known sources of pollutants, although they do not fall among the highest 15% of the values recorded for copper in resident populations of bay mussels by State Mussel Watch. We also found a significant negative relationship between growth rate and tissue concentration of copper. It is possible that SONGS Unit 1 was the cause of these higher concentrations, but this potential source of copper was removed by mid-1981. However, lower growth was seen near the diffusers in both the "off" and the "on" periods of the 1976-1977 study, even though concentrations of copper were not especially high during the "on" period. Furthermore, lower mussel growth was still seen in the vicinity of the SONGS outfall during 1986, when tissue concentrations of copper were not especially high. The results from 1986 suggest that the correlation between growth and tissue copper concentration in 1976-1977 may be spurious. A more likely alternative hypothesis accounting for lower growth of mussels outplanted near SONGS that can explain both the early data and 1986 results as well, is that seston or sediments in the area of the SONGS outfall interfere with mussel feeding, and lead to reduced growth rate (Widdows *et al.* 1979, Kastendiek *et al.* 1981).

# 4. MRC SAND CRAB STUDIES AND METALS

The MRC has conducted a number of studies on sand crabs, and the results of these studies are reported in detail in Final Technical Report A. The conclusion of that report is that although sand crabs in the San Onofre area tended to be smaller and to reproduce less successfully than elsewhere, these spatial patterns are best explained by natural characteristics of the local beaches.

The MRC first became concerned that metallic releases by SONGS might be adversely affecting sand crabs based on an informal report (Wenner 1982a, also see Wenner 1988) that metal concentrations were high in sand crabs collected at beaches near SONGS in 1982. As a consequence, metal concentrations were evaluated in beach sediments and sand crab tissues at several subsequent times. Details of the methods and results are reported in the Final Technical Report A. Here, we summarize the data on metal concentrations presented in that report. For completeness we include tables of the metal concentrations measured in beach sediments and sand crab tissues at each beach (Tables 10-16).

The data which led to the original report of high metal concentrations in sand crabs (Wenner 1982a) are reproduced in Table 10. These same data have subsequently been published (Wenner 1988), although the values for chromium and cadmium were not included in that publication. Wenner (1988) concluded, based on these results, that the concentrations of manganese, nickel, zinc, and iron were high near SONGS. For nickel and zinc, this conclusion appears to be based on high values from single samples at a site 0.4 km north of SONGS (Unit 1) (Table 10). The conclusion for iron seems to be based on high concentrations in two samples (from 0.4 and 1.5 km north of SONGS; Table 10). Only for manganese is there evidence that the concentrations were higher in a broad area about SONGS. In Section 6 we note both that there is no known source of significant amounts of manganese at SONGS, and that manganese is not considered to be a particularly toxic metal. Of the patterns seen in the 1982 data, however, only that seen in manganese is consistent with later MRC studies of metal concentrations in sand crab tissues. In addition, these later studies indicate that the high concentrations for manganese seen within approximately 7.5 km about SONGS during 1982, do not appear to be confined to this region. The concentrations seen near SONGS are not particularly high when considered in the broader context of the beaches in a region extending up to 30 km from the plant; there appear to be local maxima in at least three different locations within that area (e.g., Tables 15 and 16).

From studies done for the MRC, measures of the concentration of eight metals in beach sediments are available from 15 or 16 beaches for one time in July and one time in August during 1983. Metal concentrations in sand crab tissues are available from most of these beaches for these same time periods, and from 27 beaches during August 1986. A majority of the beaches where metals were assayed are within 20 km of SONGS, but other more distant beaches were also sampled.

In general, metal concentrations in sediments were low at beaches near SONGS relative to other beaches, and the concentrations were notably high at Cabrillo Beach in Los Angeles (Tables 11 and 12). Copper showed an obvious declining trend going from north to south, starting at Cabrillo Beach. In both months, manganese was higher at 1.5 km North than at the 0.4 km North station immediately downcoast, or the next beach sampled upcoast (6.5 km North). This local maximum is consistent with results from the MRC mussel studies (Section 3). Neither nickel nor zinc showed indications of taking higher concentrations in sediments near SONGS (Tables 11 and 12). In August 1983, a local maximum for iron was seen at 1.5 km north of SONGS (Table 12). The metal concentrations in these beach sediments were much lower than is evident in subtidal sediments (Section 5). This is not too surprising since metal concentrations in sediments are negatively associated with sediment grain size and, perhaps because of this, positively associated with depth, with finer sediments occurring in deeper subtidal areas (Thompson *et al.* 1987).

Metal concentrations in sand crab tissues were not generally higher in the vicinity of SONGS than elsewhere (Tables 13 - 16). There was no indication of especially high concentrations of either nickel or zinc. Concentrations of nickel varied considerably, with high and low concentrations occurring at adjacent beaches away from obvious sources of the metal (Tables 13 - 15).

There tended to be a preponderance of high values for manganese tissue concentrations at beaches within roughly 30 kilometers of SONGS, in comparison with La Jolla (Tables 13 - 16). Within this zone, higher concentrations were sometimes seen near Dana Point (about 15 km north), 1.5 and 0.4 km north of SONGS, and at Oceanside (25 km South). In one case, the local maximum for manganese near SONGS was clearly upcoast of the generating station (Table 13). In only one of the four sets of data (Table 16) is there clear evidence that the local maximum is centered within a kilometer of SONGS, and not at other beaches only a few kilometers upcoast. In two other cases (Tables 14 and 15), the highest concentrations for manganese in the area around SONGS were at 0.4 km North, but data were not available from other upcoast beaches nearer than 6.5 km North. None of the concentrations seen within a few kilometers of SONGS, however, were the highest in comparison with those at other beaches in the general area.

Chromium and iron tissue concentrations appeared high in one category of sand crabs collected at the beach closest to SONGS during August 1983 (Table 15). Chromium tended to be at higher concentrations in the general area about SONGS during August 1986 (Table 16). The high concentration seen for chromium in 1983 (Table 15), however, was no higher than that seen at another beach (for a different category of crabs) 12 km north of SONGS (Table 14). In addition, the "high" concentrations seen for chromium near SONGS in 1986 (Table 16) were lower than a number of observations in 1983 (Tables 13 - 15, see for example Table 15, Oceanside).

# 5. EFFECTS OF SONGS ON THE CONCENTRATIONS OF METALS IN MARINE SEDIMENTS AND SEAWATER

## 5.1 Summary

Evidence from marine sediments and seawater sampling done by the Southern California Coastal Water Research Project (SCCWRP), Southern California Edison Company (SCE), and the Marine Review Committee (MRC), indicate that SONGS has not substantially modified metal concentrations in the region.

The two reference surveys done by SCCWRP in 60 m of water show that the concentrations of seven metals in marine sediments near SONGS are representative of those found at "uncontaminated" mainland shelf sites. Metal concentrations found at San Onofre in these studies were also similar to those found at control sites to the immediate north and south. The concentration of copper in 1985, and zinc in both 1977 and 1985 were somewhat higher in sediments from San Onofre than the average at the reference sites. However, these concentrations were within the range observed at other reference sites, and in each case were exceeded by one or both of the two nearest reference sites (Carlsbad and San Clemente). Because of the depth at which these sediments were collected we would expect only severe contamination by SONGS to be detected in them.

Both the SCE measures of metals in seawater and sediments in 15 m of water, and MRC studies of beach sediments, also fail to implicate SONGS as a major influence on metal concentrations. Indications that iron concentrations have increased in seawater samples could easily be due to changes in levels of suspended material in the water column due to wave action and run-off from winter storms. An increase in chromium concentrations in sediments at a 15 meter depth from 1978-1980 to 1985-1987 is evident in SCE data. This increase is seen at both an impact site near SONGS and a control site approximately 7 km downcoast of SONGS. Because the increase is slightly greater at the impact site than at the control site, and because there are no control stations substantially upcoast from SONGS, we cannot firmly rule out SONGS as the cause of the temporal change. However, the evidence is not compelling that SONGS is the cause, and other sediment data from 30 and 60 meter depths do not indicate an increase in chromium concentrations localized near SONGS.

Assessing whether the metal concentrations in seawater prior to 1985 were at toxic concentrations is complicated by the fact that estimates of metal concentrations in "clean" seawater have declined through time as analytical techniques improved. Avoidance of contamination of samples is also a major problem since metal concentrations in seawater are often extremely low, and near the detection limit of the analyses. The average concentration of copper in seawater samples collected by SCE in 1978 to 1980, both in an impact area and in a control area, were slightly above the current "Conservative Estimate of Chronic Toxicity" (CECT) developed by the State Water Quality Control Board in 1988. Our confidence in these data on copper concentrations is reduced because of the high average copper concentration detected in the control area, very high values occasionally being detected in both control and impact areas, suggesting possible contamination, and the general problem associated with overestimation of metal concentrations in seawater during earlier years. Virtually all metal concentrations for seawater reported by SCE after Units 2 and 3 began operations were below detection limits. Unfortunately, the detection limit used for analyses of copper is above the CECT. However, we do not suspect that there is currently a problem with copper contamination from SONGS because copper is not used in Unit 2 and 3's cooling system, and copper was eliminated from the cooling system of Unit 1 in 1981.

## 5.2 Introduction

The operation of SONGS could alter the chemical composition of local marine waters and benthic sediments. This is of concern because such changes might result in ecological impacts on the marine community, via changes in the food web due to impacts on plankton composition and abundance, or as a direct result of toxicity of chemicals to marine organisms at higher trophic levels. We review elsewhere the evidence for effects of metals on mussels (Section 3) and sand crabs (Section 4), and have examined spatial patterns in metal concentrations using mussels as bio-indicators (Sections 2 and 3). Here we evaluate the available data on the extent to which SONGS influences the concentrations of metals in local seawater and marine sediments.

Nuclear generating stations with flow-through cooling systems can potentially alter the metallic composition of the local marine environment in several ways. Operation of the cooling system involves pumping large quantities of seawater, and the occasional release of effluents potentially containing metals into these waters. In addition, metal concentrations in the cooling waters could be altered by erosion or corrosion of structural components of the cooling system. When discharged, these cooling waters could influence the chemical composition of the local seawater and sediment. Physical structures of the generating station on the beach or extending into the subtidal area could alter local oceanographic conditions and thereby influence chemical balances in the local waters and substrate. Construction tressels for the diffusers were steel pilings, and steel sheet piling was used to enclose the construction lay-down pad until 1984. Finally, the rapid outflow of large quantities of seawater could exert a hydrodynamic effect that might influence water and sediment characteristics in the region.

## 5.3 Background

We located three primary sources of information regarding metal concentrations in seawater and sediment from the vicinity of SONGS, including information from the Southern California Coastal Water Research Project (SCCWRP), data collected by Southern California Edison (SCE), and an MRC-sponsored study of metal concentrations in beach sediments near SONGS. We focus first on the baseline reference surveys undertaken by SCCWRP in 1977 (Word and Mearns 1979) and 1985 (Thompson *et al.* 1987). SCCWRP originally assessed sediment samples from 71 stations along the southern California coastline. They were seeking to identify control or reference sites: areas with metal contaminant concentrations that reflect "background" conditions (Word and Mearns 1979), for comparison with areas known to be subject to anthropogenic elevations of pollutants. Since sediment characteristics can vary with depth, they sampled only along the 60 m isobath. They measured the concentrations of seven metals which are EPA priority pollutants.

SCCWRP designated 29 of their stations as control sites that apparently reflected uncontaminated conditions, and used these sites to calculate mean "background" concentrations for each of seven metals (Word and Mearns 1979). The site at San Onofre was included among these control stations. A second reference site survey was done by SCCWRP in 1985 (Thompson *et al.* 1987), which resampled many of the control stations from the earlier study. The control stations mentioned above lie between Point Conception and Imperial Beach (south of San Diego). We report the mean and range of the concentrations seen, averaged over all these sites during 1977 and 1985 for the 60 m depth sampled in both studies. We also report individual concentrations from the three reference stations closest to SONGS: San Clemente to the north, San Onofre, and Carlsbad to the south. Because of a special concern over chromium concentrations, we also report the concentrations of chromium at a 30 m depth from all sites sampled in 1985, even though there are no data from 1977 for this depth.

We examined SCE's data on metal concentrations in sediments and seawater collected from 1975-1980, and 1985-1987. The studies by SCE were conducted to comply with the Nuclear Regulatory Commission's Environmental Technical Specifications for Unit 1 and the Preoperational Monitoring Program for Units 2 and 3; and the California Regional Water Quality Control Board's National Pollutant Discharge Elimination System requirements for Units 1, 2 and 3. We contrast data collected during the 1978-1980 period with data collected in 1985-1987 at the same stations.

The MRC collected data on metal concentrations in beach sediments from sites situated at varying distances from SONGS. Samples were only collected during two months in 1983. These results are also discussed in Section 4, and in greater detail in the Final Technical Report on sand crabs (Report A).

We examine these studies for evidence that metal concentrations are higher in the vicinity of San Onofre than elsewhere. When possible, we determine whether metal concentrations have increased through time near San Onofre relative to other locations. We also evaluate whether the metal concentrations detected are likely to be having toxic effects on the local marine biota.

## 5.4 Results

The SCCWRP data from 1977 indicated that metal concentrations in sediments from San Onofre were not elevated relative to the control stations immediately to the north and south of the area; nor did they differ substantially in comparison with the mean "background" concentrations averaged over all sites in southern California (Table 17). In 1985 concentrations from San Onofre were equal to or lower than those at the neighboring sites for six of the seven metals assessed (Table 17). The concentration of chromium was only marginally higher at San Onofre than San Clemente or Carlsbad in 1985, and well below the maximum concentrations recorded from other control areas (Table 17).

Although comparisons between the two SCCWRP studies should be treated cautiously (Thompson *et al.* 1987), there are apparently no substantial increases in metal concentrations at San Onofre between the 1977 and 1985 studies (Table 17). Three of the metal concentrations at San Onofre declined and four increased between 1977 and 1985, but these changes could easily reflect natural temporal fluctuations in metal concentrations since fluctuations of these same magnitudes are apparent at the other two sites, as well as in the overall mean concentrations from the reference stations (Table 17). None of the increases at San Onofre were extreme when compared with the ranges of concentrations seen at the other control stations representing "background" conditions ("overall" values from Table 17). The most conspicuous change was in silver, which showed a major decline in concentration at reference stations throughout southern California, including the three sites near SONGS (Table 17). Thompson *et al.* (1987) offered no explanation for this large-scale temporal pattern, and we do not know its cause. Other metals showing smaller, but statistically significant large-scale changes from 1977 to 1985 were cadmium and lead (decreases); and chromium, copper, and nickel (increases) (Thompson *et al.* 1987).

SCE measured the concentrations of chromium, copper, iron and nickel in sediments and seawater at varying distances from SONGS from 1975 through mid 1980. They found no evidence of any spatial or temporal patterns in these samples for copper, chromium or nickel (SCE 1981), and our examination of the data supports this conclusion. The data collected through the end of 1979 were portrayed graphically in SCE (1980), and we have included these graphs as appendix C. Concentrations of iron in seawater samples increased over the duration of their study, and this is attributed to increases in suspended material due to storm runoff and higher wave action (SCE 1981). Since this increase occurred at all sites sampled, including a control site approximately 7 km from the generating station, SONGS is probably not the primary source for the elevations in iron. It is worth noting, however, that the mean iron concentration in seawater from the Unit 1 discharge sampling station was at least twice as high as concentrations from the other sites (see Appendix C). This station was most nearshore, and so subject to generally higher turbidity, which would tend to elevate measures of iron in water samples (SCE 1981). SCE also acknowledged that operation of Unit 1 and construction of Units 2 and 3 could have contributed to the higher concentrations via increases in turbidity (SCE 1981). Since the SCE sampling program began after Unit 1 began operations, it is not possible to evaluate from the data the extent to which this Unit was responsible for the changes.

At a different set of stations SCE collected data on sediment and water column metal concentrations both before (1978-1980) and after (1985-1987) Units 2 and 3 became operational. In Tables 18 and 19 we report their results (15 m depth) for the station immediately downcoast of the diffusers of Units 2 and 3, and for the control station approximately 7 km downcoast.

Although sediment metal concentrations tend to be somewhat higher near SONGS, this pattern is generally no more pronounced in 1985-1987 than it was in 1978-1980. With the exception of chromium, metal concentrations were not much different in 1985-1987 than they were in 1978-1980 (Table 18). Chromium sediment concentrations were approximately double their 1978-1980 concentrations in 1985-1987 (Table 18). This increase was seen both at the impact and the control sites, but percentage-wise, was marginally higher near SONGS. SCE did not sample control stations substantially upcoast of SONGS at the 15 m depth so we cannot rule out SONGS as a source of the increased chromium. However, data collected by SCCWRP at 30 meters depth indicate higher concentrations of chromium upcoast of SONGS (Fig. 2), and at 60 m depth there was a small but significant increase in chromium in sediments from 1977 to 1985 throughout southern California (Thompson *et al.* 1987). In addition, there was a change in contractor and methodology used in determining metal concentrations from 1978-1980 to 1985-1987 (SCE 1986), and this could have contributed to the change in observed chromium concentrations.

There is no indication in the SCE data that concentrations of metals in seawater have increased due to the operations of Units 2 and 3 (Table 19). There is also no obvious difference in concentration between Control and Impact sites.

However, the concentrations of metals were often below detection levels in 1985-1987, and these detection levels were higher than those used in 1978 - 1980.

The MRC-sponsored studies of metal concentrations in beach sediments failed to show any clear patterns with distance from SONGS (Section 4: Tables 11 and 12). Since metal concentrations in sediments decrease with grain size and increase with depth (Thompson *et al.* 1987), we cannot directly compare these concentrations with those collected by SCCWRP or SCE.

## 5.5 Discussion

The biological significance of metal concentrations in the waters and sediments near SONGS depends upon how the organisms in the area respond to these concentrations. Assessing the toxicity of the metal concentrations measured in sediments, from the region about SONGS, or in general, is difficult. It seems likely that the metallic content of sediments will affect burrowing and infaunal organisms to a greater extent than those living in the water column, and the toxic effects of a given metal concentration can depend up the grain size of the sediments, their organic content and many other factors. The toxic effects of contaminated sediments is now an active area of research (e.g. SCCWRP 1987). The regulation of pollutant concentrations in sediments was a high priority issue in the 1987 triennial review of the Ocean Plan (SWRCB 1988).

To date the State Water Resources Control Board (SWRCB) has not established standards for metal concentrations in sediments. They are currently investigating the possibility of applying the "Apparent Effects Threshold" (AET) method that was developed by EPA for the Puget Sound. This work has included sampling of sediment contaminants and infauna, bioassays of the sediments in the Southern California Bight by SCCWRP, and the analysis of these data along with data collected by NOAA in San Francisco Bay. The thrust of this method is to determine concentrations for each contaminant, individually, above which statistically significant declines in infaunal densities are *always* detected. Although the AET's developed so far by EPA are for the Puget Sound, and are probably only marginally applicable to California, they are far above the concentrations seen in sediments near San Onofre (see PTI 1988). However, AET's are not environmentally conservative contamination limits because they are concentrations at which effects are *always* detected. The measurement of sediment toxicity and the establishment of appropriate regulatory standards based on this information is clearly necessary for establishing effective protection for the marine biota. However, the lack of sufficient information on this topic has little impact on our evaluation of the significance of metal contamination in sediments near SONGS since the evidence does not suggest that such contamination has occurred.

There have been numerous studies of the responses of marine organisms subjected to differing concentrations of metals in seawater. In particular, there is a growing literature on chronic effects of metals in seawater. This literature was recently reviewed to aid in the revision of the effluent standards in the Water Quality Control Plan for Ocean Waters of California (SWRCB 1988). This review considered all marine or estuarine studies that could be found of native North American species published between 1979 (the last time the standards were updated) and 1987. They found 326 new studies (some of which evaluated more than one metal or species) of chronic toxicity of metals in sea water that met EPA guidelines for appropriate design and methodology (Stephan *et al.* 1985). Table 20 gives the geometric mean of the three lowest concentrations at which chronic effects were detected (the new CECTs) for each metal, along with the prior CECTs that were, in part, extrapolated from studies of acute effects. The 1988 revision of the Ocean Plan established new regulatory requirements for discharges into the ocean, based on the new CECTs.

Measurement of metallic concentrations in field samples of seawater is difficult, due to the extremely small quantities of metal generally found in natural seawater samples. Contamination and differences in analytical techniques can lead to widely varying estimates of metal concentrations in seawater (Bryan 1984; SCCWRP 1973). Of importance here is that estimates of "natural" concentrations of metals in seawater have declined as analytical techniques were refined (Bryan 1984).

Virtually all of SCE's values for seawater concentrations of metals were below detection limits in 1985-1987. Because of the declining trend in recorded metal concentrations in seawater, we do not place much confidence in comparisons of metal concentrations recorded by SCE in 1975-1980 with laboratory estimates of metal toxicities. It is worth noting that the average concentration of copper in sea water samples during 1978 - 1980 exceeded the CECT both at the control and at the impact locations (compare Table 19 with Table 20). Our confidence in these metal concentration data is further reduced because of the extremely high copper concentrations occasionally detected both near and far from Unit 1. For example, concentrations of 3200 μg/l (1.5 km upcoast of SONGS), and 100 μg/l (6.6 km downcoast of SONGS) (SCE 1981) suggest that there may be a problem with contamination in these early data.

# 6. ESTIMATES OF METALLIC RELEASES IN SONGS EFFLUENTS

## 6.1 Summary

The routine operation of SONGS appears to involve the addition of metals to the local marine environment. Sampling of effluents indicates that metal concentrations in SONGS' discharges were usually well below concentration standards in the National Pollutant Discharge Elimination System (NPDES) permit. These standards are based on "conservative estimates of chronic toxicity" (CECT) established by the State Water Resources Control Board (SWRCB).

Values in excess of the regulatory standards are occasionally reported from SONGS. For example, from 1980 - 1986, two of 19 values for chromium concentrations in the combined discharges of Units 2 and 3 reported by SCE to the Regional Water Quality Control Board were above the standards set in the NPDES permit. One of these values was also high enough that the CECT in the receiving waters could have been exceeded. Due to the sparseness of the sampling regime, and lack of replication, however, it is not possible to determine whether these elevated levels reflect rare and intermittent events, sampling variability, or more routine emissions. These different possibilities lead to quite different conclusions regarding the extent of metallic emissions from SONGS, and they cannot currently be distinguished based on the effluent sampling data. Other information reported in previous sections suggests that the occasionally high concentrations seen in the discharges have not led to consistently high concentrations in the receiving waters.

Although a search of available information has not uncovered any substantial sources of toxic metals within the SONGS facility, we have not been able to obtain all the information needed to perform a "mass-balance" analysis, in order to firmly rule SONGS out as an important source of such materials. There has been particular concern over the amount of chromium discharges by SONGS because preliminary research indicated that there might be an association between unusual patterns in egg production among sand crabs living on beaches near the station, and high concentrations of chromium in the tissues of specimens from those same areas (Section 4). The MRC sponsored two studies which used information on the chemical and mechanical aspects of operating SONGS in order to evaluate the station as a source of metallic emissions into the ocean. These reports encountered difficulties in accurately assessing the magnitude of releases by SONGS for chromium as well as other metals. Still, liberal estimates of mass emission discharges of chromium from chromated systems within SONGS amount to less than two metric tons per year. This amount is far below the effluent limitation requirement specified in the NPDES permits for SONGS Units 1, 2, and 3. These studies do not provide evidence that metals are typically released at such high concentrations that they reach toxic levels in the receiving waters. However, two potential sources of chromium within SONGS, chromium-based paints and erosion or corrosion of metal structures containing chromium, were not included in the calculations.

## 6.2 Introduction

Concerns about the concentrations of metals contained in SONGS' effluents arose when some ecological analyses suggested that there might be a relationship between reproduction in sand crabs and the concentrations of metals in their tissues (Wenner 1982a; Wenner 1982b; Siegel and Wenner 1984; Wenner 1988). The MRC sponsored studies of metal concentrations in sand crab tissues during 1983 and 1986, and preliminary analyses revealed possible relationships between tissue chromium, iron, and manganese concentrations, and distance from SONGS (Section 4; also see Final Technical Report A. Sand Crabs). Attention here is focused on chromium because it is generally considered the most toxic of these metals, and several of the systems within SONGS produce chromium-containing waste products. Since sand crabs from some of the beaches near SONGS also showed indications of anomalous patterns in egg production, there was concern that 1) elevated concentrations of metals in sand crab tissues might be affecting sand crab reproduction; and 2) SONGS might be responsible for these higher tissue concentrations because its effluents contain elevated concentrations of metals.

This report examines how, and how much SONGS might be elevating metal concentrations in the seawater passing through its cooling system. Here we focus on attempts to directly quantify the chemical contents of SONGS' discharges. Our data come from several sources. First, the MRC sponsored two engineering studies aimed at identifying potential sources and magnitudes of metallic discharges from SONGS. We report their findings, and discuss them in light of additional information provided by SCE regarding the use of chromated products in SONGS. Second, we examine metal concentrations in effluent samples collected by SCE from the discharges and in-plant waste streams of SONGS. These values are taken from SCE's semi-annual reports to the Regional Water Quality Control Board. Finally, we review the state water quality regulations, and the resulting limitations placed on SONGS for discharge concentrations. The estimates of potential metal releases from the engineering studies are contrasted with those legally permitted by current governmental standards. We make these comparisons because the standards are based upon conservative estimates of toxicity levels (State Water Resources Control Board 1983, 1988).[1]

## 6.3 Engineering analyses of potential releases of metals from SONGS

The MRC sponsored two engineering studies designed to estimate the magnitude of metallic releases from SONGS into the local seawater (SAIC 1986, MHB 1987; reproduced here as Appendix D). Both of these studies focused their attention on potential releases of chromium, iron, and manganese, for the reasons described above (Section 6.2). The primary concern was over chromium, generally the most toxic of these metals (Bryan 1984).

The two engineering reports show huge discrepancies in their estimates of chromium releases from the station, indicating that information regarding metal emissions from SONGS in particular, and nuclear generating stations in general, is not readily available. Indeed, one recent book on the environmental aspects of nuclear power devoted virtually no space to the subject of non-radioactive, metallic effluents (Eichholz 1985).

[In the following discussion, concentrations are specified in metric units, and mass emissions rates are given in U.S. equivalents. This is in agreement with other usage, in particular the regulatory standards in the NPDES permits.]

SAIC (1986) concluded, using data from water samples collected by SCE in the vicinity of the outfalls, that chromium releases by SONGS would not

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[1] New standards have recently been adopted (State Water Resources Control Board 1988). However, these changes do not affect our conclusions. Only the CECT for Ni and Pb decreased substantially, and the CECT for Cr increased (See section 5).

significantly elevate local seawater above ambient concentrations for that metal. This is based on estimates by SCE that Unit 1 will release a maximum of 6 lbs of chromium per day, into about 504 million gallons of cooling water (SAIC 1986). This would lead to a concentration of 0.0014 mg/l in the effluents of Unit 1, as opposed to natural concentrations of approximately 0.00025 mg/l of chromium in nearshore seawater. Since the longshore current transports huge volumes of water past the SONGS discharges, further diluting the effluents, SAIC concluded that releases from Unit 1 would lead to a negligible increase in the chromium concentration of local seawater. For Units 2 and 3, SAIC uses SCE's estimate of chromic acid concentrations being 0.003 mg/l at the outfalls, to again conclude that local chromium concentrations would not become significantly elevated over ambient seawater concentrations, following dilution of the discharges by surrounding waters (SAIC 1986). For manganese, SAIC concluded that negligible amounts (up to a milligram per year) might be emitted in the forms of radioactive waste products, $^{54}$Mn and $^{56}$Mn, and that there were no other known sources of manganese discharges within the plant. Note that radioactive isotopes of manganese are decay products from other elements (principally Cr and Fe) and their presence does not imply a significant source of stable Mn releases from SONGS. SAIC's (1986) overall conclusion was that "it is not recommended...that [further qualitative and quantitative estimates of metals discharges from SONGS into the marine environment] be conducted due to the relatively low levels of input into the ocean."

MHB (1987) used a different approach in estimating potential discharges of metals from SONGS. They noted that there are three sources of metals in the plant which might be discharged into the effluents: 1) chemical additives, used primarily as anti-corrosion and anti-fouling agents; 2) corrosion and erosion of physical components of the plant; and 3) concentration and discharge of metals in natural seawater or municipal waters used by the station. Of these, the first two sources are considered to be of much greater magnitude than the third, but sufficient information to develop an estimate of mass emissions are only available for the chemical additive sources (MHB 1987). MHB's mass emission estimates thus do not include potential inputs from the other sources of metal.

MHB (1987) provided estimates of mass emissions for chromium, copper, iron, and manganese, although their report focused on clarifying chromium releases, for the reasons described above (Section 6.2). They found no evidence for sources of manganese within the plant. MHB estimated releases of copper and iron at only 6 lbs and 60 lbs per year, respectively. These estimates for copper and iron are minima, however, based solely on information regarding discharge concentrations in the steam generator blowdown, i.e. drainage from the steam generator (MHB 1987). The efficiency of various demineralizing systems, and the extent of corrosion could both substantially influence the levels of release for these metals, but inputs from these sources could not be estimated without additional information (MHB 1987).

Sources of chromium within SONGS have included potassium chromate and chromic acid, which are used within several "closed" systems as corrosion inhibitors, but could possibly leak into the plant's effluents. MHB obtained information submitted by SCE to the NRC regarding the chromate concentrations used to prevent corrosion in these systems. By combining these figures with estimates of leakage rates into SONGS' flow-through cooling system, MHB (1987) derived estimates of annual mass emissions of chromium into the local seawater. They estimated that SONGS could be discharging anywhere between 5467 and 19,139 lbs of chromium into the ocean per year, depending on the chromate concentration used in the systems. These figures include leakages from the two largest chromated systems within each of the SONGS units, the turbine plant cooling water system (TPCW) and the component cooling water system (CCWS). Leakages directly from these closed systems into the flow-through cooling waters, and indirectly from floor drains which eventually discharge into the flow-through system, are both included in this estimate (MHB 1987). However, MHB mistakenly assumed that a number of closed-loop systems within SONGS were chromated, when in fact they were not.[2] The only chromated systems within SONGS were the Unit 1 TPCW and CCWS, and the Emergency Diesel Generators for Units 2 and 3. With this information, we can use MHB's estimates to predict chromium releases from SONGS of between 966 and 2675 lbs/yr.

The MHB estimate of annual chromium releases is based on several critical assumptions. The calculations use estimates of the *mean* chromium concentrations maintained within the systems for effective corrosion inhibition, and of the *maximum* leakage rate of these chromated wastes into plant effluents (MHB 1987). We cannot determine whether these values are representative of normal operating conditions. SCE states that chromates are maintained at different concentrations, depending on the specific cooling system involved.[3] In addition, the most substantial inputs of chromated wastes into SONGS' effluents may not occur from *chronic* leakages of the closed-loop systems. When repair activities require that a cooling system be drained, a new batch of coolants may be added (MHB 1987), or the same coolants are reintroduced into the system (personal communication from E.S. Medling, Health Physics and Environmental Group, SCE, to B.J. Mechalas

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[2] This information is based on responses by SCE to MRC queries, which are included in Appendix E.

[3] This information is based on responses by SCE to MRC queries, which are included in Appendix E.

11/3/88). A mass release or spilling of this chromated material into the cooling waters would lead to a pulse of high concentrations.

Several potential sources of chromium emissions were not included in MHB's estimate, either because they could not be quantified, or because they are probably relatively insignificant. Potential inputs from the chromated, closed-loop Emergency Diesel Generators for Units 2 and 3, which contain a total of about 80 lbs. of chromium (MHB 1987), were not considered, as the systems would have to be drained numerous times to become substantial sources of chromium releases. Also not included in the MHB estimate is the potential input of chromium from corrosion of plant structures. Several of the closed-loop systems are constructed with alloys, such as stainless steel or inconel, consisting of 15-20% chromium, although the main, flow-through cooling system itself is constructed of titanium and concrete. The magnitude of inputs from corrosion and erosion will depend on the total tonnage of the plant structures containing chromium alloys, and the extent to which such products could enter the flow-through cooling system. In general, corrosion rates will be low (probably <0.03 mm/yr; USAEC Final Environmental Statement for Unit 1, 1973). Another potential chromium source that was not included in MHB's estimate is that arising from sludges of anti-fouling or anti-corrosion paints which commonly contain heavy metals, including chromium.

Still, the chromated waste sources considered in MHB's estimate of annual releases should represent a significant component of the total releases of chromium from SONGS (MHB 1987). Since several potential sources of chromium within SONGS were not addressed, it is possible that our update of MHB's estimate of annual chromium releases is an underestimate. Information provided in reports by SCE to the RWQCB-SDR, however, indicate that this is probably not the case for systems using potassium chromate. Records of the yearly consumption rates of potassium chromate, the major source of chromated wastes within SONGS, constitute another estimate of yearly emissions of chromium from the plant. From 1978 to 1984, Unit 1, the major source for chromated wastes at SONGS, consumed roughly 50 lbs. of potassium chromate per year, which would contain about 14 lbs. of chromium (SCE semi-annual effluent reports to the RWQCB-SDR, 1979-1985). These data indicate that the mass emissions figure derived by MHB may be a vast overestimate of chromated waste leakage into effluents. The likely reason for this is that the leakage rate used by MHB was a maximum rate and not an average rate estimated during the actual operations of SONGS. We have been unable to locate information regarding annual inputs of chromic acid to SONGS (MHB 1987), but it seems that potassium chromate is currently used in its stead. Also, we could not find information regarding annual chromate additions to the Emergency Diesel Generators, but as mentioned earlier, these are almost certainly relatively insubstantial.

In response to MHB's report (1987), Southern California Edison has provided further information clarifying the status of chromium wastes from SONGS, particularly with regard to the disposition of "spent" chromate wastes from the closed-loop systems.[4] Paint sludges are classified as hazardous wastes, and are consolidated and shipped offsite per state and federal regulations. Spent chromated wastes are disposed of either through discharge into the ocean according to National Pollutant Discharge Elimination System standards (see Section 6.4), or as hazardous wastes. If disposed of as a hazardous waste in the form of "aqueous solvents with metals" (hazardous waste category 132), the total chromium concentration is not to

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[4] The following information is based on responses by SCE to MRC queries, which are included in Appendix E.

exceed 500 parts per million. Thus, even though SONGS typically generates this type of waste in extremely high volumes and tonnages, only relatively small amounts of chromium could potentially leak into the station's effluents from this source. SCE records of chromate disposals in aqueous solvents from 1981-1983 indicate that a maximum of approximately 30 tons of wastes were disposed of during 1981, containing roughly 30 lbs. of chromium (assuming the maximum permitted concentration of 500 ppm of chromium). The chromium contents of wastes in subsequent years through the present were less than 10 lbs. per year, despite generally large volumes of wastes (e.g., 26,380 gals. in 1983).

In spite of the information discussed above we are unable to firmly rule out SONGS as an important source of chromium, based solely on the known uses of chromium within the plant. We have been unable to estimate the amount of chromated paint used in SONGS or how much chromium from this source may eventually reach the ocean. Although SCE has kept records of how much paint they purchase, they were not able to provide us with the amount of paint used by contractors, and it is likely that this is a substantial portion of the total. In addition we have not been able to estimate the rate of chromium release from the corrosion or erosion of chromium containing structures within SONGS. Although estimates of corrosion and erosion rates are available and indicate a loss of less than 0.03 mm/yr from these surfaces, we can not estimate the mass emissions from this source since we have been unable to determine the total surface area and chromium content of structures exposed to such erosion and corrosion.

## 6.4 Estimates of metal concentrations in emissions from the SCE sampling program

Southern California Edison takes water samples of its effluents biannually, and submits them to a lab for chemical analysis. The concentrations of nine metals are assessed, including chromium. The results are then reported to the Regional Water Quality Control Board (RWQCB) in compliance with the National Pollutant Discharge Elimination System (NPDES) permits for Units 1, 2, and 3. SCE's reports to the RWQCB indicate that SONGS is generally in compliance with the standards set in its NPDES permits, but that occasionally effluent concentration limits are exceeded for one or several of the metals.

The NPDES permits for SONGS Unit 1 (permit no. CA0001228), and Units 2 and 3 (permit nos. CA0108073 and CA0108181, respectively) stipulate receiving water concentration limits for each of nine metals. These concentrations were derived from standards contained in the 1983 Water Quality Control Plan for the Ocean Waters of California (The Ocean Plan, State Water Resources Control Board 1983). These were based on studies measuring the acute and chronic toxicity of the metals in question, and were not changed in 1988 when the standards in the Ocean plan were revised based on additional information on chronic toxicity (see below). Three emission concentration limits for receiving waters were specified in the permits for each metal: an instantaneous maximum concentration, a daily maximum concentration, and a 6-month median concentration. These values specify concentrations following initial dilution of effluents; they are also used to calculate the allowable mass emissions rates for waters from the combined discharges and the in-plant waste streams (State Water Resources Control Board 1983; and see NPDES permits). In practice, compliance has been judged by comparing the concentrations in the combined discharges with the concentrations that would lead to a mass emission surpassing the allowable amount. In reports by SCE starting in mid-1985, measured concentrations have been compared with the maximum instantaneous concentrations based on the mass emission limits in the NPDES permit. This instantaneous limit for chromium concentrations which is applied to water samples from the combined discharges of Units 2 and 3 is 220 μg/l. In comparison, the six month median limit is 22 μg/l and the daily maximum limit is 88 μg/l. These latter two standards have been applied to in plant waste streams of Units 2 and 3 starting in 1985. Prior to mid-1985, concentrations in the combined discharges were compared with much stricter standards that were established in the 1976 NPDES permits for SONGS Units 1, 2, and 3, and no inplant waste stream standards for metals were in force. These standards for the combined discharges required that concentrations of chromium in the effluents not exceed 5 μg/l 50% of the time and not exceed 10 μg/l more than 10% of the time. In general, however, the detection limit was at 10 μg/l, thus only allowing comparison with the less stringent, "more than 10% of the time" limit.

Chromium concentrations reported by SCE to the RWQCB were generally not higher than the standards to which they were compared. Occasionally, however, they exceeded the standards. For example, we reviewed records of metal emissions in samples of SONGS effluents from 1978-1986, and found concentrations ranging from 3.7 to 400 μg/l of chromium in the combined discharges (SCE semi-annual effluent reports to the RWQCB, 1979-1987). While the majority of concentrations in the combined discharges were 10 μg/l or lower, and well within the current instantaneous discharge limit of 220 μg/l, occasionally high values indicate that chromium releases from SONGS may become somewhat elevated under certain circumstances. Between 1980 and 1986, we found two violations of chromium concentration standards in 19 records. These violations occurred at a time when the earlier more stringent comparisons were in force, and only one of them (400 μg/l) would exceed the current instantaneous standard, or lead to concentrations in receiving waters exceeding the current "conservative estimates of chronic toxicity" (CECTs) (see Section 5). However, given that small samples of effluents are taken only twice a year, it is impossible to determine whether the occasionally high values reflect intermittent releases of water with high metal concentration, or are the result of sampling variability, or are representative of more chronic events. Violations of standards are generally not flagged in reports to the RWQCB, and there often is no discussion of the circumstances that might account for the elevated concentrations.

The effluent data do not provide evidence of chronic contamination by high concentrations of chromium or other metals. However, the current instantaneous standard for chromium concentration (220 μg/l) theoretically allows the releases to raise the concentration of chromium in receiving waters to 20 μg/l, assuming a 10 to 1 initial dilution. This concentration is in excess of the current CECT for chromium of 18 μg/l. Since measurements of the combined discharges are taken only once every six months, a comparison with the six-month median standard (contained in Table B of the Ocean Plan), as is currently done for samples of the in plant waste stream, seems more appropriate. In addition, it should be kept in mind that the CECT values do not take into account the possible build up of metals in a local area via contamination of the sediments (SWRCB 1988).

It is useful to examine potential releases of chromium from SONGS in the context of the mass emissions limitations specified in the NPDES permits. Using Unit 3 as an example, and assuming normal operational flow volumes, emissions of chromium in the combined discharge is not to exceed an instantaneous maximum of 2558 lbs/day. For in-plant waste streams, conditions are more stringent, with allowances of 256 lbs/day for the 6-month median, and a daily maximum of 1023 lbs/day. Considering that our modification of MHB's estimate of chromium releases from SONGS has an upper value of less than 3000 lbs *per year*, it appears that SONGS will probably be well within the limits specified in its operating permits, unless there are large and unquantified sources of this metal at SONGS. It is also worth noting that the use of chromate corrosion inhibitors, potentially the largest source of chromium in the plant, has been phased out over the past few years.[5]

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[5] This information is based on responses by SCE to MRC queries, which are included in Appendix E.

# 7. EFFECTS OF RADIOLOGICAL DISCHARGES FROM SONGS ON THE LOCAL MARINE BIOTA

## 7.1 Summary

Under normal operating conditions radiological emissions from SONGS seem unlikely to produce measurable ecological effects on the local marine biota. We base this conclusion primarily on two observations: 1) *maximum* estimates of routine radiological releases from SONGS would result in exposures of local marine organisms to activity levels approximately 100 times lower than the *lowest* levels found to produce any sublethal effects in controlled laboratory studies; and 2) measures in tissues of organisms collected near SONGS reveal that generally less than 10% of the total internal activity is due to artificial radionuclides released by the plant, with the remainder coming from natural sources of radiation.

We present these assessments with several caveats: 1) species can differ substantially in their response to radiological pollution due to differences in absorbed dosage and tissue sensitivity; 2) the toxicological effect of contamination depends on the specific identities of the constituent radionuclides, since these can emit different types of radiation containing different amounts of energy; and 3) little work has been done on the biological effects of chronic, low dose rate exposures to radiation, effects on low fecundity species, synergistic effects of multiple contaminants, or the effects of exposure for multiple generations. Nevertheless, because the radiological emissions from SONGS are so much lower than the levels found to produce adverse effects in past studies, we conclude that there is no reason to suspect that radiological emissions from SONGS have significant ecological impacts on the marine biota. In order for our general conclusion to be incorrect, the currently accepted estimates of doses and dose rates at which biological effects occur would need to be off by a very wide margin. If this were the case we would then expect substantial biological responses to natural variations in activity, and radiological releases from SONGS would have an additional incremental effect that might difficult to detect.

## 7.2 Introduction

The routine operation of SONGS results in the production of radioactive wastes. The vast majority of these wastes are isolated and stored onsite or conveyed offsite to toxic waste dumps. Some radiological wastes, however, can enter into SONGS' effluents through leakages and the corrosion of structural components that have become radioactive due to neutron activation. More than 100 different isotopes may be released from SONGS, although most of these only in negligible amounts. Since radiation is known to have harmful effects on living organisms, releases of radionuclides from SONGS' effluents might potentially affect the local marine community.

In this section we examine information regarding radiological releases from SONGS, and evaluate these data in light of several recent reviews of the effects of radioactive contamination on the marine environment. Our primary concern is in evaluating whether concentrations of radionuclides released by SONGS are having ecological effects on the local marine biota, but none of the MRC's studies at SONGS were specifically designed for this purpose. Moreover, extremely few field studies have examined the effects of exposure to radiation on natural populations or communities. This necessitates our adopting a less direct approach to the question of the effects of SONGS' radiological emissions on marine organisms. While field studies are relatively scarce, laboratory studies have assessed the effects of radiation on numerous aquatic organisms. These studies have the advantages of control of exposure levels and rates, and control over potentially critical aspects of the environment, such as salinity, temperature, and dissolved oxygen. Laboratory studies also enable the scientist to more sensitively detect a broad range of potential effects on organisms, including changes in fecundity and mortality, or changes in genetic and cellular characteristics.

It is possible to extrapolate from the results of laboratory studies on radiation to the potential effects on organisms in the field. A recent review (Woodhead 1984) presents estimates of the dose rates of exposures for various marine organisms arising from background levels of radiation, and additional exposure from diet, seawater, and benthic sediment sources in the vicinity of several nuclear generating facilities. We do not have corresponding estimates of exposure rates for marine organisms living near SONGS. Instead, we contrast the levels of activity in emissions from SONGS and sediments near SONGS, with the levels found in seawater and sediments in the region of the nuclear facilities examined in the review article. Although the dose rate estimates presented in Woodhead (1984) are site-specific, we feel that the general similarity in emissions levels from the different nuclear facilities justifies their use as rough approximations of the exposure rates of organisms near SONGS. These exposure rates can then be compared with those found to have biological effects in laboratory studies.

We first provide the reader with a brief review of some fundamentals of radiobiology. Individuals already familiar with this material can skip the section (Section 7.3) with no loss of continuity. We then present the estimates of radiological emissions into the ocean for several nuclear facilities, including

SONGS. These are followed by an examination of activity levels in sediments, seawater, and the tissues of selected marine organisms from the region of the nuclear facilities, which are contrasted with levels from more pristine conditions. These figures can be used to calculate the approximate doses and dose rates of radiation to organisms living in the vicinity of the facilities. These estimates are compared with the levels leading to pathologies in organisms in laboratory studies. Finally, we examine the evidence from field studies for ecological effects of radiological releases on aquatic communities. We relate these findings to the likelihood that operations of SONGS will have a measurable ecological impact on the local marine biota as a result of normal releases of radioactive effluents. By normal we mean within the parameters set by the relevant permits and operating licenses, and excluding disaster scenarios of the type experienced at Three Mile Island or Chernobyl nuclear generating stations.

## 7.3 Some fundamentals of radiobiology

Exposure to radiation is damaging, in large part, because biomolecules can become ionized or attain excited states when bombarded by high energy waves or particles. Biological processes can then become disrupted, leading to a variety of potential effects, ranging from factors such as higher rates of mutation or chromosomal breakage, to impaired functioning of organs and organ systems--which can ultimately influence fecundity and mortality (Anderson and Harrison 1985, Woodhead 1984, Whicker and Schultz 1982).

Radiation can be quantified in a number of ways. The basic unit of activity is the *curie* (Ci), which is a measure of the number of nuclear disintegrations per second. Each disintegration is accompanied by the release of some form of radiation, which can be characterized by several features, including mass, charge, and energy content. The released particles can vary considerably in mass, ranging from $\alpha$ particles (helium nuclei) with relatively high mass, to $\beta$ particles (electrons or positrons) with relatively low mass, and $\gamma$ rays (photons) with no measurable mass. In addition, these different particles each have different ranges of energy content. Mass, charge, and energy content will affect the nature of the interaction of the radiation with matter. The curie does not differentiate among these types and energy levels of radiation, but provides a general measure of activity. Our measures of environmental activity levels will be presented as *specific activities*, i.e., curies per gram of substance.

We are primarily interested in the effects of the interaction of radiation with living tissues. Two measures are relevant in quantifying this extent of exposure to organisms: *dose* and *dose rate*. Dose or dosage represents the amount of radiation energy absorbed per weight of substance, and is usually expressed in *rads*, equivalent to 100 ergs of energy absorbed per gram of tissue. Dose rate is simply the dose per unit of time, often expressed as dose per hour, day or year. In this report, we express dose rate in $\mu$rad/hr.

Most studies of the biological effects of radiation have examined the implications of varying doses administered as acute exposures. Generally speaking, damage to tissues will be directly related to the quantity of absorbed radiation or dose. For a given dose, however, radiation delivered as an acute exposure will tend to do more damage. Unfortunately, few studies have examined the biological effects of chronic exposure to low levels of radiation, which would more closely reflect the pattern of exposure of marine organisms near the outfalls of nuclear facilities, such as SONGS. Comparison of chronic exposures with results from acute exposures could be misleading, even when total accumulated doses are similar, because organisms may be able to mobilize their immune system, or repair genetic and tissue damage when exposed to lower *dose rates*. Such responses would be less feasible under higher dose rates, where the extent of biological damage would more severely impair any restorative capabilities of organisms.

Measurement of dose and dose rate to organisms in their environment is not simple. These quantities will be affected by the organism's shape and size, and a number of its behaviors, including dietary habits and orientation to substrate. It is possible to develop mathematical models that take into account some of these factors, enabling one to convert environmental activity levels into estimates of dose rates for several categories of marine organisms (Woodhead 1974, 1984). Because these formulae incorporate rather specifically the identities of the different sources of activity at a given site, the corresponding estimates of doses and dose rates are site-specific. In addition, these values are calculated for several generalized categories of marine organisms, and will only roughly approximate the actual dose rates for specific individual organisms. Quantification of the potential biological effects of radiation can be further refined by considering the microdistribution of energy absorption within tissues, and the density of energy transfer (both incorporated into measures of *rems*), but here we will use the more common unit of exposure, the *rad*.

Of course, organisms are continually exposed to background radiation arising from natural sources. Organisms living close to the ocean's surface will be exposed to $\gamma$ radiation from cosmic rays (Woodhead 1984). Within seawater, $^{40}K$ is by far the predominant naturally occurring radionuclide, usually accounting for greater than 95% of the total activity (Woodhead 1984). Natural concentrations of radionuclides in the seabed will vary depending on the nature of the underlying strata and local inputs from terrestrial runoff, but represent a potentially important source of exposure, especially for marine organisms living on or within the benthos. Finally, due to concentration factors, organisms and specific tissues within organisms, may exhibit higher levels of activity than those in the environment. These "concentration factors" of certain radioisotopes over ambient levels can become especially high when the elements in question are nutritionally important, or chemical analogues of essential nutrients that can be taken up by the same biochemical pathways. Such *internal activity* can accumulate due to uptake from seawater and dietary components, and can comprise a substantial fraction of the organism's total exposure to radiation (Woodhead 1984).

The world's oceans have received substantial inputs of artificial radionuclides as a result of atmospheric and underwater detonations of nuclear weapons. Although activity levels in the ocean from fallout have been generally declining since the Test Ban Treaty of the mid-1960's (Eichholz 1985; Whicker and Schultz 1982), they must still be considered as part of the background level above which contributions by nuclear facilities such as SONGS are to be evaluated.

## 7.4 Magnitude of radiological discharges from SONGS relative to other sources

We first contrast the levels of radiological discharges from SONGS with those from two other nuclear generating stations and a nuclear reprocessing plant that have been studied intensively for many years (Woodhead 1984). Radiological discharges from the gas-cooled Bradwell nuclear power plant are due to leaked fuel products from spent-fuel storage ponds (Woodhead 1984). The Oyster Creek power plant is more similar to SONGS in that its radiological releases are primarily from leakage of reactor coolant waters into the condenser cooling waters. Both of these plants have radioactive emissions on the same order as those from SONGS, and all three generating stations have emissions *far below* those from the reprocessing plant, Windscale (now called Sellafield, but we will refer to the plant by its former name for consistency with earlier studies) (Table 19). We emphasize that the main purpose of our comparisons of the activity near SONGS with other nuclear generating stations, and with Windscale, is to indirectly gauge the dose rate that organisms near SONGS are exposed to. It is not our purpose to argue that the release of radiation from SONGS is either high or low in comparison with what it should be for a nuclear generating station of its type. It is thus largely irrelevant that these other sources of radiation differ in a number of important physical aspects from SONGS.

Using the minimum estimates of discharges from Windscale and the maximum estimates of releases from the generating stations, we calculate the total activity of radiological discharges from Windscale each year to be about 300 times higher than annual releases from SONGS and Bradwell, and 2,000 times higher than discharges from Oyster Creek. These figures include contributions from tritium (T), which is often the most abundant radionuclide released in plant effluents in the form of tritiated water, HTO. Tritium is believed to be the most innocuous radionuclide, however, and discharge standards are higher for it (Osterberg 1985). Active isotopes of noble gases are also a common by-product of nuclear facilities, but these elements are chemically inert, and generally don't tend to become bioaccumulated or bioconcentrated (Whicker and Schultz 1982). By excluding tritium and other dissolved gaseous releases from the totals, the margin between radiological discharges from Windscale and the generating stations becomes even larger: about 1,000 to 14,000 times more radiation is released per year by the reprocessing plant, Windscale, compared with the three power plants: Bradwell, Oyster Creek, and SONGS (Table 19). Again, these margins are conservative, since we have used the maximum estimates for releases from the nuclear generating facilities, and the minimum estimate for releases from the reprocessing plant at Windscale.

The discharges listed on Table 19 must be interpreted in the context of background levels of radiation, as there are many natural sources of radiation in the environment (see Section 7.3). Potassium-40 ($^{40}$K) is the predominant $\beta$ and $\gamma$ emitter in seawater, typically occurring in concentrations of 320 pCi/l (Woodhead 1984). Assuming that SONGS discharges roughly $10^{12}$ liters of seawater per year, and using a liberal estimate of its total radiological discharges as 15.8 Ci/yr (excluding tritium and gases: Table 19), this represents an addition of about 15.8 pCi/l of artificially produced radionuclides to the entrained seawater, which is roughly equivalent to an increase in activity of 5% over the level due to naturally occurring $^{40}$K. Southern California Edison (SCE) assesses the activity levels in seawater sampled from locations near the discharges of Units 1, 2, and 3, on a monthly basis (see SCE: Annual Radiological Environmental Operating Reports (AREORs), submitted by SCE per technical specifications to the Nuclear Regulatory Commission). Concentrations of naturally occurring $^{40}$K account for most of the activity in these samples, and only rarely is there evidence of activity due to emissions from SONGS.

While SONGS emissions have only an insignificant effect on the activity levels in seawater, it is possible that plant-related radionuclides may accumulate in the local sediments and, thereby subject organisms to elevated levels of radiation.

Southern California Edison measures activity levels in beach sand, benthic sediments, and tissues of several marine species collected from sites near the SONGS discharges and from control stations at least 40 km upcoast of SONGS (e.g., AREOR 1986). These data indicate that SONGS-related radionuclides are not detected in beach sand and comprise only an insignificant component of the total activity in benthic sediments from stations near SONGS (Table 20). Similar to the pattern in seawater, naturally occurring, non-station related $^{40}$K is by far the most concentrated radionuclide in both shoreline and benthic sediments, typically followed in prevalence by naturally occurring isotopes of radium and thorium. Within the benthic sediments, $^{60}$Co was the only station-related radionuclide that occasionally showed detectable concentrations near SONGS, reaching concentrations roughly the same magnitude as some of the higher measures of natural activity from $^{228}$Th (Table 20). The maximum values for $^{60}$Co at the two Unit 1 stations were both recorded in 1981, and almost all the subsequent values from these stations were below 0.10 pCi/g (see AREOR 1986).

Activity due to station-related radionuclides is consistently evident in the tissues of marine species collected near SONGS (Table 21; also see AREORs). There is often a detectable, but relatively small, elevation in the tissue concentrations of $^{58}$Co, $^{60}$Co, and $^{137}$Cs, in organisms collected in the vicinity of the plant as opposed to control stations elsewhere (e.g. AREOR 1986). Two aspects of the data are of particular interest. First, activity levels in organisms from near SONGS are generally similar in magnitude to those in organisms collected near other nuclear generating facilities, but these are generally all much lower than the activities in tissues of organisms collected near Windscale (Table 21). Second, the relative contribution of station-related radionuclides to total tissue activity is quite small for specimens collected near the three nuclear generating facilities. The major component of specific-activity in tissues from these organisms is from naturally-occurring $^{40}$K.

In 1986, the MRC sponsored an analysis of radiological activity in sand crabs collected from beaches at varying distances from SONGS (Table 22; for further details see Final Technical Report A. Sand Crabs, Appendix B). These samples provide evidence of SONGS' radiological emissions through the presence of two plant-related radionuclides, $^{54}$Mn and $^{60}$Co. These activity levels are negligible with respect to the levels for the naturally-occurring $^{40}$K (Table 22). Activities measured by the MRC in sand crab tissues are generally lower than those reported by SCE for some subtidal crustaceans (Tables 21 and 22; also see AREORs).

## 7.5 Estimates of exposure, and effects of radiation on marine organisms

The preceding section has shown that radiological discharges from SONGS account for only a small proportion of the total activity in seawater, sediments, and tissues of marine organisms sampled near the station. Naturally occurring radionuclides, primarily $^{40}$K, usually account for the majority of the observed activity. We now evaluate the potential biological effects of the radiological discharges from SONGS. The evidence strongly indicates that radiological emissions on the order of those released by SONGS are very unlikely to lead to measurable ecological effects, or to more than negligible effects on individual physiology.

Since no studies have directly examined whether radiological exposures resulting from the operation of SONGS have biological effects, we first attempt to gauge, at least approximately, the dose rates experienced by organisms living near

SONGS, and then evaluate whether these dose rates are likely to have adverse effects. Woodhead (1984) presents estimates of the dose rates for several types of marine organisms living near two nuclear generating stations, Bradwell and Oyster Creek, and the nuclear reprocessing plant, Windscale (Table 23). Although these estimates are meant to be specific for the given type of organism at the particular site, we feel that the general similarity in tissue activity levels (Table 21), as well as in the total activity discharged per year (Table 19) at the different sites, justifies our using the estimates of dose rate from the two nuclear generating stations, Oyster Creek and Bradwell, as *rough* approximations of dose rates for organisms near SONGS.

It is necessary to relate these dose rate estimates to the likelihood of biological effects. Ideally, we would like to compare the evidence from studies measuring impacts of chronic, low-level exposures to radiation, similar to those experienced by organisms living near SONGS. Unfortunately, few studies have examined how organisms respond to chronic, low-level doses of radiation (Anderson and Harrison 1985; Woodhead 1984). We thus adopt the environmentally conservative approach of examining pathologies associated with doses administered under relatively high (acute) dose rate regimes, which are more likely to have adverse effects for a given dosage (see Section 7.3), as well as from studies of chronic exposures. The doses and dose rates that have led to adverse biological effects in laboratory studies are then contrasted with the estimated exposures for marine organisms near SONGS.

### 7.5.1 Estimates of dose rates for marine organisms living near SONGS

The large differences in radiological emissions from the Windscale reprocessing station compared with the nuclear generating stations (Table 19), are apparent in the estimates of radiation dose rates experienced by marine organisms in the vicinity of these different facilities (Table 23). Elevations in exposure to radiation due to the presence of nuclear generating facilities are very modest, ranging from a small fraction of the natural background, to a level roughly equal to the dose rate from background radiation (Table 23). Organisms living near the reprocessing plant, Windscale, on the other hand, experience dose rates elevated from 10 to 1000 times over natural background levels.

Woodhead (1984) measured *in situ* dose rates for plaice from the vicinity of Windscale by implanting dosimeters into the skeletal muscles of these benthic fish. The mean dose rate for recaptured individuals was 350 μrad/hr, with some specimens showing exposures up to 2500 μrad/hr (Woodhead 1984). These direct measures of dose rate are within the range of dose rates estimated from environmental activity levels for benthic fish at that site (Table 23).

The additional dose rates from α and β emitters in the sediments are listed parenthetically in Table 23, since these will vary widely depending on the morphology and behavior of the study organism (Woodhead 1984). However, the estimate of elevation in dose rate from α and β emissions in sediments due to the two generating stations (<2 μrad/hr) is far below the background levels of these emitters from natural sources in marine sediments (16-191 μrad/hr; Table 23). The potential elevation at Windscale from α and β activity accumulated in the local sediments as a result of the reprocessing plant can be substantial, however, exceeding natural background sediment levels by up to several hundred times (240-5950 $\mu$rad/hr; Table 23).

Given the similarity in discharge levels (Table 19), and in various measures of environmental radioactivity (Tables 20 and 21), it is likely that organisms living near SONGS will be exposed to dose rates roughly similar to those from the two nuclear generating stations (Oyster Creek and Bradwell), and very much less than those from Windscale. The elevation in dose rate due to emissions from SONGS is thus likely to be roughly similar in magnitude to the exposure from natural background radiation. But what is the evidence that the low levels of radiological discharges from SONGS, or even the much higher releases from Windscale, have an adverse effect on the local marine biota? We address this question next by examining results from studies relating radiation exposure to biological effects.

### 7.5.2 Estimates of biological effects of radiation exposure experienced by marine organisms living near SONGS

We now review the evidence for biological effects from exposure to different doses and dose rates. Most of the information reported here was obtained from two recent reviews of radiation effects on marine organisms (Anderson and Harrison 1985; Woodhead 1984). Studies have quantified the effects of radiation dose and dose rate on a number of biological features, including gross factors such as mortality rate and fecundity, as well as more subtle aspects such as frequency of chromosomal aberrations and sister chromatid exchange. We focus here on the *lowest* reliable levels of radiation doses or dose rates found to have biological effects, even if other studies have failed to detect effects at those same exposure levels using other organisms. We feel that this cautious and environmentally conservative approach is justified by our current lack of understanding of the detailed mechanisms underlying radiation damage. Much of the work on the effects of radiation exposure has been done on fishes, which appear to be some of the most radiosensitive aquatic organisms (Woodhead 1984). Accordingly, we mainly report results from experiments on fishes, since the radiation levels and dose rates producing effects are generally lower than those for aquatic invertebrates.

No adverse effects on fishes have been detected at dose rates below 20,000 $\mu$rad/hr. Developmental defects and lowered fecundity have been documented in fishes subjected to dose rates of about 21,000 $\mu$rad/hr and 24,000 $\mu$rad/hr, respectively (Woodhead 1984). Another species of fish exhibited lower numbers of spermatogonia at a dose rate of 42,000 $\mu$rads/hr, although this effect was not statistically significant (Woodhead 1984). A decrease in gonad size was detected in one species of fish at a dose rate of 120,000 $\mu$rads/hr, although more or less complete recovery took place after 30 days of continual exposure (Woodhead 1984). These results represent the lowest dose rates for which there is evidence of a biological effect, even though in several cases the findings were not statistically significant, or damage to the organisms was only transient.

A *maximum* estimate of the radiation dose rate for benthic fishes from Windscale, including exposure from sediment sources of $\alpha$ and $\beta$ emitters, is about 9500 $\mu$rad/hr (Table 23), which is 2-10 times below the levels that appear to result in minor damage to the fecundity or mortality of the most radiosensitive species yet tested. Given the order of magnitude correspondence between dose rates at Windscale and the lowest dose rates at which biological effects have been detected, we do not think that these results argue strongly against possible effects of radiation at Windscale. However dose rates at SONGS are much lower. For the Oyster

Creek nuclear power station, 225 μrad/hr is a maximum estimate of the dose rate to benthic fishes, again including α and β emitters in sediments. This level, which is probably roughly similar to the corresponding *maximum* dose rate near SONGS (see Section 7.5.1: estimates of dose rates), is 100 times lower than the lowest levels found to have sublethal effects. Discounting the highly variable contribution from α and β emitters in the sediments, the margin between the dose rates found to have effects, and those likely to be experienced by organisms near Windscale and Oyster Creek (representing an approximation of levels near SONGS), becomes even larger (Table 23).

Other aquatic organisms, aside from fishes, are also unlikely to be affected by the levels of radiological emissions from SONGS. A recent review of the effects of chronic and acute radiation on aquatic organisms concluded that there was no evidence for significant detrimental effects at the maximum level of discharge from Windscale, which is reported as 10,000 μrads/hr (0.240 rads/day) at the end of the outfall pipe (Anderson and Harrison 1985). This document includes evidence from studies examining genotoxic and developmental defects, as well as mortality and reproductive criteria. Tests on an aquatic snail revealed reproductive changes induced by continuous exposure to 27,000 μrads/hr, but there was no decrease in the total numbers of eggs produced (Cooley 1973). A recent study of a marine polychaete detected effects on reproduction after exposure to 21,000 μrad/hr (0.5 rad/day) for an entire life cycle (Harrison and Anderson 1988). This dose rate is the lowest level for which effects have been detected in an aquatic invertebrate, but it is still about 100 times higher than the *maximum* dose rate (including the maximum possible additions from the highly variable α and β emitters in sediments) estimated for areas near the nuclear generating facilities (Table 23).

We have one direct estimate of dose rate for organisms collected near SONGS. Dr. D. Woodhead, a noted authority on the biological effects of radiation, estimated the internal dose rate attributable to $^{60}$Co using the MRC sand crab data (Table 22; also see Final Technical Report A. Sand Crabs, Appendix B). The estimated dose rate of .012 μrad/hr (pers. comm., Dr. D. Woodhead) is far below typical levels for background radiation (Table 23). Thus, even though operations by SONGS lead to detectable levels of artificial radionuclides in the tissues of organisms near the station, these levels are extremely unlikely to have any adverse effect on the local marine biota.

The total dose absorbed by organisms is another factor that should be considered in evaluating potential effects of radiological exposure. For several of the studies cited above, exposure was chronic, so that the relative magnitude of dose rates can be used to estimate potential effects among organisms with similar lifespans. Indeed, for low-level chronic exposures, dose rate is probably more important than total dose in determining biological impact (Whicker and Schultz 1982). As mentioned earlier (Section 7.3), a dose accumulated over a longer time span will be less deleterious than the equivalent acute exposure. The lowest doses leading to effects were measured in some of the chronic exposure studies described above, primarily because acute exposures are rarely delivered at such low total doses. Fishes show evidence of adverse symptoms from acute exposures starting as low as 300,000 μrads, but there is also a report of change in physiological response due to a dose of only 20,000 μrads (Woodhead 1984). The first of these values is from a set of studies exhibiting inconsistencies that require clarification, while the second measure was an estimate of dose rate to a specific organ (Woodhead 1984). Consistent effects on mortality and fecundity in fishes begin to appear at doses above $1.6 \times 10^7$ μrads, although this figure is for acute exposures (Anderson and

Harrison 1985). Minimum doses having effects on invertebrates begin at even higher levels. Organisms living near SONGS would require *over eight years* of exposure at the *maximum* estimated levels in order to accumulate a total dose of about 1.6 x $10^7$ $\mu$rads. While many invertebrates do live this long, it is important to keep in mind that the figures discussed above are based on an estimate of maximum exposure, and the dose required to produce effects under acute exposure.

## 7.6 Evidence from field studies for ecological effects of radiation

There are only a small number of field studies in the aquatic environment that have attempted to directly assess whether local levels of radiation are leading to adverse ecological effects, i.e., changes in population or community characteristics such as abundance or diversity (reviewed in Anderson and Harrison 1985; Whicker and Schultz 1982; Woodhead 1984). The scarcity of field work quantifying radiation effects is understandable, given the difficulty in accurately assessing dose and dose rate, even under laboratory conditions, and the generally low exposure levels found in the natural environment.

We have already reported on some of the results from these studies in describing the biological effects of varying dose rates (Section 7.5). Some of the lowest radiation levels leading to effects were detected in field studies of chronic exposures. Donaldson and Bonham (1964; 1970; also see Bonham and Donaldson 1966) carried out a series of experiments in which they irradiated salmon eggs and fry in the laboratory, released these individuals into a river, and measured the return rates from the ocean and various morphological characteristics of the returning adults several years later. They found that the minimum dose leading to deleterious effects was 21,000 $\mu$rads/hr, administered for a total dose of 4.0 x $10^7$ $\mu$rads.

Consistently adverse effects over a broad range of life history characteristics were not evident, however, until the dose rate was elevated to over 400,000 $\mu$rads/hr, administered for a total dose of 8.1 x $10^8$ $\mu$rads (Woodhead 1984). These are essentially the only studies directly quantifying an ecological effect of radiation exposure in the field.

A maximum estimate of the exposure rate at Windscale (approx. 10,000 $\mu$rad/hr, including $\alpha$ and $\beta$ emitters in sediments) is about one-half the minimal dose rate (21,000 $\mu$rad/hr) found to produce deleterious effects in the studies by Bonham and Donaldson. For the nuclear generating stations, the maximum dose rate estimate (approx 225 $\mu$rad/hr) is one hundred times below this level. At the maximal exposures estimated for Windscale, it would take about 160 days to accumulate a dose of 4 x $10^7$ $\mu$rads--the minimum level found to produce deleterious effects in the studies by Bonham and Donaldson (Woodhead 1984). It would require over 20 years to accumulate this dose at the maximum exposure levels estimated for organisms living near the Oyster Creek nuclear power station, which should be roughly equivalent to exposures near SONGS.

Another set of studies has been done in White Oak Lake, which received radioactive wastes from a nearby generating station for many years. We reported above on the radiation levels found to affect fish (Trabalka and Allen 1977), an aquatic snail (Cooley 1973), and aquatic insect larvae (Blaylock 1966) living in White Oak Lake. These organisms showed some adverse effects at dose rates of about 25,000 $\mu$rad/hr or slightly higher, relative to control populations in a nearby, "unpolluted" lake. It is not clear, however, whether the abundance or composition of these populations have been affected. In addition, these studies did not control for other, non-radiological differences between White Oak Lake and the control lake, either due to the input of nuclear industrial wastes or other conditions. Other environmental factors, such as water level or water temperature, could also affect the quality of the habitat in the study lakes, so that biological differences between the two may not simply be due to the effects of radiation.

## 7.7 Conclusion

Extrapolating from the few existing studies to the situation at SONGS must be done cautiously, as numerous factors may influence the outcomes of studies. These include the sensitivity of the specific organism being studied to low concentrations of various metals and radionuclides; the duration over which the study examined for effects; the nature of the effects assessed-- changes in mortality and fecundity, or more subtle damage such as mitotic aberrations or mutation rate; the dose rate and total dose administered; and the nature of the radiological source-- whether it is an $\alpha$, $\beta$, or $\gamma$ emitter, its energy level, and particle charge (e.g. Woodhead 1984). A further problem arises in measuring the absorbed dose, which can be highly sensitive to organism size, morphology, and habitat preferences. With these logistic difficulties and complications in a laboratory controlled situation, it seems clear that accurate assessment of the ecological effects of low level radiological discharges into the ocean is even more difficult.

Nevertheless, it seems extremely unlikely that the radioactive effluents released from SONGS lead to measurable ecological effects. We have examined data on the activity of seawater, shoreline and benthic sediments, and the activity of tissues of various marine organisms collected from near SONGS, and in the vicinity of other nuclear facilities. These data reveal that elevations in radioactivity due to the presence of SONGS and other nuclear generating facilities generally represent only a small percentage increase over the concentrations due to natural background radiation. Studies relating dose rates and doses of radiation to biological effects also indicate that increased exposures due to emissions from nuclear generating facilities pose little threat to the health of local marine organisms. There is no evidence for even sublethal effects of radiation at the levels of release by the relatively "dirty" Windscale, and liberal estimates of dose rates in the region around SONGS are roughly 100 times lower than the *lowest* levels documented as leading to sublethal biological effects.

Putting aside the question of biological effects of radiation, the measurement of activity levels of radionuclides produced by SONGS in the tissues of organisms or in the sediments has potential for indicating the extent to which a given area is exposed to SONGS' effluents. This procedure would best be applied to sedentary organisms, to avoid confounding the spatial extent of the plume with movement of the organisms being monitored. Care would also need to be taken to ensure that the uptake rates of radionuclides did not vary spatially in response to other differences in the environment. These potential difficulties might be avoided by assaying sediments instead of organisms. However, in practice, activity levels of artificial radionuclides have usually been below detection limits in sediments, while station-related radionuclides are often detected in the tissues of organisms collected near SONGS.

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# 9.0 TABLES

Table 1

**Summary of California State Mussel Watch Program measurements of trace metal concentrations in tissues of Mytilus californianus, from the San Onofre outfall (1985-86), and other selected stations within the southern California bight (1977-86). The mean and range are given for dry weight concentrations in μg/g (ppm). Values for San Onofre are from populations outplanted for 4.9 months. Values for all other sites are from resident populations. From Hayes and Phillips (1987).**

| STATION (SMW NO.) | ALUMINUM | CADMIUM | CHROMIUM | COPPER | MANGANESE |
|---|---|---|---|---|---|
| San Miguel Is. E.<br>(501) | 17.8<br>(11.3-25.7) | 9.60<br>(6.9-12.0) | 1.50<br>(1.0-1.8) | 4.13<br>(3.2-5.4) | 2.3<br>(1.9-2.5) |
| Santa Barbara Is.<br>(504) | 91.5<br>(31-160) | 11.2<br>(8.5-15.2) | 2.03<br>(1.7-2.5) | 4.63<br>(4.3-5.0) | 3.9<br>(2.3-5.9) |
| Royal Palms<br>(662) | 215<br>(84-593) | 3.19<br>(2.3-4.4) | 5.36<br>(3.27-8.50) | 8.60<br>(6.8-10.5) | 10.0<br>(6.9--16.5) |
| San Onofre outfall<br>(744) (1/2/86) | 367 | 1.94 | 1.42 | 4.63 | 6.3 |
| Bodega Head (8/02/85) | 137.3 | 6.27 | 2.02 | 5.10 | 7.0 |
| Oceanside Beach<br>(750) | 674<br>(300-1579) | 1.55<br>(0.8-3.1) | 1.49<br>(0.9-2.6) | 6.90<br>(5.5-9.9) | 14.5<br>(7.8-24.3) |
| La Jolla<br>(832) | 246<br>(49-627) | 2.98<br>(2.6-3.6) | 1.88<br>(0.9-2.6) | 6.92<br>(4.9-8.0) | 6.2<br>(4.5-8.3) |

| STATION (SMW NO.) | LEAD | MERCURY | NICKEL | SILVER | ZINC |
|---|---|---|---|---|---|
| San Miguel Is. E.<br>(504) | 2.33<br>(1.7-2.7) | 0.123<br>(.081-.211) | 0.70<br>(0.6-0.8) | 0.646<br>(.517-.733) | 118<br>(96-133) |
| Santa Barbara Is.<br>(501) | 3.55<br>(2.9-4.3) | 0.134<br>(.079-.187) | 1.55<br>(1.5-1.6) | 0.951<br>(.637-1.43) | 148<br>(131-173) |
| Royal Palms<br>(662) | 10.9<br>(6.6-17.7) | 0.307<br>(.149-.533) | 2.10<br>(1.5-2.6) | 6.2<br>(3.3-9.2) | 250<br>(170-313) |
| San Onofre outfall<br>(744) (1/2/86) | 1.26 | 0.072 | --- | 0.112 | 90.3 |
| Bodega Head (8/02/85) | 0.93 | 0.192 | 1.98 | 0.108 | 83.1 |
| Oceanside Beach<br>(750) | 1.93<br>(1.06-3.80) | 0.142<br>(.007-.617) | 0.73<br>(.40-1.30) | 0.678<br>(.180-1.43) | 146<br>(90-246) |
| La Jolla<br>(832) | 16.8<br>(12.5-19.7) | 0.291<br>(.19-.45) | 1.13<br>(.80-1.3) | 7.24<br>(4.0-9.37) | 199<br>(171-230) |

# Table 2

**Elevated data levels (EDL's) for metal concentrations detected by the State Mussel Watch Program from stations all along the California coast, during 1977-86. Values represent the levels (μg/g, dry weight) which equal or exceed 85% or 95% of all measurements of that substance collected in organisms of the same species and exposure condition.**

| | RESIDENT CALIFORNIA MUSSELS | | | TRANSPLANTED CALIFORNIA MUSSELS | | | RESIDENT BAY MUSSELS | | |
|---|---|---|---|---|---|---|---|---|---|
| CHEMICAL | EDL85 | EDL95 | (N) | EDL85 | EDL95 | (N) | EDL85 | EDL95 | (N) |
| Aluminum | 424.52 | 646.98 | (370) | 690.23 | 909.95 | (358) | 826.80 | 1302.75 | (65) |
| Cadmium | 8.50 | 10.93 | (370) | 11.14 | 13.21 | (358) | 6.64 | 8.55 | (65) |
| Chromium | 3.31 | 4.61 | (370) | 4.07 | 6.34 | (358) | 3.45 | 7.17 | (65) |
| Copper | 8.64 | 13.48 | (370) | 19.30 | 39.31 | (358) | 16.30 | 35.10 | (65) |
| Lead | 9.17 | 22.34 | (370) | 10.85 | 22.54 | (367) | 23.63 | 49.83 | (65) |
| Manganese | 11.48 | 16.91 | (370) | 33.49 | 45.10 | (358) | 35.89 | 49.68 | (65) |
| Mercury | 0.40 | 0.73 | (364) | 0.39 | 0.52 | (349) | 0.40 | 0.67 | (63) |
| Nickel | 3.82 | 4.71 | (165) | 5.25 | 5.72 | (81) | 4.87 | 7.63 | (19) |
| Silver | 4.35 | 16.89 | (370) | 0.77 | 1.47 | (358) | 0.32 | 0.65 | (65) |
| Zinc | 231.98 | 270.30 | (370) | 329.57 | 426.86 | (358) | 355.26 | 479.23 | (65) |

## Table 3

**Metal concentrations in mussel tissues (μg/g dry wt.) from the MRC outplants in 1976-77 and 1986, and the State Mussel Watch Program for 1985-86. The MRC outplants were Bay Mussels (Mytilus edulis), and the SMW outplants were California Mussels (Mytilus californianus). Values for the MRC 1986 data are means (± one S.E.). "On" and "off" denote different time periods at the outplants in 1976-1977 (see Section 3).**

| STATION | CADMIUM | | CHROMIUM | | COPPER | | MANGANESE | | LEAD | | ZINC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ON | OFF | ON | OFF | ON | OFF | ON | OFF | ON | OFF | ON | OFF |
| **1976-77 MRC OUTPLANT** | | | | | | | | | | | | |
| 25 m south | 2.40 | 2.31 | 0.62 | 1.33 | 6.1 | 12.0 | 7.8 | 13.4 | 0.88 | 2.26 | 85 | 126 |
| 50 m south | 2.99 | 1.72 | 0.66 | 1.58 | 7.0 | 13.2 | 8.3 | 15.6 | 1.20 | 1.94 | 109 | 116 |
| 1600 m south | 2.34 | 1.60 | 0.33 | 1.34 | 5.1 | 8.4 | 4.8 | 12.4 | 0.93 | 1.46 | 78 | 103 |
| 12800 m south | 3.15 | 1.74 | 0.36 | 0.66 | 5.8 | 10.1 | 5.7 | 8.2 | 1.13 | 1.41 | 92 | 96 |

| STATION | CADMIUM | CHROMIUM | COPPER | MANGANESE | LEAD | ZINC |
|---|---|---|---|---|---|---|
| **1986 MRC OUTPLANT** | | | | | | |
| SMKU (~5 km upcoast) | 3.4±0.16 | 0.96±0.07 | 6.54±0.31 | 11.8±0.58 | 1.08±0.13 | 129.3±17.5 |
| SMKD (~4 km upcoast) | 3.6±0.30 | 1.59±0.03 | 6.45±0.26 | 18.0±1.05 | 1.40±0.16 | 114.3±3.5 |
| SOKN (<0.5 km upcoast) | 3.4±0.16 | 1.52±0.19 | 6.22±0.22 | 16.0±0.70 | 1.11±0.11 | 120±4.0 |
| Diffusers | 4.6±0.27 | 1.36±0.09 | 5.94±0.17 | 14.4±0.72 | 0.89±0.04 | 127±3.2 |
| SOKU (~0.5 km downcoast) | 4.6±0.41 | 1.30±0.05 | 6.04±0.19 | 12.7±0.60 | 0.81±0.27 | 132±21.0 |
| PAR (~5 km downcoast) | 4.0±0.31 | 0.89±0.03 | 5.24±0.05 | 9.1±0.56 | 0.60±0.01 | 112±6.7 |
| **1985-86 SMW OUTPLANT** | | | | | | |
| San Onofre Outfall | 1.94 | 1.42 | 4.63 | 6.3 | 1.3 | 90.3 |

# Table 4

**Outplant dates and description of conditions for MRC mussel outplant studies.**

| PERIOD | OUTPLANT DATES | SONGS OPERATIONS | CURRENTS | STATIONS (N) |
|---|---|---|---|---|
| 1976-1977 "OFF" | 12/27/76-<br>4/22/77 | Power (Unit 1): 5.7 %<br>Flow volume (Unit 1): 0.9 x $10^6$ $m^3/d$ | Data on direction and velocity of current available from Feb. 1, 1977. Mean current 0.004 cm/s downcoast. Current downcoast on average 47.5% of the days. | 25 m from outfall (1)<br>50 m from outfall (1)<br>1600 m from outfall (1)<br>12800 m from outfall (1) |
| 1976-1977 "ON" | 5/18/77-<br>9/21/77 | Power (Unit 1): 86.2%<br>Flow volume (Unit 1): 1.6 x $10^6$ $m^3/d$ | Mean current 4.0 cm/s downcoast. Current downcoast on average 68.9% of the days. | 25 m from outfall (1)<br>50 m from outfall (1)<br>1600 m from outfall (1)<br>12800 m from outfall (1) |
| | | | | |
| 1986 Study | 9/4/86-<br>12/31/86 | Power: Unit 1 - 56.2%<br>Units 2 & 3 - 79.9%<br>Flow volume: Unit 1 - 1.5 x $10^6$ $m^3/d$<br>Units 2 & 3 - 8.62 x $10^6$ $m^3/d$ | Mean current 3.3 cm/s downcoast. Current downcoast on average 70.6% of the days. | Distance from Diffusers:<br>SMKU (3) ~5 km upcoast<br>SMKD (3) ~4 km upcoast<br>SOKN (3) <0.5 km upcoast<br>Diffusers (3) --<br>SOKU (2) ~ 0.5 km downcoast<br>PAR (3) ~5 km downcoast |

## Table 5

**Biological variables and metal concentrations ($\mu$g/g dry wt.) for 1976-1977 MRC mussel outplant. "On" and "Off" designate different time periods for the outplants (see Table 4).**

| STATION (DISTANCE DOWNCOAST OF UNIT 1 DISCHARGE) | GROWTH RATE (mm $d^{-1}$) | | CD | | CR | | CU | | FE | | MN | | NI | | PB | | ZN | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ON | OFF | ON | OFF | ON | OFF | ON | OFF | ON | OFF | ON | OFF | ON | OFF | ON | OFF | ON | OFF |
| 25 m | 0.11 | 0.11 | 2.40 | 2.31 | 0.62 | 1.33 | 6.1 | 12.0 | 392 | 1100 | 7.8 | 13.4 | 0.94 | 1.71 | 0.88 | 2.26 | 85 | 126 |
| 50 m | 0.10 | 0.09 | 2.99 | 1.72 | 0.66 | 1.58 | 7.0 | 13.2 | 430 | 988 | 8.3 | 15.6 | 1.39 | 2.00 | 1.20 | 1.94 | 109 | 116 |
| 1600 m | 0.12 | 0.15 | 2.34 | 1.60 | 0.33 | 1.34 | 5.1 | 8.4 | 149 | 785 | 4.8 | 12.4 | 0.90 | 2.05 | 0.93 | 1.46 | 78 | 103 |
| 12800 m | 0.13 | 0.11 | 3.15 | 1.74 | 0.36 | 0.66 | 5.8 | 10.1 | 148 | 134 | 5.7 | 8.2 | 1.06 | 1.36 | 1.13 | 1.41 | 92 | 96 |

## Table 6

**Summary of results of ANCOVA for metal concentrations during 1976-1977 MRC mussel outplants. Distance was the coviariate and Period ("on" or "off") was the class variable. Distance x Period represents a test for homogeneity of slopes for the independent variable Distance during the two periods. Entries in the table are F values (d.f. = 1,7 in all cases). * indicates $p < 0.05$, t indicates $p < 0.10$.**

| DEPENDENT VARIABLE | SOURCE | | |
|---|---|---|---|
| | DISTANCE | PERIOD | DISTANCE X PERIOD |
| Cd | 0.14 | $4.57^t$ | 1.02 |
| Cr | $7.44^t$ | 19.90* | 0.63 |
| Cu | 0.35 | 13.04* | 0.05 |
| Fe | 19.86* | 13.76* | 3.64 |
| Mn | $4.83^t$ | 15.15* | 0.75 |
| Ni | 1.29 | 13.90* | 0.99 |
| Pb | 0.42 | 16.77* | 2.01 |
| Zn | 0.74 | 4.54 | 0.70 |

## Table 7

**Summary of ANCOVA results for growth rate during the 1976-1977 MRC mussel outplants. Metal concentration was the covariate (separate analyses for each metal: Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn) and Period was the class variable. Preliminary analyses indicated that slopes were homogeneous across periods. Entries in the table are F values. * indicates p < 0.05.**

| COVARIATE (METAL) | ---------- SOURCE ---------- | |
|---|---|---|
| | METAL CONCENTRATION | PERIOD |
| Cd | 0.02 | <0.01 |
| Cr | 0.46 | 0.49 |
| Cu | 12.70* | 11.08* |
| Fe | 0.34 | 0.32 |
| Mn | 1.23 | 1.10 |
| Ni | 0.01 | 0.04 |
| Pb | 0.86 | 0.82 |
| Zn | 1.27 | 0.87 |

# Table 8

**Mean (± one S. E.) of biological variables and metal concentrations [μg/g dry wt.] for 1986 MRC mussel outplant. Solid lines connect means that are not significantly different. Dotted lines are used to jump stations when a group of means that are not significantly different from one another are separated from one another by a station that differs from at least one of the group. Stations are arranged in order from upcoast to downcoast.**

| STATIONS | GROWTH RATE (mm $d^{-1}$) | GONAD MASS (g wet) | GONAD INDEX | CD | CR | CU | FE | MN | PB | ZN |
|---|---|---|---|---|---|---|---|---|---|---|
| SMKU (~5 km upcoast) | 0.13±0.002 | 3.99±0.15 | 0.41±0.005 | 3.4±0.16 | 0.96±0.07 | 6.54±0.31 | 346±74 | 11.8±0.58 | 1.08±0.13 | 129.3±17.5 |
| SMKD (~4 km upcoast) | 0.13±0.007 | 2.90±0.41 | 0.35±0.025 | 3.6±0.30 | 1.59±0.03 | 6.45±0.26 | 841±22 | 18.0±1.05 | 1.40±0.16 | 114.3±3.5 |
| SOKN (<0.5 km upcoast) | 0.13±0.006 | 4.62±0.22 | 0.44±0.032 | 3.4±0.16 | 1.52±0.19 | 6.22±0.22 | 739±121 | 16.0±0.70 | 1.11±0.11 | 120±4.0 |
| DIFF (Diffusers of Units 2 & 3) | 0.10±0.004 | 3.70±0.25 | 0.39±0.02 | 4.6±0.27 | 1.36±0.09 | 5.94±0.17 | 657±61 | 14.4±0.72 | 0.89±0.04 | 127±3.2 |
| SOKU (~0.5 km downcoast) | 0.11±0.0003 | 3.05±0.62 | 0.33±0.04 | 4.6±0.41 | 1.30±0.05 | 6.04±0.19 | 582±27 | 12.7±0.60 | 0.81±0.27 | 132±21.0 |
| PAR (~5 km downcoast) | 0.13±0.003 | 4.18±0.44 | 0.34±0.01 | 4.0±0.31 | 0.89±0.03 | 5.24±0.05 | 289±19 | 9.1±0.56 | 0.60±0.01 | 112±6.7 |

## Table 9

**Coefficients of determination ($r^2$) of biological variables versus metal concentrations for 1986 MRC mussel outplant. In all cases, d. f. = 15. ** indicates $p < 0.01$.**

| METAL | GROWTH RATE | GONAD MASS | GONAD INDEX |
|---|---|---|---|
| Cd | 0.46** | 0.09 | 0.14 |
| Cr | 0.004 | 0.05 | 0.05 |
| Cu | 0.07 | 0.04 | 0.04 |
| Fe | 0.006 | 0.07 | 0.03 |
| Mn | 0.005 | 0.06 | 0.05 |
| Pb | 0.05 | 0.06 | 0.05 |
| Zn | 0.02 | 0.03 | 0.007 |

## Table 10

**Metal concentrations in ppm (from Parker (1985) based on undated data sheets provided to MRC circa late 1982). Pismo Beach was sampled on 15 July 1982. Goleta was sampled on 25 August 1982. All other beaches were sampled on 3 August 1982. Crab sizes are as follows: S = "Box 23" ≈ 13 mm; M = "Box 28" ≈ 16mm; L = ">Box 32" ≈ > 18mm.**

| STATION | CHROMIUM | | | MANGANESE | | | NICKEL | | |
|---|---|---|---|---|---|---|---|---|---|
| | S | M | L | S | M | L | S | M | L |
| 0.4 km N | | 1.4 | | | 20.8 | | | 7.9 | |
| 1.5 km N | | 0.8 | | | 34.9 | | | 1.8 | |
| 6.5 km N | 0.7 | 0.7 | 0.8 | 13.6 | 15.8 | 12.3 | 1.3 | 1.4 | 1.5 |
| 6.5 km N egg-bearing | | 0.7 | | | 19.1 | | | 1.7 | |
| San Clemente Pier (~7.5 km N) | 0.6 | 0.7 | 1.2 | 22.4 | 18.0 | 21.7 | 1.4 | 1.5 | 1.7 |
| Goleta Pier | 0.6 | 0.8 | 0.7 | 4.4 | 4.3 | 7.1 | 1.5 | 1.8 | 1.9 |
| Pismo Beach Pier | | | 0.8 | | | 6.5 | | | 2.0 |

| STATION | LEAD | | | IRON | | | ZINC | | |
|---|---|---|---|---|---|---|---|---|---|
| | S | M | L | S | M | L | S | M | L |
| 0.4 km N | | 3.3 | | | 211.2 | | | 81.7 | |
| 1.5 km N | | 3.1 | | | 132.1 | | | 16.9 | |
| 6.5 km N | 4.6 | 4.1 | 3.4 | 74.9 | 32.1 | 68.2 | 19.1 | 17.1 | 13.6 |
| 6.5 km N egg-bearing | | 3.8 | | | 62.0 | | | 16.4 | |
| San Clemente Pier (~7.5 km N) | 3.4 | 4.4 | 5.0 | 15.9 | 23.4 | 26.6 | 14.6 | 17.5 | 19.6 |
| Goleta Pier | 2.9 | 2.9 | 3.2 | 32.2 | 37.0 | 48.7 | 13.6 | 12.7 | 15.5 |
| Pismo Beach Pier | | | 4.6 | | | 34.6 | | | 18.6 |

| STATION | COPPER | | | CADMIUM | | | SILVER | | |
|---|---|---|---|---|---|---|---|---|---|
| | S | M | L | S | M | L | S | M | L |
| 0.4 km N | | 11.5 | | | 1.1 | | | 12.0 | |
| 1.5 km N | | 21.5 | | | 0.6 | | | 14.8 | |
| 6.5 km N | | 20.4 | 24.8 | 0.7 | 0.7 | 1.8 | 14.0 | 12.6 | 26.9 |
| 6.5 km N egg-bearing | | 19.7 | | | 0.7 | | | 13.7 | |
| San Clemente Pier (~7.5 km N) | | 15.7 | 20.9 | 0.6 | 0.7 | 0.8 | 12.0 | 13.4 | 14.6 |
| Goleta Pier | 12.0 | 13.5 | 15.6 | 0.8 | 1.7 | 2.9 | 7.5 | 8.5 | 30.1 |
| Pismo Beach Pier | | | 22.8 | | | 0.9 | | | 14.4 |

# Table 11

Metal concentration (µg/g dry wt.) in sediments for all beaches during the July 1983 MRC study. XLOCBCH is the straight-line distance in meters from SONGS. Negative values are North (upcoast) of the generating station.

| XLOCBCH | Cd | Cr | Cu | Fe | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| -115000 | 0.0223 | 0.302 | 0.308 | 104 | 5.15 | 0.462 | 1.58 | 2.93 |
| -100000 | 0.0128 | 0.428 | 0.197 | 124 | 2.403 | 0.677 | 1.52 | 3.02 |
| -79000 (Cabrillo Beach) | 0.363 | 2.27 | 2.38 | 943 | 34.6 | 1.18 | 3.32 | 13.8 |
| -15500 | 0.0208 | 0.109 | 0.277 | 104 | 9.42 | 0.623 | 0.261 | 1.39 |
| -12000 | 0.0158 | 0.130 | 0.184 | 98.1 | 5.57 | 0.440 | 0.197 | 1.36 |
| -6500 | 0.006 | 0.172 | 0.101 | 82.4 | 4.08 | 0.699 | 0.373 | 1.61 |
| -1500 | 0.0105 | 0.153 | 0.173 | 84.3 | 6.43 | 0.559 | 1.21 | 1.39 |
| -400 | 0.00725 | 0.116 | 0.169 | 79.4 | 4.61 | 0.490 | 0.251 | 1.13 |
| SONGS | | | | | | | | |
| 1500 | 0.00675 | 0.085 | 0.125 | 52.0 | 2.52 | 0.487 | 0.183 | 1.20 |
| 6500 | 0.006 | 0.193 | 0.132 | 56.4 | 4.56 | 0.497 | 0.183 | 1.14 |
| 12000 | 0.00350 | 0.167 | 0.130 | 46.6 | 2.85 | 0.603 | 0.1003 | 1.13 |
| 18000 | 0.00575 | 0.188 | 0.0985 | 86.8 | 2.94 | 0.648 | 0.216 | 1.33 |
| 25000 (Oceanside) | 0.00500 | 0.186 | 0.149 | 118 | 5.50 | 0.609 | 0.242 | 1.43 |
| 45000 | 0.00325 | 0.192 | 0.101 | 68.9 | 1.67 | 0.632 | 0.471 | 1.44 |
| 65000 (La Jolla) | 0.00500 | 0.340 | 0.173 | 50.4 | 1.89 | 0.614 | 0.944 | 1.54 |

**Table 12**

**Metal concentration (μg/g dry wt.) in sediments for all beaches during the August 1983 MRC study. XLOCBCH is the straight-line distance in meters from SONGS. Negative values are North (upcoast) of the generating station.**

| XLOCBCH | Cd | Cr | Cu | Fe | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| -450000 | 0.006 | 0.357 | 0.0713 | 107 | 2.03 | 0.718 | 0.113 | 1.44 |
| -115000 | 0.0095 | 0.339 | 0.208 | 99.4 | 4.83 | 0.586 | 1.50 | 2.75 |
| -100000 | 0.0120 | 0.582 | 0.231 | 165 | 3.39 | 0.336 | 1.48 | 3.50 |
| -79000<br>(Cabrillo Beach) | 0.338 | 2.46 | 0.606 | 1144 | 30.8 | 1.36 | 4.81 | 14.1 |
| -15500 | 0.0215 | 0.0703 | 0.227 | 93.7 | 9.27 | 0.606 | 0.242 | 1.34 |
| -12000 | 0.0138 | 0.051 | 0.199 | 72.9 | 5.56 | 0.513 | 0.203 | 1.10 |
| -6500 | 0.0070 | 0.0938 | 0.133 | 88.5 | 2.58 | 0.507 | 0.271 | 1.52 |
| -1500 | 0.0075 | 0.0590 | 0.187 | 340 | 4.52 | 0.519 | 0.848 | 1.19 |
| -400 | 0.00375 | 0.0523 | 0.112 | 53.5 | 3.11 | 0.466 | 0.208 | 1.12 |
| SONGS | | | | | | | | |
| 1500 | 0.00425 | 0.116 | 0.138 | 59.3 | 2.30 | 0.517 | 0.197 | 1.11 |
| 6500 | 0.0053 | 0.0593 | 0.115 | 38.8 | 2.69 | 0.483 | 0.136 | 1.02 |
| 12000 | 0.0060 | 0.0985 | 0.122 | 45.6 | 2.54 | 0.538 | 0.145 | 1.81 |
| 18000 | 0.00625 | 0.166 | 0.0913 | 47.6 | 2.76 | 0.454 | 0.150 | 1.22 |
| 25000<br>(Oceanside) | 0.00675 | 0.178 | 0.138 | 114 | 4.49 | 0.557 | 0.246 | 1.43 |
| 45000 | 0.00725 | 0.183 | 0.106 | 57.9 | 1.76 | 0.604 | 0.358 | 1.35 |
| 65000<br>(La Jolla) | 0.00573 | 0.177 | 0.093 | 80.0 | 2.60 | 0.694 | 0.491 | 1.78 |

# Table 13

**Metal concentration (μg/g dry wt.) in sand crab tissue for the "no eggs" category for all sites during the July 1983 MRC study. XLOCBCH is the straight-line distance in meters from SONGS. Negative values are North (upcoast) of the generating station.**

| XLOCBCH | Cd | Cr | Cu | Fe | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| -115000 | 1.08 | 0.323 | 366 | 107 | 35.8 | 0 | 1.57 | 92.4 |
| -100000 | 1.09 | 0.694 | 267 | 90.0 | 15.8 | 2.42 | 0.535 | 102 |
| -15500 | 1.56 | 1.33 | 181 | 200 | 73.7 | 0 | 0 | 71.2 |
| -12000 | 1.76 | 0.615 | 165 | 239 | 49.2 | 0 | 0 | 77.2 |
| -6500 | 2.62 | 0.284 | 198 | 135 | 38.0 | 0.618 | 0.166 | 131 |
| -1500 | 1.81 | 0.592 | 148 | 370 | 62.1 | 0 | 0 | 82.4 |
| -400 | 1.69 | 0.306 | 124 | 220 | 44.9 | 0 | 0 | 86.9 |
| SONGS | | | | | | | | |
| 1500 | 2.41 | 0.466 | 110 | 139 | 31.8 | 2.09 | 0.478 | 85.6 |
| 6500 | 2.94 | 0.721 | 99.6 | 147 | 28.3 | 2.96 | 0.302 | 92.1 |
| 12000 | 3.59 | 0.441 | 73.1 | 85.3 | 31.1 | 0.880 | 0.376 | 88.3 |
| 18000 | 2.71 | 0.271 | 59.7 | 108 | 37.9 | 0.766 | 0.068 | 81.0 |
| 25000 (Oceanside) | 3.76 | 0.115 | 98 5 | 117 | 41.3 | 1.07 | 0.348 | 85.1 |
| 45000 | 2.35 | 0.308 | 81.2 | 113 | 25.8 | 0 | 0 | 83.2 |
| 65000 (La Jolla) | 3.38 | 0.398 | 80.1 | 103 | 18.0 | 5.28 | 0.120 | 92.2 |

## Table 14

**Metal concentration (μg/g dry wt.) in sand crab tissue for the "no eggs" category for all sites during the August 1983 MRC study. XLOCBCH is the straight-line distance in meters from SONGS. Negative values are North (upcoast) of the generating station.**

| XLOCBCH | Cd | Cr | Cu | Fe | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| -450000 | 2.23 | 0.20 | 76.1 | 119 | 17.5 | 0 | 0 | 76.5 |
| -100000 | 2.76 | 1.10 | 281 | 194 | 16.0 | 2.60 | 0.796 | 110 |
| -79000 (Cabrillo Beach) | 2.34 | 0.551 | 240 | 464 | 28.3 | 0 | 0 | 95.8 |
| -12000 | 1.10 | 4.57 | 249 | 228 | 47.8 | 0 | 1.07 | 95.8 |
| -6500 | 2.18 | 0.491 | 237 | 158 | 36.5 | 0.617 | 0.895 | 109 |
| -400 | 1.14 | 1.22 | 179 | 383 | 63.2 | 0 | 0 | 95.5 |
| SONGS | | | | | | | | |
| 1500 | 2.15 | 2.25 | 183 | 386 | 33.9 | 0 | 0.137 | 109 |
| 6500 | 3.07 | 1.91 | 205 | 571 | 39.3 | 2.40 | 1.28 | 107 |
| 12000 | 2.21 | 1.09 | 183 | 319 | 32.5 | 2.93 | 0 | 109 |
| 25000 (Oceanside) | 2.86 | 0.739 | 165 | 327 | 30.1 | 0.983 | 0.224 | 96.8 |
| 45000 | 2.22 | 0.242 | 182 | 115 | 21.3 | 3.31 | 1.67 | 104 |
| 65000 (La Jolla) | 0.949 | 0.384 | 125 | 231 | 15.4 | 0 | 0 | 88.9 |

# Table 15

**Metal concentration ($\mu$g/g dry wt.) in sand crab tissue for the "with eggs, size 10-14 mm" category for all sites during the August 1983 MRC study. XLOCBCH is the straight-line distance in meters from SONGS. Negative values are North (upcoast) of the generating station.**

| XLOCBCH | CD | CR | CU | FE | MN | NI | PB | ZN |
|---|---|---|---|---|---|---|---|---|
| -100000 | 0.887 | 0.634 | 276 | 184 | 11.5 | 4.19 | 0.865 | 94.7 |
| -15500 | 2.11 | 0.618 | 286 | 153 | 59.5 | 0 | 0 | 88.0 |
| -6500 | 2.18 | 0.364 | 199 | 236 | 36.8 | 0 | 0 | 113 |
| -400 | 1.41 | 4.40 | 193 | 779 | 56.7 | 0 | 0 | 110 |
| SONGS | | | | | | | | |
| 12000 | 4.93 | 0.396 | 218 | 234 | 22.2 | 0 | 0 | 106 |
| 25000 (Oceanside) | 3.56 | 1.43 | 240 | 769 | 41.1 | 1.89 | 2.13 | 113 |
| 45000 | 6.63 | 1.20 | 217 | 181 | 23.3 | 3.52 | 0.286 | 125 |
| 65000 (La Jolla) | 2.09 | 1.09 | 161 | 445 | 21.5 | 1.90 | 0.536 | 109 |

## Table 16

**Metal concentration ($\mu$g/g dry wt.) in sand crab tissue for the "10-13 mm" category during the 1986 MRC study. XLOCBCH is the straight-line distance in meters from SONGS. Negative values are North (upcoast) of the generating station.**

| XLOCBCH | Cr | Fe | Mn |
|---|---|---|---|
| -17500 | 0.470 | 439 | 55.4 |
| -14000 | 1.060 | 934 | 44.8 |
| -12500 | 0.542 | 353 | 61.3 |
| -11500 | 0.453 | 232 | 104 |
| -10500 | 0.562 | 296 | 46.0 |
| -8500 | 0.540 | 201 | 23.7 |
| -7500 | 1.360 | 932 | 53.2 |
| -6500 | 1.160 | 891 | 33.7 |
| -5500 | 0.595 | 333 | 31.0 |
| -4500 | 0.543 | 305 | 26.2 |
| -1500 | 1.100 | 617 | 44.4 |
| -400 | 0.907 | 296 | 64.7 |
| SONGS | | | |
| 500 | 1.200 | 445 | 58.7 |
| 1500 | 1.160 | 396 | 31.7 |
| 2500 | 0.944 | 235 | 46.0 |
| 3500 | 1.190 | 538 | 14.4 |
| 4500 | 1.100 | 516 | 25.4 |
| 5500 | 1.250 | 535 | 40.2 |
| 6500 | 0.667 | 409 | 41.7 |
| 7500 | 0.523 | 279 | 17.9 |
| 8500 | 0.742 | 306 | 27.1 |
| 9500 | 0.875 | 817 | 37.4 |
| 10500 | 0.510 | 179 | 64.4 |
| 12000 | 1.13 | 646 | 49.8 |
| 45000 | 0.636 | 329 | 19.1 |
| 65000 | 0.645 | 266 | 12.0 |

## Table 17

**Concentrations of metals ($\mu$g/g dry wt.) in bottom sediments along the 60 m isobath from 1977 and 1985. Data were collected by the Southern California Coastal Water Research Project (SCCWRP) from control stations representing "uncontaminated" conditions. Values reported for the overall categories are Means (min - max).**

| YEAR & STATION | CADMIUM | CHROMIUM | COPPER | LEAD | NICKEL | SILVER | ZINC |
|---|---|---|---|---|---|---|---|
| 1977 | | | | | | | |
| San Clemente | 0.21 | 22 | 9.7 | 6.7 | 9.7 | 0.13 | 48 |
| San Onofre | 0.1 | 22 | 11 | 6.9 | 10 | 0.11 | 51 |
| Carlsbad | 0.33 | 25 | 15 | 9.3 | 11 | 0.17 | 62 |
| 1977 overall | 0.39 | 23 | 9.1 | 6.6 | 12 | 0.38 | 42 |
| (N = 29) | (0.1-1.4) | (6.5-43) | (2.8-31) | (2.7-12) | (1.6-35) | (0.06-1.7) | (9.8-62) |
| 1985 | | | | | | | |
| San Clemente | 0.11 | 27 | 20.0 | 7.7 | 17 | <0.024 | 73 |
| San Onofre | 0.08 | 29 | 16.0 | 4.3 | 13 | <0.025 | 61 |
| Carlsbad | 0.10 | 23 | 17.0 | 4.6 | 13 | <0.022 | 66 |
| 1985 Overall | 0.142 | 25.4 | 10.5 | 4.8 | 12.9 | 0.025 | 48 |
| (N = 13) | (0.02-0.28) | (7.8-40) | (1.4-20) | (1.0-9.3) | (1.1-26) | (0.012-0.112) | (7.5-73) |

## Table 18

**Metal concentrations ($\mu g/g$ dry wt.) in bottom sediments at 15 m depth at an impact site just downcoast of the SONGS Units 2 and 3 diffusers, and at a control site ~7 km south of SONGS. Data are from SCE Annual Reports: Marine Environmental Analysis and Interpretation.**

| METAL | MEAN | MIN | MAX | MEAN | MIN | MAX |
|---|---|---|---|---|---|---|
| | Station J2S (impact) | | | Station J22S (control) | | |
| | 1978-1980 | | | | | |
| Cr | 16.9 | 10 | 23 | 14.8 | 8.3 | 24 |
| Cu | 4.7 | 1.2 | 6.6 | 3.73 | 1.7 | 5.3 |
| Fe | 8019.3 | 1240 | 11800 | 6607.1 | 4300 | 8180 |
| Ni | 7.8 | 1.3 | 9.7 | 6.4 | 3.5 | 7.9 |
| Ti | 657.2 | 125 | 1150 | 593.3 | 180 | 1140 |
| | 1985-1987 | | | | | |
| Cr | 39.8 | 33 | 46 | 29.9 | 21 | 42 |
| Cu | 6.2 | 4 | 7 | 4.3 | 3 | 6 |
| Fe | 8689 | 6200 | 10100 | 6295.6 | 3900 | 8200 |
| Ni | 6.3 | <1 | 11 | 5.4 | 3 | 7 |
| Ti | 731.1 | 270 | 1090 | 645.6 | 400 | 1080 |

## Table 19

**Metal concentrations (mg/l) in receiving waters at an impact site just downcoast of the SONGS Units 2 and 3 diffusers, and at a control site ~7 km south of SONGS. Data are from SCE Annual Reports: Marine Environmental Analysis and Interpretation.**

| Metal | Mean | Min | Max | Mean | Min | Max |
|---|---|---|---|---|---|---|
| | Station J2S (impact) | | | Station J22S (control) | | |
| | 1978-1980 | | | | | |
| Cr | >0.002 | 0.0004 | 0.007 | >0.0026 | 0.0007 | 0.006 |
| Cu | 0.0065 | 0.0007 | 0.018 | 0.0071 | 0.001 | 0.10 |
| Fe | 0.13 | 0.04 | 0.30 | 0.13 | 0.005 | 0.26 |
| Ni | >0.01 | 0.0004 | 0.026 | >0.008 | <0.001 | 0.013 |
| Ti | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 1985-1987 | | | | | |
| Cr | <0.01 | 0.001 | <0.01 | <0.01 | 0.002 | <0.01 |
| Cu | <0.01 | 0.001 | <0.01 | <0.01 | 0.002 | <0.01 |
| Fe | <0.01 | <0.005 | <0.01 | <0.01 | <0.005 | <0.01 |
| Ni | <0.01 | <0.001 | <0.01 | <0.01 | <0.001 | <0.01 |
| Ti | <0.23 | <0.01 | <0.5 | <0.23 | <0.01 | <0.5 |

## Table 20

**Conservative estimates of chronic toxicity of metals from SWRCB (1988). New (1988) estimates are the geometric average of the three lowest concentrations where chronic exposure led to effects. Old (1983) estimates extrapolated from acute studies in some cases.**

| METAL | 1983 VALUE | 1988 VALUE |
|---|---|---|
| Cadmium | 7.6 | 8 |
| Hexavalent Chromium | 14.6 | 18 |
| Copper | 6.4 | 5 |
| Lead | 26.0 | 22 |
| Mercury | 1.6 | 0.4 |
| Nickel | 146.0 | 48 |
| Silver | -- | 3 |
| Zinc | 56.0 | 51 |

# Table 21

**Annual discharge rates of the major radioactive products at SONGS and three other nuclear facilities. Values are the ranges among years in Ci/year. -- indicates no data. "<LLD" indicates value was below lower limit of detection. Note: SONGS data are from the Semiannual Effluent Reports reported by SCE to the Nuclear Regulatory Commission; data for other localities are from Woodhead (1984), Tables 2-10 to 2-12.**

| | Windscale Reprocessing Plant 1972-79 | SONGS Units 1-3 1981-1984 | Oyster Creek Generating Station 1971-74 | Bradwell Generating Station 1972-79 |
|---|---|---|---|---|
| Total, Excluding $^{3}$H and gases | 141,000-270,000 | 2.2-15.8 | 0.45-10.3 | 43-120 |
| $^{110}$Ag | -- | <LLD-0.02 | -- | 0.007-0.11 |
| $^{58}$Co | -- | 0.27-3.3 | 0.01-0.15 | -- |
| $^{60}$Co | --* | 0.69-2.6 | 0.07-1.7 | -- |
| $^{51}$Cr | -- | 0.05-2.7 | 0.11-0.49 | -- |
| $^{134}$Cs | 5,800-29,000 | 0.09-0.62 | 0.03-2.1 | 2-13 |
| $^{137}$Cs | 21,000-141,000 | 0.38-2.92 | 0.01-3.0 | 13-52 |
| $^{59}$Fe | -- | 0.01-0.28 | 0.001-0.04 | -- |
| $^{3}$H | 20,000-38,000 | 253-543 | 14-62 | 88-309 |
| $^{54}$Mn | -- | 0.03-0.28 | 0.04-0.63 | -- |
| $^{106}$Ru | 11,000-38,000 | -- | -- | -- |
| $^{65}$Zn | -- | <LLD-0.02 | 0.001-0.002 | 0.03-0.22 |

* Cobalt-60 was reported in organisms from Windscale.

## Table 22

**Activity levels (pCi/g wet weight) of naturally occurring and station-related radionuclides in ocean bottom sediments and shoreline sediments (sand) from stations near and far from SONGS during 1981-1986. Values preceded by a "<" indicate the measure was below that limit of detection. Blanks indicate that isotope was not detected. Data are from the Annual Radiological Environmental Operating Report for 1986, submitted by SCE to the Nuclear Regulatory Commission.**

| | -- Naturally occurring Radionuclides -- | | | ---------- Station-related Radionuclides ---------- | | | | |
|---|---|---|---|---|---|---|---|---|
| Location | $^{40}$K | $^{226}$Ra | $^{228}$Th | $^{137}$Cs | $^{58}$Co | $^{60}$Co | $^{54}$Mn | $^{110m}$Ag |
| Ocean Bottom Sediments | | | | | | | | |
| SONGS Unit 1 - E | 8.9-14.0 | 0.17-0.68 | 0.21-0.95 | <0.04-0.09 | <0.04-0.046 | <0.04-0.98 | <0.04 | <0.05 |
| SONGS Unit 1 - W | 6.8-19.0 | 0.13-0.67 | 0.19-0.90 | 0.04-0.041 | <0.04 | <0.04-0.93 | <0.04-0.08 | <0.05 |
| SONGS Unit 2 | 9.7-16.0 | 0.16-0.52 | 0.12-0.57 | <0.04 | <0.04 | <0.04-0.062 | <0.04 | <0.05 |
| SONGS Unit 3 | 10.1-16.8 | 0.13-0.50 | 0.26-0.59 | <0.04 | <0.04 | 0.04 | <0.04 | <0.05 |
| Control - Newport Beach (~40 km north of SONGS) | 7.1-17.0 | 0.08-0.50 | 0.09-0.79 | <0.04 | <0.04 | <0.04-0.09 | <0.04 | <0.05 |
| Shoreline Sediments (Sand) | | | | | | | | |
| Beach near Unit 1 | 10.6-18.0 | 0.17-0.88 | 0.14-1.05 | <0.05 | | | | |
| San Onofre Beach I | 12.0-17.0 | 0.12-0.59 | 0.14-0.87 | | | | | |
| San Onofre Beach II | 11.4-16.0 | 0.12-0.73 | 0.11-1.07 | | | | | |
| Control - Newport Beach (~40 km north of SONGS) | 15.0-20.0 | 0.24-1.27 | 0.45-3.80 | | | | | |

# Table 23

**Concentrations of major radionuclides in organisms sampled near nuclear facilities. Values are expressed as pCi/g wet weight. ND indicates not detected. -- indicates not measured. (G) indicates generating facility and (R) indicates reprocessing facility. The SONGS data are taken from the Annual Operating Reports of the Radiological Environmental Monitoring Program, submitted by SCE to the Nuclear Regulatory Commission, from 1981-1986. Values for the other sites are from Woodhead (1984), Tables 2-17 to 2-20.**

| | $^{40}$K (NATURAL) | $^{60}$CO | $^{134}$CS | $^{137}$CS | $^{95}$ZR-$^{95}$NB | $^{54}$MN | $^{110}$AG | OTHER PARTICULATES |
|---|---|---|---|---|---|---|---|---|
| MOLLUSCS | | | | | | | | |
| Oyster Creek(G) | 2.9* | 0.25 | -- | ND | ND | ND | -- | |
| Bradwell(G) | 2.9* | 0.28 | 0.6 | 1.4 | ND | -- | 0.38 | 8.13 |
| SONGS(G) | <0.2-2.6 | <0.007-2.9 | <0.01 | 0.003-0.006 | <0.03 | <0.01-0.014 | <0.07-0.27 | ~0.1 |
| Windscale(R) | 2.9* | 0.54-1.2 | 2.0-3.6 | 14-26 | 46-91 | -- | 4.2 | 556-775$^{+}$ |
| CRUSTACEANS | | | | | | | | |
| SONGS(G) | 1.9-3.6 | 0.008-0.32 | <0.01 | 0.004-0.012 | <0.03 | <0.01-0.067 | 0.016-0.36 | ~0.30 |
| Windscale(R) | 2.5* | 0.23 | 2.2-6.5 | 17-52 | 0.35 | -- | 0.016-0.92 | 21-31$^{+}$ |
| FISHES | | | | | | | | |
| Oyster Creek(G) | 2.5* | 0.044 | 0.069 | 0.12 | ND | 0.024 | -- | 0.081 |
| Bradwell(G) | 2.5* | ND | 0.036 | 0.24 | ND | -- | ND | |
| SONGS(G) | 1.8-3.9 | <0.007-0.086 | <0.01 | 0.003-0.059 | <0.03 | <0.01 | <0.07 | |
| Windscale(R) | 2.5* | -- | 0.2-2.6 | 0.7-23.0 | -- | -- | -- | -- |

* estimated value from Woodhead (1984)

$^{+}$ primarily from Ruthenium-106

## Table 24

**Isotope activity levels (pCi/g dry wt.) in sand crab tissue during August 1986. Note that activity levels measured on a dry weight basis are approximately five times higher than wet weight estimates. Site designations represent distances north (-) or south (+) of SONGS in meters.**

| SIZE CLASS | SITE | $^{40}$K (NATURAL) | $^{54}$Mn | $^{60}$Co |
|---|---|---|---|---|
| ≥ 13 mm | | | | |
| | -11500 | 1.3 | 0 | 0 |
| | -8500 | 2.1 | 0 | 0 |
| | -7500 | 3.4 | 0 | 0.04 |
| | -6500 | 3.6 | 0 | 0 |
| | SONGS | | | |
| | 2500 | 4.0 | 0 | 0 |
| | 4500 | 2.3 | 0 | 0 |
| | 6500 | 3.4 | 0 | 0 |
| | 7500 | 2.2 | 0 | 0 |
| | 8500 | 2.2 | 0 | 0 |
| | 9500 | 2.7 | 0 | 0 |
| | 10500 | 2.4 | 0.03 | 0.06 |
| | 12500 | 6.0 | 0 | 0 |
| | 65000 | 2.2 | 0 | 0 |
| 10 - 13 mm | | | | |
| | -17500 | 3.0 | 0 | 0 |
| | -14000 | 3.3 | 0.01 | 0.02 |
| | -12500 | 2.5 | 0 | 0 |
| | -11500 | 2.6 | 0 | 0 |
| | -10500 | 2.6 | 0 | 0 |
| | -8500 | 2.7 | 0.03 | 0.02 |
| | -7500 | 2.4 | 0 | 0.03 |
| | -6500 | 3.8 | 0 | 0 |
| | -5500 | 2.3 | 0.02 | 0.03 |
| | -4500 | 3.2 | 0 | 0 |
| | -1500 | 3.4 | 0.04 | 0.06 |
| | -400 | 2.7 | 0.03 | 0.04 |
| | 0 (SONGS) | 4.2 | 0 | 0.04 |
| | 500 | 2.6 | 0.06 | 0.06 |
| | 1500 | 3.6 | 0.04 | 0.06 |
| | 2500 | 2.1 | 0.05 | 0.05 |
| | 3500 | 2.5 | 0.03 | 0.05 |
| | 4500 | 3.7 | 0.03 | 0.03 |
| | 5500 | 2.9 | 0 | 0.04 |
| | 6500 | 2.4 | 0.04 | 0.03 |
| | 7500 | 2.9 | 0.07 | 0.04 |
| | 8500 | 2.9 | 0.04 | 0.04 |
| | 10500 | 3.2 | 0.07 | 0.05 |
| | 12000 | 2.8 | 0 | 0 |
| | 45000 | 3.0 | 0 | 0 |
| | 65000 | 1.2 | 0 | 0 |

# Table 25

**Estimated exposure rate (μrad/hr) of marine organisms from different sources of radioactivity. Possible contributions from α and β radiation in the sediments are given in parentheses, but not included in the totals, because the magnitude of the dose rate is very sensitive to the precise geometry. This table is abridged from Table 2-30 in Woodhead (1984).**

| | PHYTOPLANKTON, 2 M DEPTH, REMOTE FROM SEABED | ZOOPLANKTON, 2 M DEPTH, REMOTE FROM SEABED | MOLLUSCS, 5 M DEPTH, ON THE SEABED | CRUSTACEANS, 10 M DEPTH, ON THE SEABED | FISH, 50 M DEPTH, ON THE SEABED |
|---|---|---|---|---|---|
| Natural background | | | | | |
| Cosmic radiation, internal activity, sea water | 4.5-9.9 | 5.0-32 | 9.8-36 | 7.8-91 | 4.3-21 |
| (Sediment: α, β) | -- | -- | (16-191) | (16-191) | (16-191) |
| Fallout | 0.26-26 | 1.4-150 | 0.1-8.0 | 0.36-0.46 | 0.12-1.8 |
| Waste disposal | | | | | |
| Bradwell nuclear generating station | -- | -- | 0.70 | 0.62 | 0.76 |
| (Sediment: β) | -- | -- | (0.2-1.3) | (0.2-1.3) | (0.2-1.3) |
| Oyster Creek nuclear generating station | $9.6 \times 10^{-4}$ - $3.4 \times 10^{-2}$ | $7.9 \times 10^{-4}$ - $3.0 \times 10^{-2}$ | $7.6 \times 10^{-2}$ - 11 | $7.1 \times 10^{-2}$ - 11 | $7.8 \times 10^{-2}$ - 11 |
| (Sediment: β) | -- | -- | (0.01-1.0) | (0.01-1.0) | (0.01-1.0) |
| Windscale nuclear reprocessing plant | 200-2100 | 530-6900 | 1780-5770 | 110-3450 | 45-3350 |
| (Sediment: α, β) | -- | -- | (240-5950) | (240-5950) | (240-5950) |

# 10. FIGURES

Figure 1: Locations of mussel outplant stations during the 1976-1977 and 1986 MRC studies. The diffusers for SONGS Units 2 and 3 are indicated by straight lines in the vicinity of the SOKU and DIFF stations.

Locations of MRC Mussel Outplant Stations

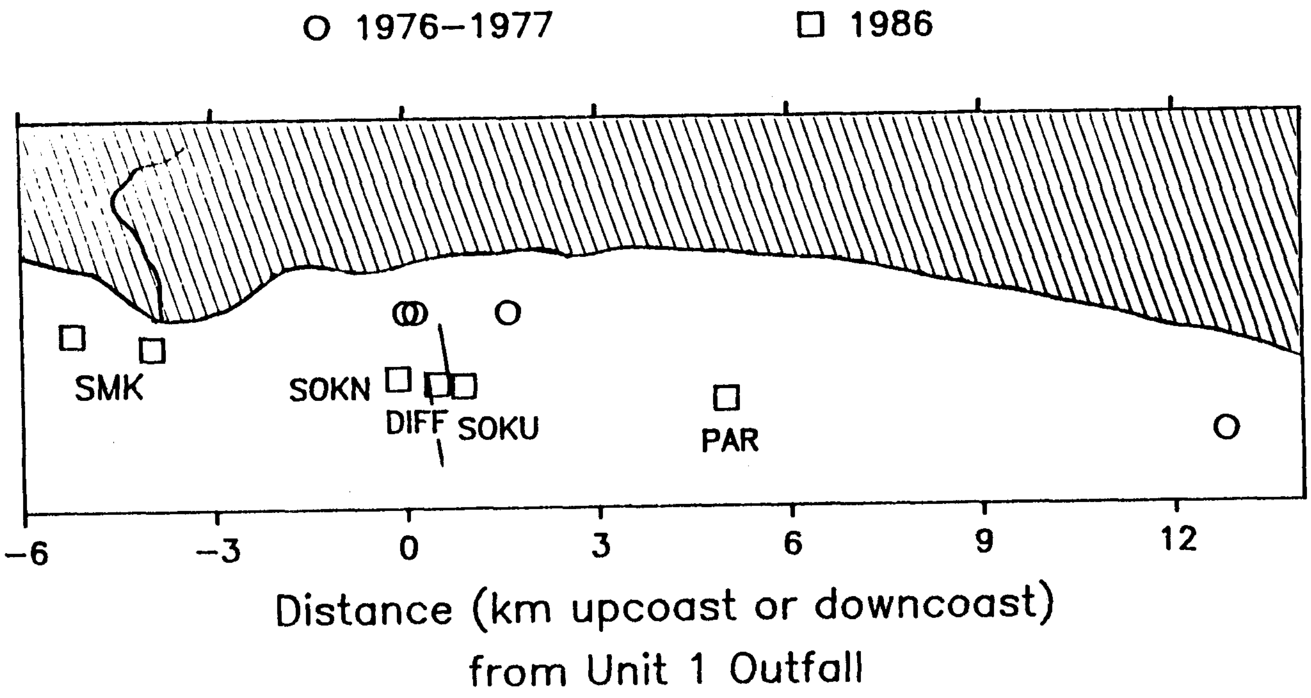
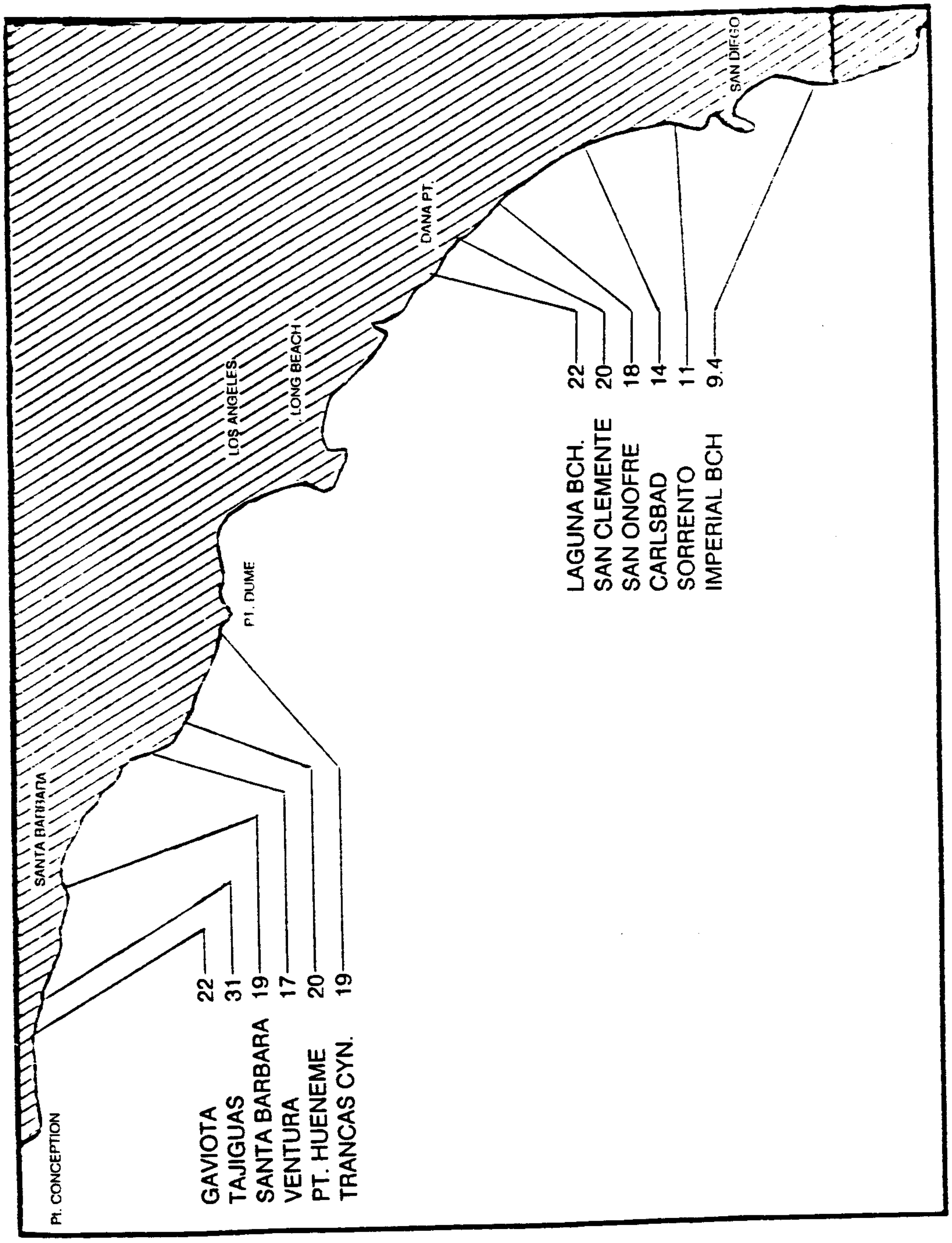


**Figure 2:** Concentrations of chromium in sediments (ppm, dry wt.) from the 30 m isobath, at SCCWRP Reference sites. (Data are from Thompson _et al_. 1987).



Pt. CONCEPTION
SANTA BARBARA
PT. DUME
LOS ANGELES
LONG BEACH
DANA PT.
SAN DIEGO
GAVIOTA 22
TAJIGUAS 31
SANTA BARBARA 19
VENTURA 17
PT. HUENEME 20
TRANCAS CYN. 19
LAGUNA BCH. 22
SAN CLEMENTE 20
SAN ONOFRE 18
CARLSBAD 14
SORRENTO 11
IMPERIAL BCH 9.4

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# APPENDICES

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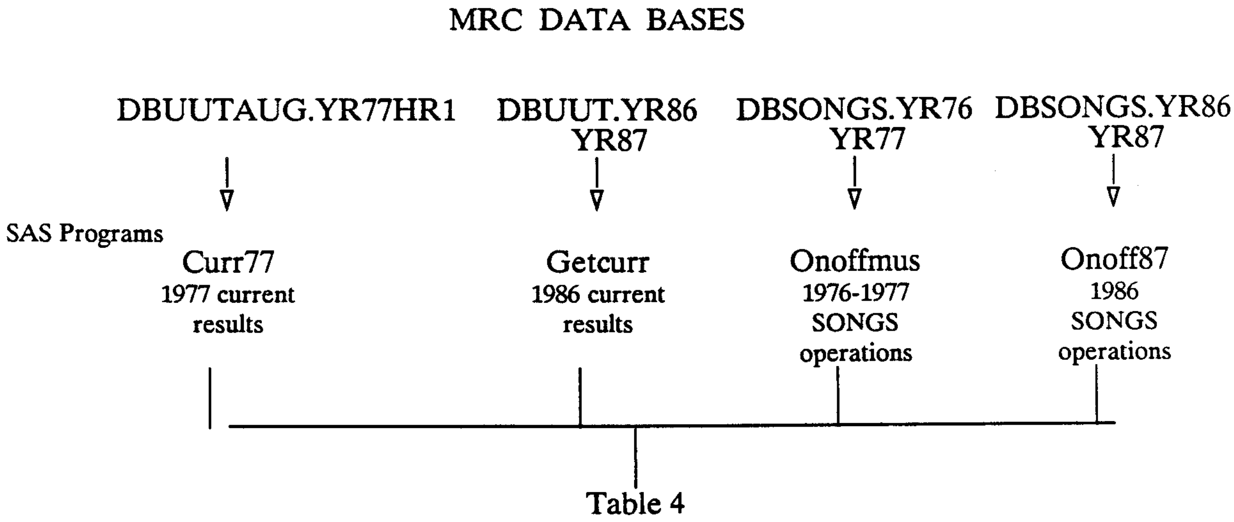
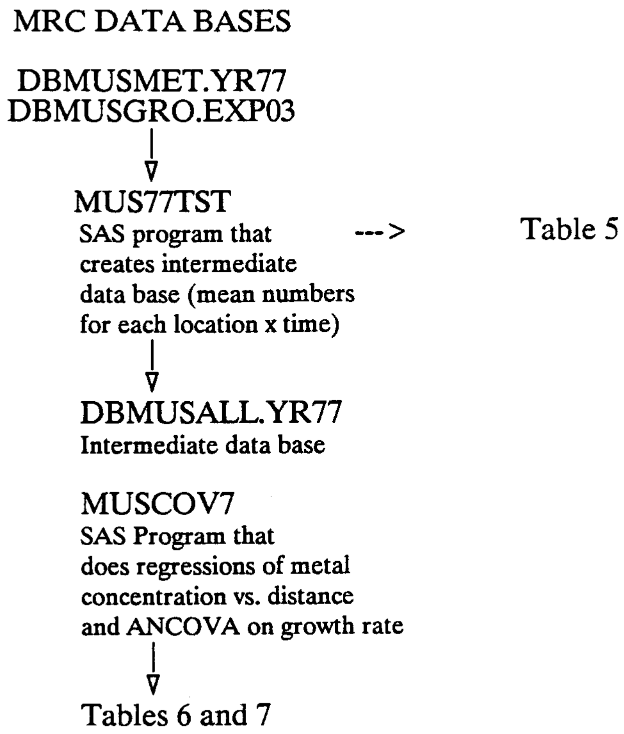
# Appendix A. Programs and data bases used in the analyses of the MRC mussel data (Section 3).

**Flow chart for data on current direction and SONGS operation used in description of MRC mussel outplants.**



**Flow chart for analyses of 1976-1977 mussel data.**



MRC DATA BASES

DBMUSMET.YR77
DBMUSGRO.EXP03

MUS77TST
SAS program that creates intermediate data base (mean numbers for each location x time)

---> Table 5

DBMUSALL.YR77
Intermediate data base

MUSCOV7
SAS Program that does regressions of metal concentration vs. distance and ANCOVA on growth rate

Tables 6 and 7

## Flow chart of analyses of 1986 mussel metal data.

MRC DATA BASES
DBMUSSAI.YR86
DBMUSSMET.YR86

↓

MUS86TST
SAS program: creates
data base with mean
values for each
field station

↓

DBMUSALL.YR86 --> MUSMEAN8 --> Table 8
intermediate data base with station meansfor each general location

SAS program: calculates means

↓

MUSGLM8
SAS Program:
Does ANOVA to
compare stations and
regresses biological
variables
against metals

↓

Tables 8 and 9

## Appendix B: Source documents on the methods used to assay metal concentrations in mussels.

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## REPORT ON ANALYSIS OF 1976-1977 SAMPLES

# DATA REPORT FOR BULK ANALYSIS OF MUSSEL SAMPLES FOR TRACE METALS

Prepared by:

Science Applications International Corporation
476 Prospect Street
La Jolla, CA 92037

Prepared for:

Marine Review Committee, Inc.
531 Encinitas Blvd., Suite 105
Encinitas, CA 92024

June, 1987

## 1.0 INTRODUCTION

This data report "Bulk Analysis of Mussel Samples for Trace Metals" is submitted by Science Applications International Corporation (SAIC), La Jolla, CA to the Marine Review Committee, Inc. (MRC), Encinitas, Ca. Frozen mussel (Mytilus edulis) samples were received by SAIC on April 7, 1987. Samples were placed in a freezer (-20°C) and stored frozen until sample log-in and analysis. Eight (8) samples were analyzed (Table 1-1).

A description of the analytical methods and results is presented in Sections 2.0 and 3.0, respectively. Data tape documentation is included as Section 4.0.

## 2.0 METHODS

Whole mussel (Mytilus edulis) samples were received in the frozen state. Next, the samples were logged in according to standard chain-of-custody procedures by assigning unique SAIC check-in numbers as a cross-reference to all MRC sample numbers. The samples were frozen until preparation and analysis.

In order to minimize the possibility of contamination, all labware used was cleaned in 3N $HNO_3$ for at least 48 hours, followed by rinsing and soaking in deionized water for 24 hours. The labware was then allowed to dry, covered with lab wipers, at ambient laboratory temperature. All sample handling and preparation was carried out in a clean bench or polyethylene hood.

Sample preparation and analysis is discussed in Sections 2.1 and 2.2, respectively.

### 2.1 Samples Preparation (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn)

All bivalve (mussel) samples were dissected while still partially frozen in order to ensure most of the sample is removed from the shell.

The dissection proceeded as follows:

The adducter muscle was cut using a plastic knife, this allows for the mussel to be opened easily. All abyssal hairs were removed using teflon forceps. The gonads were removed from the peripheral of the individual using a teflon policeman. The gonad mass was weighed and recorded. Next, the remaining muscle mass was removed with a teflon policeman, weighed and recorded. After each sample was weighed the muscle tissues were combined for each sample respectively and placed in a clean, labeled polyethylene bottle. The gonads were combined for each respective sample, and stored in a clean, labeled polypropylene jar. Fifteen (15) individuals were dissected and measured from each sample.

Each individual of a sample was measured for length in the folloiwng manner. A total length of the shell of the individual was measured and recorded. A growth length of the shell of the individual (defined as the distance from 1st notch in shell to the foot of the individual) was measured and recorded. (Note: for Batch #2 there were no notches observed, therefore, no growth length measurement could be made.) The Caliper used for measuring shell length was a Fowler Carbon Fibre Dial Calipers Dial-15 with a minimum reading of 0.01 inches.

Table 1.1.

MUSSEL SAMPLES TO BE ANALYZED BY SAIC/Batch 2 (Spring 1987)

| SAIC ID # | MRC ID # |
|---|---|
| | (Mytilus edulis) |
| 87131001 | M-19 |
| 87131002 | M-20 |
| 87131003 | M-21 |
| 87131004 | M-22 |
| 87131005 | M-23 |
| 87131006 | M-24 |
| 87131007 | M-25 |
| 87131008 | M-26 |

Following the dissections, the gonads were stored in a freezer. The whole soft tissues (minus gonads) were homogenized and a aliquot was taken to a constant dry weight using a Virtis Unitrap II freeze-dryer. Following the drying process, the samples were ground to a homogenous powder. Next, the samples were digested in the following manner.

Approximately 0.75 g. of dry homogenized sample was aliquoted and transferred to 30 ml teflon (FEP) screw-cap centrifuge tubes. Next, a modification of the oxidation described by Risby (1979) was performed. Five ml of double distilled concentrated $HNO_3$ (G.F. Smith Company) were added to the samples. The samples were then tightly capped and left to stand overnight, in a hood, at room temperature. The next day the samples were loosely capped and heated in a 95°C water bath for 2 hours. Next, the tubes were removed, tightly capped and placed in an autoclave for 2 hours at a temperature of 115°C. Following this period, the sample tubes were removed, cooled, rinsed with deionized water, and blotted dry with a wiper. The samples were next quantitatively tansferred to 50 ml polypropylene volumetric flasks and brought to volume with deionized Milli-Q water. Lastly, the samples were transferred to labeled 60 ml polyethylene bottles and stored until time for analysis. Sample method blanks and N.R.C. standards were prepared in the same manner.

## 2.2 Sample Analyses (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn)

Samples were analyzed by atomic absorption spectrophotometry (AAS) using both flame and graphite according to parameters outlined in Perkin-Elmer (1976 and 1977). The instrument used is a Perkin-Elmer 603 equipped with air/$C_2H_2$ and $N_2O/C_2H_2$ burners, an HGA-2200 graphite furnace, an AS-1 Autosampler, a deuterium ($D_2$) lamp background corrector and a Perkin-Elmer 056 recorder. The $D_2$ background corrector was used for all analyses. Sample calculations were determined using the method of standard additons (MOSA). Instrument operating conditions and parameters are summarized in Table 2-1 and 2-2. Sample blanks and N.R.C. reference materials were analyzed in the same manner as the samples. AAS working standards were prepared from a mixed 10 ppm stock using Fisher 1000 ppm standards. Computerized data reduction was used for all samples.

## 3.0 RESULTS

Final sample data for Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn concentrations are presented in Table 3-1. Sample precision and accuracy data are presented in Tables 3-2 and 3-3, respectively. The precision and accuracy data are well within acceptable limits. Shell length and gonadal and muscle weights are presented in Appendix A.

## 4.0 DATA TAPE FORMAT/DOCUMENTATION

Documentation for the data tape (submitted as a separate enclosure) is presented in this section. The tape represents those data presented in Tables 3-1 through 3-3., Table 1-1 and Appendix A.

Specification for Data Tape created 6-19-87 by Cynthia Aygarn, SAIC
for MRC Trace Metals in Mussels Analysis.

9-Track, EBCDIC, 1600 BPI
Recordlength = 80 bytes
Blocksize = 80 bytes

There are 5 files on the tape:

1. F1.PRN (Trace Metal concentrations)

| Columns | Description |
|---|---|
| 1-8 | SAIC Sample ID Number |
| 11-14 | MRC Sample ID Number |
| 19 | Replicate ID |
| 22-25 | Cd concentration (ug/g) |
| 28-32 | Cr concentration (ug/g) |
| 35-38 | Cu concentration (ug/g) |
| 41-44 | Fe concentration (ug/g) |
| 47-50 | Mn concentration (ug/g) |
| 53-57 | Ni concentration (ug/g) |
| 60-64 | Pb concentration (ug/g) |
| 67-70 | Zn concentration (ug/g) |

2. F2.PRN (Precision Data)

| Columns | Description |
|---|---|
| 1-8 | SAIC Sample ID Number |
| 11-16 | Sample Description |
| 19 | Replicate ID |
| 21-25 | Cd |
| 28-33 | Cr |
| 36-40 | Cu |
| 43-46 | Fe |
| 49-53 | Mn |
| 56-61 | Ni |
| 64-68 | Pb |
| 71-74 | Zn |

Note: Replicate E = Mean value
F = Standard Deviation
G = Coefficient of Variation (%)

3. F3.PRN (Accuracy Data)

| Columns | Description |
|---|---|
| 1-2 | Element |
| 6-9 | Reported Value |
| 15-18 | Reported Standard Deviation |
| 25-28 | Certified Value |
| 34-36 | Certified Standard Deviation |
| 52-54 | Percent Recovery |

Specification for Data Tape created 6-19-87 by Cynthia Aygarn, SAIC
for MRC Trace Metals in Mussels Analysis.

4. F4.PRN (Mussel Samples)

| Columns | Description |
|---|---|
| 1-8 | SAIC Sample ID Number |
| 19-22 | MRC Sample ID Number |

5. F5.PRN (Tissue Masses and Shell Length Measurements)

| Columns | Description |
|---|---|
| 2-9 | SAIC Sample ID Number |
| 14-17 | MRC Sample ID Number |
| 21-24 | Shell # |
| 26-27 | # individual |
| 31-34 | Total Shell Length (inches) |
| 40 | Shell Length to Notch (inches) |
| 47 | Gonads (Y/N) |
| 49-52 | Gonad Mass (wet g) |
| 58-61 | Muscle Mass w/o Gonads (wet g) |

## TABLE 2-1

### INSTRUMENT OPERATING CONDITIONS AND DETECTION LIMITS FOR METALS ANALYZED BY GRAPHITE FURNACE ATOMIC ABSORPTION SPECTROMETRY

| ELEMENT | WAVELENGTH (nm) | CURRENT (mA) | SLIT WIDTH (mm) | INJECTION VOLUME (ul) | GAS | FURNACE CONDITIONS | MINIMUM DETECTION LIMIT (ppb) | ABSOLUTE DETECTION LIMIT (picograms) | SENSITIVITY (ppb/ 0.0044 Abs.) | SENSITIVITY (picograms/ 0.004 Abs.) | ADDITIONAL COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cd | 228.8 | 4 | 1.0 | 10 | Ar(3 sec,normal flow,20) | Dry:$110^{o}$C,22sec.<br>Char:$250^{o}$C,22sec.<br>Atomize:$2100^{o}$C,7sec. | 0.07 | 0.7 | 0.2 | 2 | $D_2$correction |
| Cr | 357.9 | 14 | 1.0 | 20 | Ar(3sec,normal flow,3) | Dry:$110^{o}$C,22sec.<br>Char:$1100^{o}$C,22sec.<br>Atomize:$2700^{o}$C,7sec. | 0.2 | 4 | 0.7 | 14 | $D_2$correction |
| Cu | 324.7 | 10 | 1.0 | 20 | Ar(3sec,normal flow,40) | Dry:$110^{o}$C,22sec.<br>Char:$900^{o}$C,22sec.<br>Atomize:$2700^{o}$C,7sec | 0.6 | 12 | 1.8 | 36 | $D_2$correction |
| Mn | 279.5 | 12 | 1.0 | 20 | Ar(3sec,normal flow,20) | Dry:$110^{o}$C,22sec.<br>Char:$1100^{o}$C,22sec<br>Atomize:$2700^{o}$C,7sec. | 0.1 | 2 | .4 | 8 | $D_2$correction |
| Ni | 232.0 | 15 | 1.0 | 20 | Ar(3sec,normal flow,30) | Dry:$110^{o}$C,22sec.<br>Char:$1000^{o}$C,22sec.<br>Atomize:$2700^{o}$C, 7sec. | 7 | 140 | 9 | 180 | $D_2$correction |
| Pb | 283.3 | 10 | 1.0 | 20 | Ar(3sec,normal flow,20) | Dry:$110^{o}$C,22sec.<br>Char:$750^{o}$C,22sec.<br>Atomize:$2300^{o}$C,7sec. | 0.5 | 10 | 2 | 40 | $D_2$correction |

## TABLE 2-2

### Instrument Operating Conditions and Detection Limits for Metals Analyzed by Flame Atomic Absorption Spetrometry

| ELEMENT | WAVELENGTH (nm) | LAMP CURRENT (mA) | SLIT WIDTH (mm) | GAS OXIDANT/FUEL | FLAME TYPE | MINIMUM DETECTION LIMIT (ppm) | SENSIVITY (ppm/0.0044 Abs) | ADDITIONAL COMMENTS |
|---|---|---|---|---|---|---|---|---|
| Cd | 228.8 | 4 | 1.0 | AIR/$C_2H_2$ | Oxidizing | 0.01 | 0.03 | $D_2$ correction |
| Cu | 324.8 | 10 | 1.0 | Air/$C_2H_2$ | Oxidizing | 0.02 | 0.1 | $D_2$ correction |
| Fe | 248.3 | 20 | 1.0 | Air/$C_2H_2$ | Oxidizing | 0.03 | 0.2 | $D_2$ correction |
| Mn | 279.5 | 15 | 1.0 | Air/$C_2H_2$ | Oxidizing | 0.010 | 0.06 | $D_2$ correction |
| Zn | 213.9 | 15 | 1.0 | Air/$C_2H_2$ | Oxidizing | 0.008 | 0.03 | $D_2$ correction |

Table 3.1.

FINAL DATA TABLE (Trace Metals in Tissue)
MRC MUSSELS / Batch 2 (SPRING 1987)

(Concentration in ug/g, dry weight)

| SAIC ID # | Description | Cd | Cr | Cu | Fe | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| | (Mytilus edulis) | | | | | | | | |
| 87131001 | M-19 | 2.31 | 1.33 | 12.0 | 1100 | 13.4 | 1.71 | 2.26 | 126 |
| 87131002 | M-20 | 1.72 | 1.58 | 13.2 | 988 | 15.6 | 2.00 | 1.94 | 116 |
| 87131003 | M-21 | 1.60 | 1.34 | 8.39 | 785 | 12.4 | 2.05 | 1.46 | 103 |
| 87131004 | M-22 | 1.74 | 0.660 | 10.1 | 134 | 8.17 | 1.36 | 1.41 | 96.2 |
| 87131005 | M-23 | 2.40 | 0.621 | 6.09 | 392 | 7.80 | 0.938 | 0.879 | 84.7 |
| 87131006 | M-24 | 2.99 | 0.663 | 7.02 | 430 | 8.33 | 1.39 | 1.20 | 109 |
| 87131007 | M-25 repA | 2.13 | 0.325 | 4.56 | 145 | 4.34 | 0.872 | 0.780 | 74.3 |
| 87131007 | M-25 repB | 2.44 | 0.310 | 5.12 | 150 | 4.84 | 0.923 | 1.06 | 77.1 |
| 87131007 | M-25 repC | 2.29 | 0.347 | 5.49 | 154 | 4.88 | 0.988 | 0.837 | 79.4 |
| 87131007 | M-25 repD | 2.44 | 0.308 | 5.27 | 144 | 4.84 | 0.785 | 0.85 | 79.1 |
| 87131007 | M-25 repE | 2.38 | 0.337 | 5.05 | 150 | 5.06 | 0.926 | 1.11 | 80.1 |
| 87131008 | M-26 | 3.15 | 0.362 | 5.82 | 148 | 5.69 | 1.06 | 1.13 | 91.5 |
| | method blank #1 (ug) | 0.018 u | 0.024 u | 0.074 u | 2.4 u | 0.045 u | 0.3 | 0.01 u | 0.4 u |
| | method blank #2 (ug) | 0.018 u | 0.024 u | 0.074 u | 2.4 u | 0.045 u | 0.3 | 0.01 u | 0.4 u |

Table 3.2.

PRECISION DATA TABLE (Trace Metals in Tissue)
MRC MUSSELS / Batch 2 (SPRING 1987)

(Concentration in ug/g, dry weight)

| SAIC ID # | Description | Cd | Cr | Cu | Fe | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| | (Mytilus edulis) | | | | | | | | |
| 87131007 | M-25 repA | 2.13 | 0.325 | 4.56 | 145 | 4.34 | 0.872 | 0.780 | 74.3 |
| 87131007 | M-25 repB | 2.44 | 0.310 | 5.12 | 150 | 4.84 | 0.923 | 1.06 | 77.1 |
| 87131007 | M-25 repC | 2.29 | 0.347 | 5.49 | 154 | 4.88 | 0.988 | 0.837 | 79.4 |
| 87131007 | M-25 repD | 2.44 | 0.308 | 5.27 | 144 | 4.84 | 0.785 | 0.85 | 79.1 |
| | $\bar{x}$ | 2.32 | 0.32 | 5.11 | 148 | 4.7 | 0.89 | 0.88 | 77 |
| | S.D. | 0.126 | 0.0156 | 0.344 | 4.02 | 0.222 | 0.0743 | 0.106 | 2.04 |
| | C.V. | 5 | 5 | 7 | 3 | 5 | 8 | 12 | 3 |
| 87131009 | TORT-1 repA | 27.0 | 1.99 | 429 | 192 | 23.1 | 1.97 | 9.93 | 164 |
| 87131009 | TORT-1 repB | 27.7 | 2.19 | 418 | 174 | 24.1 | 1.79 | 9.62 | 178 |
| 87131009 | TORT-1 repC | 26.0 | 1.75 | 433 | 187 | 22.6 | 1.92 | 13.1 | 171 |
| 87131009 | TORT-1 repE | 28.2 | 1.91 | 445 | 197 | 25.8 | 1.87 | 11.4 | 180 |
| | $\bar{x}$ | 27.2 | 1.96 | 431 | 188 | 23.9 | 1.89 | 11.0 | 173 |
| | S.D. | 0.84 | 0.16 | 9.7 | 8.56 | 1.24 | 0.0665 | 1.38 | 6.30 |
| | C.V. | 3 | 8 | 2 | 5 | 5 | 4 | 13 | 4 |

Table 3.3.

ACCURACY DATA TABLE (Trace Metals in Tissue)
NRC MUSSELS / Batch 2   (SPRING 1987)

NRC Lobster Hepatopancreas Tissue  (TORT-1)
(concentration in ug/g dry weight)

| ELEMENT | SAIC REPORTED VALUE | NRC CERTIFIED VALUE [1] | % RECOVERY |
|---|---|---|---|
| Cd | 27.2 +/- 0.84 | 26.3 +/- 2.1 | 103 |
| Cr | 1.96 +/- .16 | 2.4 +/- 0.6 | 82 |
| Cu | 431 +/- 9.7 | 439. +/- 22. | 98 |
| Fe | 188 +/- 8.56 | 186. +/- 11. | 101 |
| Mn | 23.9 +/- 1.24 | 23.4 +/- 1.0 | 102 |
| Ni | 1.89 +/- .07 | 2.3 +/- 0.3 | 82 |
| Pb | 11 +/- 1.38 | 10.4 +/- 2.0 | 106 |
| Zn | 173 +/- 6.3 | 177. +/- 10. | 98 |

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[1] This is a certified reference material distributed by the National Research Council of Canada Ottawa, Canada KIA 0R6.

# APPENDIX A

Tissue Masses and Shell Length Measurements

| SAIC Sample # | MRC Sample # | Shell# | # Individual | Total Shell Length (inches) | Shell Length to Notch (inches) | Gonads Y/N | Gonad Mass (wet g) | Muscle Mass w/o Gonads (wet g) | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| 87131001 | M-19 | 409 | 1 | 2.61 | ---- | Y | 0.24 | 3.49 | No notches found |
| 87131001 | M-19 | 65 | 2 | 2.14 | ---- | Y | 0.22 | 1.95 | in shell. |
| 87131001 | M-19 | 438 | 3 | 2.45 | ---- | Y | 0.44 | 4.02 | |
| 87131001 | M-19 | 403 | 4 | 2.49 | ---- | Y | 0.18 | 2.16 | Mussels extremely |
| 87131001 | M-19 | 237 | 5 | 2.15 | ---- | Y | 0.19 | 3.92 | decomposed. |
| 87131001 | M-19 | 344 | 6 | 2.29 | ---- | Y | 0.39 | 2.26 | |
| 87131001 | M-19 | 1 | 7 | 1.99 | ---- | Y | 0.27 | 1.51 | |
| 87131001 | M-19 | 361 | 8 | 2.49 | ---- | Y | 0.39 | 3.17 | |
| 87131001 | M-19 | 273 | 9 | 2.48 | ---- | Y | 0.29 | 2.54 | |
| 87131001 | M-19 | 249 | 10 | 2.34 | ---- | Y | 0.22 | 1.69 | |
| 87131001 | M-19 | 342 | 11 | 2.38 | ---- | Y | 0.13 | 2.23 | |
| 87131001 | M-19 | 360 | 12 | 2.17 | ---- | Y | 0.20 | 2.93 | |
| 87131001 | M-19 | 197 | 13 | 2.15 | ---- | Y | 0.12 | 1.99 | |
| 87131001 | M-19 | 117 | 14 | 1.99 | ---- | Y | 0.10 | 1.41 | |
| 87131001 | M-19 | 393 | 15 | 2.65 | ---- | Y | 0.39 | 2.85 | |
| 87131002 | M-20 | 295 | 1 | 1.95 | ---- | Y | 0.18 | 1.33 | |
| 87131002 | M-20 | 440 | 2 | 2.56 | ---- | Y | 0.27 | 3.28 | No notches found |
| 87131002 | M-20 | 984 | 3 | 2.41 | ---- | Y | 0.04 | 1.90 | in shell. |
| 87131002 | M-20 | 172 | 4 | 2.20 | ---- | Y | 0.12 | 2.15 | |
| 87131002 | M-20 | 286 | 5 | 2.47 | ---- | Y | 0.30 | 3.83 | Mussels extremely |
| 87131002 | M-20 | 221 | 6 | 2.13 | ---- | Y | 0.16 | 2.78 | decomposed. |
| 87131002 | M-20 | 283 | 7 | 2.17 | ---- | Y | 0.25 | 1.77 | |
| 87131002 | M-20 | 78 | 8 | 1.98 | ---- | N | ---- | 1.44 | |
| 87131002 | M-20 | 234 | 9 | 2.22 | ---- | Y | 0.42 | 1.64 | |
| 87131002 | M-20 | 321 | 10 | 2.49 | ---- | Y | 0.48 | 2.07 | |
| 87131002 | M-20 | 263 | 11 | 1.84 | ---- | Y | 0.38 | 1.42 | |
| 87131002 | M-20 | 456 | 12 | 2.56 | ---- | Y | 0.10 | 2.39 | |
| 87131002 | M-20 | 181 | 13 | 1.77 | ---- | Y | 0.15 | 1.40 | |
| 87131002 | M-20 | 291 | 14 | 2.46 | ---- | Y | 0.41 | 1.73 | |
| 87131002 | M-20 | 121 | 15 | 2.11 | ---- | Y | 0.15 | 1.60 | |

## Tissue Masses and Shell Length Measurements (Page 2)

| SAIC Sample # | MRC Sample # | Shell# | # Individual | Total Shell Length (inches) | Shell Length to Notch (inches) | Gonads Y/N | Gonad Mass (wet g) | Muscle Mass w/o Gonads (wet g) | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| 87131003 | M-21 | 402 | 1 | 3.11 | ---- | Y | 0.65 | 7.24 | |
| 87131003 | M-21 | 435 | 2 | 2.66 | ---- | Y | 2.36 | 7.81 | No notches found |
| 87131003 | M-21 | 136 | 3 | 2.60 | ---- | Y | 2.40 | 6.88 | in shell. |
| 87131003 | M-21 | 434 | 4 | 2.52 | ---- | Y | 1.07 | 8.02 | |
| 87131003 | M-21 | 254 | 5 | 2.17 | ---- | Y | 3.90 | 3.29 | Mussels extremely |
| 87131003 | M-21 | 284 | 6 | 2.32 | ---- | Y | 1.69 | 6.24 | decomposed. |
| 87131003 | M-21 | 219 | 7 | 2.38 | ---- | Y | 0.52 | 1.72 | |
| 87131003 | M-21 | 188 | 8 | 2.09 | ---- | Y | 1.17 | 3.19 | |
| 87131003 | M-21 | 304 | 9 | 2.67 | ---- | Y | 2.30 | 6.90 | |
| 87131003 | M-21 | 53 | 10 | 1.93 | ---- | Y | 0.31 | 1.49 | |
| 87131003 | M-21 | 37 | 11 | 1.72 | ---- | Y | 0.40 | 1.20 | |
| 87131003 | M-21 | 94 | 12 | 1.87 | ---- | Y | 0.47 | 2.83 | |
| 87131003 | M-21 | 181 | 13 | 2.10 | ---- | Y | 0.81 | 4.80 | |
| 87131003 | M-21 | 48 | 14 | 2.27 | ---- | Y | 0.60 | 2.31 | |
| 87131003 | M-21 | 177 | 15 | 1.68 | ---- | Y | 0.20 | 1.24 | |
| 87131004 | M-22 | 310 | 1 | 2.17 | ---- | Y | 0.62 | 3.71 | |
| 87131004 | M-22 | 331 | 2 | 2.46 | ---- | Y | 1.05 | 5.02 | No notches found |
| 87131004 | M-22 | 412 | 3 | 2.80 | ---- | Y | 0.40 | 3.93 | in shell. |
| 87131004 | M-22 | 203 | 4 | 1.87 | ---- | N | ---- | 1.80 | |
| 87131004 | M-22 | 321 | 5 | 2.21 | ---- | Y | 0.50 | 1.88 | Mussels extremely |
| 87131004 | M-22 | 482 | 6 | 2.43 | ---- | Y | 0.42 | 2.30 | decomposed. |
| 87131004 | M-22 | 254 | 7 | 2.43 | ---- | Y | 0.69 | 2.03 | |
| 87131004 | M-22 | ---- | 8 | 2.37 | ---- | Y | 1.03 | 3.41 | |
| 87131004 | M-22 | 68 | 9 | 1.88 | ---- | Y | 0.31 | 1.02 | |
| 87131004 | M-22 | 400 | 10 | 2.61 | ---- | Y | 0.92 | 1.52 | |
| 87131004 | M-22 | ---- | 11 | 2.52 | ---- | Y | 0.60 | 2.70 | |
| 87131004 | M-22 | 111 | 12 | 2.18 | ---- | Y | 0.49 | 1.78 | |
| 87131004 | M-22 | 286 | 13 | 2.19 | ---- | Y | 0.85 | 1.84 | |
| 87131004 | M-22 | 256 | 14 | 2.24 | ---- | Y | 0.58 | 2.56 | |
| 87131004 | M-22 | 407 | 15 | 2.71 | ---- | Y | 1.21 | 2.66 | |

## Tissue Masses and Shell Length Measurements (Page 3)

| SAIC Sample # | MRC Sample # | Shell# | # Individual | Total Shell Length (inches) | Shell Length to Notch (inches) | Gonads Y/N | Gonad Mass (wet g) | Muscle Mass w/o Gonads (wet g) | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| 87131005 | M-23 | 261 | 1 | 2.16 | ---- | Y | 1.12 | 2.96 | |
| 87131005 | M-23 | 29 | 2 | 2.13 | ---- | Y | 1.01 | 2.05 | No notches found |
| 87131005 | M-23 | 152 | 3 | 2.05 | ---- | Y | 1.30 | 3.53 | in shell. |
| 87131005 | M-23 | ---- | 4 | 2.20 | ---- | Y | 1.03 | 4.52 | |
| 87131005 | M-23 | ---- | 5 | 2.54 | ---- | Y | 2.01 | 3.67 | Sample had a |
| 87131005 | M-23 | ---- | 6 | 2.74 | ---- | Y | 2.50 | 3.02 | great deal of |
| 87131005 | M-23 | 412 | 7 | 2.50 | ---- | Y | 0.79 | 3.87 | sediment. |
| 87131005 | M-23 | 179 | 8 | 2.00 | ---- | Y | 1.40 | 2.16 | |
| 87131005 | M-23 | ---- | 9 | 2.06 | ---- | Y | 0.70 | 2.51 | Sample found in |
| 87131005 | M-23 | 256 | 10 | 2.28 | ---- | Y | 1.00 | 2.80 | stapled bag and |
| 87131005 | M-23 | 74 | 11 | 1.83 | ---- | Y | 0.60 | 1.00 | all staples were |
| 87131005 | M-23 | ---- | 12 | 2.24 | ---- | Y | 0.69 | 1.60 | rusted. |
| 87131005 | M-23 | 309 | 13 | 2.23 | ---- | Y | 1.25 | 4.38 | |
| 87131005 | M-23 | ---- | 14 | 2.21 | ---- | Y | 0.83 | 3.18 | Mussels extremely |
| 87131005 | M-23 | ---- | 15 | 2.23 | ---- | Y | 1.05 | 3.34 | decomposed. |
| 87131006 | M-24 | 181 | 1 | 2.13 | ---- | Y | 2.20 | 2.42 | |
| 87131006 | M-24 | 253 | 2 | 2.00 | ---- | Y | 0.35 | 2.25 | No notches found |
| 87131006 | M-24 | 2 | 3 | 1.91 | ---- | Y | 0.40 | 2.28 | in shell. |
| 87131006 | M-24 | 132 | 4 | 2.26 | ---- | Y | 0.65 | 3.32 | |
| 87131006 | M-24 | 244 | 5 | 2.28 | ---- | Y | 0.90 | 3.41 | Sample found in |
| 87131006 | M-24 | 411 | 6 | 2.48 | ---- | Y | 2.00 | 4.22 | stapled bag and |
| 87131006 | M-24 | ---- | 7 | 2.19 | ---- | Y | 0.80 | 3.14 | all staples were |
| 87131006 | M-24 | 425 | 8 | 2.35 | ---- | Y | 0.79 | 2.65 | rusted. |
| 87131006 | M-24 | ---- | 9 | 2.50 | ---- | Y | 1.02 | 4.36 | |
| 87131006 | M-24 | 250 | 10 | 2.21 | ---- | Y | 1.20 | 1.97 | Mussels extremely |
| 87131006 | M-24 | 369 | 11 | 2.24 | ---- | Y | 0.41 | 2.55 | decomposed. |
| 87131006 | M-24 | 233 | 12 | 2.03 | ---- | Y | 0.61 | 1.81 | |
| 87131006 | M-24 | 326 | 13 | 2.15 | ---- | Y | 0.50 | 2.00 | |
| 87131006 | M-24 | 90 | 14 | 1.80 | ---- | N | ---- | 2.07 | |
| 87131006 | M-24 | ---- | 15 | 2.10 | ---- | Y | 0.73 | 2.38 | |

Tissue Masses and Shell Length Measurements (Page 4)

| SAIC Sample # | MRC Sample # | Shell# | # Individual | Total Shell Length (inches) | Shell Length to Notch (inches) | Gonads Y/N | Gonad Mass (wet g) | Muscle Mass w/o Gonads (wet g) | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| 87131007 | M-25 | ---- | 1 | 2.18 | ---- | Y | 1.01 | 3.00 | |
| 87131007 | M-25 | 387 | 2 | 2.28 | ---- | Y | 1.52 | 3.95 | No notches found |
| 87131007 | M-25 | 419 | 3 | 2.17 | ---- | Y | 2.57 | 5.43 | in shell. |
| 87131007 | M-25 | ---- | 4 | 1.89 | ---- | Y | 0.68 | 2.05 | |
| 87131007 | M-25 | 427 | 5 | 2.40 | ---- | Y | 0.91 | 3.68 | Sample found in |
| 87131007 | M-25 | 63 | 6 | 2.01 | ---- | Y | 0.55 | 2.62 | stapled bag and |
| 87131007 | M-25 | 307 | 7 | 2.50 | ---- | Y | 1.54 | 4.64 | all staples were |
| 87131007 | M-25 | 184 | 8 | 2.08 | ---- | Y | 0.62 | 2.86 | rusted. |
| 87131007 | M-25 | 116 | 9 | 2.10 | ---- | Y | 1.35 | 4.53 | |
| 87131007 | M-25 | 402 | 10 | 2.49 | ---- | Y | 1.64 | 5.55 | Mussels extremely |
| 87131007 | M-25 | ---- | 11 | 2.45 | ---- | Y | 2.15 | 5.18 | decomposed. |
| 87131007 | M-25 | 41 | 12 | 1.80 | ---- | N | ---- | 3.02 | |
| 87131007 | M-25 | 105 | 13 | 1.94 | ---- | Y | 0.68 | 3.07 | |
| 87131007 | M-25 | 11 | 14 | 1.85 | ---- | N | ---- | 2.69 | |
| 87131007 | M-25 | 271 | 15 | 1.88 | ---- | N | ---- | 3.16 | |
| 87131008 | M-26 | ---- | 1 | 2.61 | ---- | Y | 1.09 | 4.67 | |
| 87131008 | M-26 | ---- | 2 | 2.54 | ---- | Y | 2.35 | 4.21 | No notches found |
| 87131008 | M-26 | ---- | 3 | 2.41 | ---- | Y | 1.51 | 3.03 | in shell. |
| 87131008 | M-26 | 176 | 4 | 2.27 | ---- | Y | 0.70 | 2.93 | |
| 87131008 | M-26 | 423 | 5 | 2.60 | ---- | Y | 1.44 | 4.31 | Sample found in |
| 87131008 | M-26 | ---- | 6 | 2.22 | ---- | Y | 1.28 | 3.14 | stapled bag and |
| 87131008 | M-26 | ---- | 7 | 2.05 | ---- | Y | 0.45 | 2.45 | all staples were |
| 87131008 | M-26 | ---- | 8 | 2.01 | ---- | N | ---- | 2.86 | rusted. |
| 87131008 | M-26 | 47 | 9 | 1.84 | ---- | N | ---- | 2.18 | |
| 87131008 | M-26 | 329 | 10 | 2.26 | ---- | Y | 1.24 | 3.66 | Mussels extremely |
| 87131008 | M-26 | 63 | 11 | 1.98 | ---- | Y | 0.69 | 2.10 | decomposed. |
| 87131008 | M-26 | 111 | 12 | 2.35 | ---- | Y | 0.80 | 3.08 | |
| 87131008 | M-26 | ---- | 13 | 1.88 | ---- | Y | 0.62 | 2.02 | |
| 87131008 | M-26 | 423 | 14 | 2.57 | ---- | Y | 1.07 | 3.76 | |
| 87131008 | M-26 | ---- | 15 | 2.62 | ---- | Y | 1.73 | 5.35 | |

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REPORT ON ANALYSIS OF 1986 SAMPLES

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COMMITTEE INC

# DATA REPORT FOR BULK ANALYSIS OF MUSSEL SAMPLES FOR TRACE METALS

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May, 1987

## 1.0 INTRODUCTION

This data report "Bulk Analysis of Mussel Samples for Trace Metals" is submitted by Science Applications International Corporation (SAIC), La Jolla, CA to the Marine Review Committee, Inc. (MRC), Encinitas, Ca. Frozen mussel (Mytilus edulis) samples were received by SAIC on April 1, 1987. Samples were placed in a freezer (-20°C) and stored frozen until sample log-in and analysis. Seventeen (17) samples were analyzed (Table 1-1).

A description of the analytical methods and results is presented in Sections 2.0 and 3.0, respectively. Data tape documentation is included as Section 4.0.

## 2.0 METHODS

Whole mussel (Mytilus edulis) samples were received in the frozen state. Next, the samples were logged in according to standard chain-of-custody procedures by assigning. unique SAIC check-in numbers as a cross-reference to all MRC sample numbers. The samples were frozen until preparation and analysis.

In order to minimize the possibility of contamination, all labware used was cleaned in 3N $HNO_3$ for at least 48 hours, followed by rinsing and soaking in deionized water for 24 hours. The labware was then allowed to dry, covered with lab wipers, at ambient laboratory temperature. All sample handling and preparation was carried out in a clean bench or polyethylene hood.

Sample preparation and analysis is discussed in Sections 2.1 and 2.2, respectively.

### 2.1 Samples Preparation (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn)

All bivalve (mussel) samples were dissected while still partially frozen in order to ensure most of the sample is removed from the shell.

The dissection proceeded as follows:

The adducter muscle was cut using a plastic knife, this allows for the mussel to be opened easily. All abyssal hairs were removed using teflon forceps. The gonads were removed from the peripheral of the individual using a teflon policeman. The gonad mass was weighed and recorded. Next, the remaining muscle mass was removed with a teflon policeman, weighed and recorded. After each sample was weighed the muscle tissues were combined for each sample respectively, and placed in a clean, labeled polyethylene bottle. The gonads were combined for each respective sample, and stored in a clean, labeled poylpropylene jar. Ten (10) individuals were dissected and mesured from each sample.

Each individual of a sample was measured for length in the folloiwng manner. A total length of the shell of the individual was measured and recorded. A growth length of the shell of the individual (defined as the distance from 1st notch in shell to the foot of the individual) was measured and recorded. The Caliper used for measuring shell length was a Fowler Carbon Fibre Dial Calipers Dial-15 with a minimum reading of 0.01 inches.

Table 1.1.

MUSSEL SAMPLES TO BE ANALYZED BY SAIC/Batch 1 (SPRING 1987)

| SAIC ID # | MRC ID # |
|---|---|
| | (Mytilus edulis) |
| 87098001 | M-1 |
| 87098002 | M-2 |
| 87098003 | M-3 |
| 87098004 | M-5 |
| 87098005 | M-6 |
| 87098006 | M-7 |
| 87098007 | M-8 |
| 87098008 | M-9 |
| 87098009 | M-10 |
| 87098010 | M-11 |
| 87098011 | M-12 |
| 87098012 | M-13 |
| 87098013 | M-14 |
| 87098014 | M-15 |
| 87098015 | M-16 |
| 87098016 | M-17 |
| 87098017 | M-18 |

Following the dissections, the gonads were stored in a freezer. The muscle tissue samples were homogenized and a aliquot was taken to a constant dry weight using a Virtis Unitrap II freeze-dryer. Following the drying process, the samples were digested in the following manner.

Approximately 0.75 g. of dry homogenized sample was aliquoted and transferred to 30 ml teflon (FEP) screw-cap centrifuge tubes. Next, a modification of the oxidation described by Risby (1979) was performed. Five ml of double distilled concentrated $HNO_3$ (G.F. Smith Company) were added to the samples. The samples were then tightly capped and left to stand overnight, in a hood, at room temperature. The next day the samples were loosely capped and heated in a 95°C water bath for 2 hours. Next, the tubes were removed, tightly capped and placed in an autoclave for 2 hours at a temperature of 115°C. Following this period, the sample tubes were removed, cooled, rinsed with deionized water, and blotted dry with a wiper. The samples were next quantitatively tansferred to 50 ml polypropylene volumetric flasks and brought to volume with deionized Milli-Q water. Lastly, the samples were transferred to labeled 60 ml polyethylene bottles and stored until time for analysis. Sample method blanks and N.R.C. standards were prepared in the same manner.

## 2.2 Sample Analyses (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn)

Samples were analyzed by atomic absorption spectrophotometry (AAS) using both flame and graphite according to parameters outlined in Perkin-Elmer (1976 and 1977). The instrument used is a Perkin-Elmer 603 equipped with air/$C_2H_2$ and $N_2O/C_2H_2$ burners, an HGA-2200 graphite furnace, an AS-1 Autosampler, a deuterium ($D_2$) lamp background corrector and a Perkin-Elmer 056 recorder. The $D_2$ background corrector was used for all analyses. Sample calculations were determined using the method of standard additons (MOSA). Instrument operating conditions and parameters are summarized in Table 2-1 and 2-2. Sample blanks and N.R.C. reference materials were analyzed in the same manner as the samples. AAS working standards were prepared from a mixed 10 ppm stock using Fisher 1000 ppm standards. Computerized data reduction was used for all samples.

## 3.0 RESULTS

Final sample data for Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn concentrations are presented in Table 3-1. Sample precision and accuracy data are presented in Tables 3-2 and 3-3, respectively. The precision and accuracy data are well within acceptable limits. Shell length and gonadal and muscle weights are presented in Appendix A.

## 4.0 DATA TAPE FORMAT/DOCUMENTATION

Documentation for the data tape (submitted as a separate enclosure) is presented in this section. The tape represents those data presented in Tables 3-1 through 3-3., Table 1-1 and Appendix A.

Specification for Data Tape created 6-2-87 by Cynthia Aygarn, SAIC
for MRC Trace Metals in Mussels Analysis.

9-Track, EBCDIC, 1600 BPI
Recordlength = 80 bytes
Blocksize = 80 bytes

There are 5 files on the tape:

1. F1.PRN (Trace Metal concentrations)

| Columns | Description |
|---|---|
| 5-12 | SAIC Sample ID Number |
| 15-18 | MRC Sample ID Number |
| 20-23 | Replicate ID |
| 26-29 | Cd concentration (ug/g) |
| 32-36 | Cr concentration (ug/g) |
| 39-42 | Cu concentration (ug/g) |
| 45-47 | Fe concentration (ug/g) |
| 50-53 | Mn concentration (ug/g) |
| 57 | Qualifier for Ni |
| 58-62 | Ni concentration (ug/g) |
| 65-69 | Pb concentration (ug/g) |
| 72-75 | Zn concentration (ug/g) |

2. F2.PRN (Precision Data)

| Columns | Description |
|---|---|
| 1-8 | SAIC Sample ID Number |
| 11-16 | Sample Description |
| 18 | Replicate ID |
| 21-26 | Cd |
| 29-34 | Cr |
| 37-41 | Cu |
| 44-47 | Fe |
| 50-54 | Mn |
| 56 | Qualifier for Ni |
| 57-61 | Ni |
| 64-68 | Pb |
| 71-75 | Zn |

Note: Replicate E = Mean value
F = Standard Deviation
G = Coefficient of Variation (%)

3. F3.PRN (Accuracy Data)

| Columns | Description |
|---|---|
| 1-2 | Element |
| 19-22 | Reported Value |
| 28-31 | Reported Standard Deviation |
| 38-41 | Certified Value |
| 47-49 | Certified Standard Deviation |
| 73-75 | Percent Recovery |

Specification for Data Tape created 6-2-87 by Cynthia Aygarn, SAIC
for MRC Trace Metals in Mussels Analysis.

4. F4.PRN (Mussel Samples)

| Columns | Description |
|---|---|
| 1-8 | SAIC Sample ID Number |
| 19-22 | MRC Sample ID Number |

5. F5.PRN (Tissue Masses and Shell Length Measurements)

| Columns | Description |
|---|---|
| 2-9 | SAIC Sample ID Number |
| 14-17 | MRC Sample ID Number |
| 19-20 | # Individual |
| 24-27 | Total shell length (inches) |
| 31-34 | Shell length to Notch (inches) |
| 40 | Gonads (Y/N) |
| 45-48 | Gonad Mass (g) |
| 54-57 | Muscle Mass w/o Gonads (g) |

## TABLE 2-1

### INSTRUMENT OPERATING CONDITIONS AND DETECTION LIMITS FOR METALS ANALYZED BY GRAPHITE FURNACE ATOMIC ABSORPTION SPECTROMETRY

| ELEMENT | WAVELENGTH (nm) | CURRENT (mA) | SLIT WIDTH (mm) | INJECTION VOLUME (ul) | GAS | FURNACE CONDITIONS | MINIMUM DETECTION LIMIT (ppb) | ABSOLUTE DETECTION LIMIT (picograms) | SENSITIVITY (ppb/ 0.0044 Abs.) | SENSITIVITY (picograms/ 0.004 Abs.) | ADDITIONAL COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cd | 228.8 | 4 | 1.0 | 10 | Ar(3 sec,normal flow,20) | Dry:110°C,22sec.<br>Char:250°C,22sec.<br>Atomize:2100°C,7sec. | 0.07 | 0.7 | 0.2 | 2 | $D_2$correction |
| Cr | 357.9 | 14 | 1.0 | 20 | Ar(3sec,normal flow,3) | Dry:110°C,22sec.<br>Char:1100°C,22sec.<br>Atomize:2700°C,7sec. | 0.2 | 4 | 0.7 | 14 | $D_2$correction |
| Cu | 324.7 | 10 | 1.0 | 20 | Ar(3sec,normal flow,40) | Dry:110°C,22sec.<br>Char:900°C,22sec.<br>Atomize:2700°C,7sec | 0.6 | 12 | 1.8 | 36 | $D_2$correction |
| Mn | 279.5 | 12 | 1.0 | 20 | Ar(3sec,normal flow,20) | Dry:110°C,22sec.<br>Char:1100°C,22sec<br>Atomize:2700°C,7sec. | 0.1 | 2 | .4 | 8 | $D_2$correction |
| Ni | 232.0 | 15 | 1.0 | 20 | Ar(3sec,normal flow,30) | Dry:110°C,22sec.<br>Char:1000°C,22sec.<br>Atomize:2700°C, 7sec. | 7 | 140 | 9 | 180 | $D_2$correction |
| Pb | 283.3 | 10 | 1.0 | 20 | Ar(3sec,normal flow,20) | Dry:110°C,22sec.<br>Char:750°C,22sec.<br>Atomize:2300°C,7sec. | 0.5 | 10 | 2 | 40 | $D_2$correction |

## TABLE 2-2

Instrument Operating Conditions and Detection Limits for Metals Analyzed by Flame Atomic Absorption Spetrometry

| ELEMENT | WAVELENGTH (nm) | LAMP CURRENT (mA) | SLIT WIDTH (mm) | GAS OXIDANT/FUEL | FLAME TYPE | MINIMUM DETECTION LIMIT (ppm) | SENSIVITY (ppm/0.0044 Abs) | ADDITIONAL COMMENTS |
|---|---|---|---|---|---|---|---|---|
| Cd | 228.8 | 4 | 1.0 | AIR/$C_2H_2$ | Oxidizing | 0.01 | 0.03 | $D_2$ correction |
| Cu | 324.8 | 10 | 1.0 | Air/$C_2H_2$ | Oxidizing | 0.02 | 0.1 | $D_2$ correction |
| Fe | 248.3 | 20 | 1.0 | Air/$C_2H_2$ | Oxidizing | 0.03 | 0.2 | $D_2$ correction |
| Mn | 279.5 | 15 | 1.0 | Air/$C_2H_2$ | Oxidizing | 0.010 | 0.06 | $D_2$ correction |
| Zn | 213.9 | 15 | 1.0 | Air/$C_2H_2$ | Oxidizing | 0.008 | 0.03 | $D_2$ correction |

Table 3.1.

FINAL DATA TABLE (Trace Metals in Tissue)
MRC MUSSELS / Batch 1 (SPRING 1987)

(Concentration in ug/g, dry weight)

| SAIC ID # | Description | Cd | Cr | Cu | Fe | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| | (Mytilus edulis) | | | | | | | | |
| 87098001 | M-1 | 4.57 | 0.843 | 5.24 | 257 | 8.17 | <0.571 | 0.618 | 125 |
| 87098002 | M-2 | 3.87 | 0.890 | 5.32 | 289 | 9.17 | <0.543 | 0.588 | 104 |
| 87098003 | M-3 | 3.53 | 0.935 | 5.15 | 322 | 10.1 | <0.555 | 0.588 | 106 |
| 87098004 | M-5 | 5.02 | 1.34 | 6.22 | 609 | 13.3 | <0.557 | 1.08 | 153 |
| 87098005 | M-6 | 4.21 | 1.25 | 5.85 | 555 | 12.1 | <0.557 | 0.543 | 111 |
| 87098006 | M-7 | 4.34 | 1.17 | 5.60 | 537 | 13.2 | <0.533 | 0.884 | 126 |
| 87098007 | M-8 | 4.29 | 1.44 | 6.16 | 702 | 15.7 | <0.571 | 0.971 | 133 |
| 87098008 | M-9 | 5.11 | 1.46 | 6.05 | 732 | 14.4 | <0.550 | 0.828 | 122 |
| 87098009 | M-10 | 3.42 | 1.70 | 6.22 | 864 | 17.4 | <0.568 | 0.904 | 116 |
| 87098010 | M-11 repA | 3.10 | 1.14 | 6.61 | 491 | 14.7 | <0.561 | 1.30 | 130 |
| 87098010 | M-11 repB | 3.06 | 1.10 | 6.55 | 489 | 15.4 | <0.558 | 0.925 | 129 |
| 87098010 | M-11 repC | 3.09 | 1.19 | 6.53 | 498 | 15.6 | <0.559 | 0.938 | 126 |
| 87098010 | M-11 repD | 3.12 | 1.16 | 6.71 | 510 | 14.6 | <0.556 | 1.55 | 127 |
| 87098011 | M-12 | 3.64 | 1.71 | 5.83 | 857 | 15.6 | <0.558 | 1.25 | 116 |
| 87098012 | M-13 | 3.99 | 1.63 | 6.63 | 878 | 17.7 | <0.562 | 1.09 | 120 |
| 87098013 | M-14 | 3.00 | 1.53 | 6.78 | 803 | 20.0 | <0.554 | 1.65 | 108 |
| 87098014 | M-15 | 3.73 | 1.62 | 5.95 | 843 | 16.4 | <0.557 | 1.46 | 115 |
| 87098015 | M-16 | 3.37 | 0.904 | 5.92 | 285 | 10.8 | <0.552 | 0.844 | 95.0 |
| 87098016 | M-17 | 3.69 | 1.09 | 6.79 | 493 | 12.8 | <0.563 | 1.28 | 141 |
| 87098017 | M-18 | 3.15 | 0.885 | 6.92 | 261 | 11.8 | <0.541 | 1.11 | 152 |
| | method blank #1 (ug) | <0.006 | <0.036 | <0.05 | <3.4 | <0.02 | <0.2 | <0.04 | <0.7 |
| | method blank #2 (ug) | <0.006 | <0.036 | <0.05 | <3.4 | <0.02 | <0.2 | <0.04 | <0.7 |

Table 3.2.

**PRECISION DATA TABLE (Trace Metals in Tissue)**
**MRC MUSSELS / Batch 1 (SPRING 1987)**

(Concentration in ug/g, dry weight)

| SAIC ID # | Description | Cd | Cr | Cu | Fe | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| | (Mytilus edulis) | | | | | | | | |
| 87098010 | M-11 repA | 3.10 | 1.14 | 6.61 | 491 | 14.7 | <0.561 | 1.30 | 130 |
| 87098010 | M-11 repB | 3.06 | 1.10 | 6.55 | 489 | 15.4 | <0.558 | 0.925 | 129 |
| 87098010 | M-11 repC | 3.09 | 1.19 | 6.53 | 498 | 15.6 | <0.559 | 0.938 | 126 |
| 87098010 | M-11 repD | 3.12 | 1.16 | 6.71 | 510 | 14.6 | <0.556 | 1.55 | 127 |
| | $\bar{x}$ | 3.09 | 1.15 | 6.60 | 497 | 15.1 | ---- | 1.18 | 128 |
| | S.D. | 0.0217 | 0.0302 | 0.0700 | 8.22 | 0.432 | ---- | 0.261 | 1.58 |
| | C.V. | 0.7 | 2.6 | 1.1 | 1.7 | 2.9 | ---- | 22.2 | 1.2 |
| 87098018 | TORT-1 rep1 | 27.3 | 1.99 | 414 | 182 | 29.1 | 2.52 | 8.16 | 174 |
| 87098018 | TORT-1 rep2 | 26.7 | 2.76 | 406 | 207 | 24.1 | 2.00 | 8.92 | 169 |
| 87098018 | TORT-1 rep3 | 28.5 | 2.79 | 418 | 195 | 26.0 | 2.25 | 8.3 | 174 |
| | $\bar{x}$ | 27.5 | 2.51 | 413 | 195 | 26.4 | 2.25 | 8.45 | 172 |
| | S.D. | 0.75 | 0.370 | 5.0 | 10.2 | 2.06 | 0.212 | 0.34 | 2.36 |
| | C.V. | 2.7 | 14.7 | 1.2 | 5.2 | 7.8 | 9.4 | 4.0 | 1.4 |

Table 3.3.

ACCURACY DATA TABLE (Trace Metals in Tissue)
MRC MUSSELS / Batch 1 (SPRING 1987)

NRC Lobster Hepatopancreas Tissue (TORT-1)
(concentration in ug/g dry weight)

| ELEMENT | SAIC REPORTED VALUE | NRC CERTIFIED VALUE[1] | % RECOVERY |
|---|---|---|---|
| Cd | 27.5 +/- 0.75 | 26.3 +/- 2.1 | 105 |
| Cr | 2.51 +/- .4 | 2.4 +/- 0.6 | 105 |
| Cu | 413. +/- 5.0 | 439. +/- 22. | 94 |
| Fe | 195. +/- 10. | 186. +/- 11. | 105 |
| Mn | 26.4 +/- 2.0 | 23.4 +/- 1.0 | 113 |
| Ni | 2.25 +/- .2 | 2.3 +/- 0.3 | 98 |
| Pb | 8.45 +/- 0.3 | 10.4 +/- 2.0 | 81 |
| Zn | 172 +/- 2.4 | 177. +/- 10. | 97 |

---

[1] This is a certified reference material distributed by the National Research Council of Canada Ottawa, Canada KIA 0R6.

# APPENDIX A

Tissue Masses and Shell Length Measurements

| SAIC Sample # | MRC Sample # | # Individuals | Total Shell Length (inches) | Shell Length to Notch (inches) | Gonads Y/N | Gonad Mass (wet g) | Muscle Mass w/o Gonads (wet g) |
|---|---|---|---|---|---|---|---|
| 87098001 | M-1 | 1 | 2.96 | 2.07 | Y | 4.91 | 10.37 |
| 87098001 | M-1 | 2 | 2.82 | 2.38 | Y | 5.54 | 7.50 |
| 87098001 | M-1 | 3 | 2.60 | 2.12 | Y | 5.55 | 7.08 |
| 87098001 | M-1 | 4 | 2.76 | 2.21 | Y | 4.89 | 9.40 |
| 87098001 | M-1 | 5 | 2.88 | 2.01 | Y | 3.13 | 8.31 |
| 87098001 | M-1 | 6 | 2.76 | 2.07 | Y | 4.15 | 7.00 |
| 87098001 | M-1 | 7 | 2.89 | 2.27 | Y | 5.30 | 8.12 |
| 87098001 | M-1 | 8 | 3.09 | 2.53 | Y | 7.25 | 10.18 |
| 87098001 | M-1 | 9 | 2.64 | 2.10 | Y | 4.00 | 8.99 |
| 87098001 | M-1 | 10 | 2.65 | 2.20 | Y | 4.20 | 7.00 |
| 87098002 | M-2 | 1 | 3.00 | 2.40 | Y | 5.97 | 9.63 |
| 87098002 | M-2 | 2 | 2.70 | 2.31 | Y | 3.91 | 8.16 |
| 87098002 | M-2 | 3 | 2.56 | 2.04 | Y | 3.47 | 6.04 |
| 87098002 | M-2 | 4 | 2.71 | 2.20 | Y | 5.10 | 7.53 |
| 87098002 | M-2 | 5 | 2.59 | 2.04 | Y | 5.60 | 8.00 |
| 87098002 | M-2 | 6 | 2.80 | 2.02 | Y | 3.52 | 7.86 |
| 87098002 | M-2 | 7 | 2.62 | 2.09 | Y | 4.30 | 8.50 |
| 87098002 | M-2 | 8 | 2.66 | 2.08 | Y | 3.61 | 8.33 |
| 87098002 | M-2 | 9 | 2.61 | 1.80 | Y | 3.52 | 6.87 |
| 87098002 | M-2 | 10 | 2.76 | 2.28 | Y | 3.72 | 8.57 |
| 87098003 | M-3 | 1 | 2.67 | 2.05 | Y | 3.72 | 6.26 |
| 87098003 | M-3 | 2 | 2.67 | 2.17 | Y | 3.84 | 7.11 |
| 87098003 | M-3 | 3 | 2.77 | 2.11 | Y | 4.17 | 7.14 |
| 87098003 | M-3 | 4 | 2.92 | 2.08 | Y | 0.99 | 7.85 |
| 87098003 | M-3 | 5 | 2.84 | 2.09 | Y | 4.87 | 8.40 |
| 87098003 | M-3 | 6 | 2.98 | 2.48 | Y | 3.31 | 8.52 |
| 87098003 | M-3 | 7 | 2.66 | 1.97 | Y | 3.01 | 5.40 |
| 87098003 | M-3 | 8 | 2.48 | 1.95 | Y | 3.10 | 6.10 |
| 87098003 | M-3 | 9 | 2.62 | 2.16 | Y | 3.64 | 7.59 |
| 87098003 | M-3 | 10 | 2.72 | 2.11 | Y | 2.96 | 7.09 |
| 87098004 | M-5 | 1 | 2.74 | 2.24 | Y | 4.00 | 7.00 |
| 87098004 | M-5 | 2 | 2.85 | 2.02 | Y | 2.82 | 7.90 |
| 87098004 | M-5 | 3 | 2.50 | 2.08 | Y | 1.80 | 4.52 |
| 87098004 | M-5 | 4 | 2.55 | 2.03 | Y | 1.62 | 5.04 |
| 87098004 | M-5 | 5 | 2.68 | 2.32 | Y | 2.15 | 7.48 |
| 87098004 | M-5 | 6 | 2.70 | 2.12 | Y | 3.37 | 6.53 |
| 87098004 | M-5 | 7 | 2.58 | 2.14 | Y | 2.89 | 7.17 |
| 87098004 | M-5 | 8 | 2.60 | 2.18 | Y | 1.92 | 5.64 |
| 87098004 | M-5 | 9 | 2.65 | 2.21 | Y | 1.85 | 4.60 |
| 87098004 | M-5 | 10 | 2.43 | 1.81 | Y | 1.93 | 4.03 |
| 87098005 | M-6 | 1 | 2.70 | 2.14 | Y | 3.81 | 7.84 |
| 87098005 | M-6 | 2 | 2.78 | 2.28 | Y | 4.12 | 7.08 |
| 87098005 | M-6 | 3 | 2.49 | 1.96 | Y | 2.16 | 6.02 |
| 87098005 | M-6 | 4 | 3.03 | 2.35 | Y | 3.81 | 6.61 |
| 87098005 | M-6 | 5 | 2.68 | 2.20 | Y | 3.19 | 6.43 |

Tissue Masses and Shell Length Measurements (Page 2)

| SAIC Sample # | MRC Sample # | # Individuals | Total Shell Length (inches) | Shell Length to Notch (inches) | Gonads Y/N | Gonad Mass (wet g) | Muscle Mass w/o Gonads (wet g) |
|---|---|---|---|---|---|---|---|
| 87098005 | M-6 | 6 | 2.62 | 1.89 | Y | 3.51 | 6.09 |
| 87098005 | M-6 | 7 | 2.43 | 2.10 | Y | 3.69 | 4.82 |
| 87098005 | M-6 | 8 | 2.78 | 2.22 | Y | 4.14 | 7.29 |
| 87098005 | M-6 | 9 | 2.60 | 2.14 | Y | 4.42 | 6.67 |
| 87098005 | M-6 | 10 | 2.47 | 2.20 | Y | 3.85 | 3.97 |
| 87098006 | M-7 | 1 | 2.60 | 2.42 | Y | 4.86 | 8.87 |
| 87098006 | M-7 | 2 | 2.80 | 2.24 | Y | 1.00 | 5.65 |
| 87098006 | M-7 | 3 | 2.72 | 2.10 | Y | 4.49 | 5.98 |
| 87098006 | M-7 | 4 | 2.62 | 2.13 | Y | 1.42 | 3.32 |
| 87098006 | M-7 | 5 | 2.53 | 1.93 | Y | 3.76 | 4.55 |
| 87098006 | M-7 | 6 | 2.54 | 2.06 | Y | 3.38 | 4.68 |
| 87098006 | M-7 | 7 | 2.53 | 2.20 | Y | 6.88 | 6.56 |
| 87098006 | M-7 | 8 | 2.63 | 2.16 | Y | 4.44 | 6.67 |
| 87098006 | M-7 | 9 | 2.59 | 2.25 | Y | 1.40 | 2.80 |
| 87098006 | M-7 | 10 | 2.50 | 2.17 | Y | 1.66 | 5.28 |
| 87098007 | M-8 | 1 | 2.54 | 2.04 | Y | 2.42 | 3.64 |
| 87098007 | M-8 | 2 | 2.67 | 2.16 | Y | 2.98 | 7.24 |
| 87098007 | M-8 | 3 | 2.58 | 2.15 | Y | 6.34 | 4.17 |
| 87098007 | M-8 | 4 | 2.59 | 2.08 | Y | 4.89 | 5.41 |
| 87098007 | M-8 | 5 | 2.64 | 2.10 | Y | 4.84 | 6.48 |
| 87098007 | M-8 | 6 | 2.52 | 1.99 | Y | 1.04 | 3.18 |
| 87098007 | M-8 | 7 | 2.57 | 2.11 | Y | 8.42 | 5.06 |
| 87098007 | M-8 | 8 | 2.54 | 2.20 | Y | 3.38 | 5.16 |
| 87098007 | M-8 | 9 | 2.84 | 2.12 | Y | 4.21 | 7.51 |
| 87098007 | M-8 | 10 | 2.40 | 2.06 | Y | 3.24 | 4.90 |
| 87098008 | M-9 | 1 | 2.25 | 2.00 | Y | 3.66 | 4.06 |
| 87098008 | M-9 | 2 | 2.66 | 2.05 | Y | 5.16 | 7.25 |
| 87098008 | M-9 | 3 | 2.48 | 2.00 | Y | 3.07 | 5.16 |
| 87098008 | M-9 | 4 | 2.45 | 1.95 | Y | 4.35 | 5.32 |
| 87098008 | M-9 | 5 | 2.48 | 2.16 | Y | 3.20 | 6.71 |
| 87098008 | M-9 | 6 | 2.52 | 2.00 | Y | 3.03 | 5.87 |
| 87098008 | M-9 | 7 | 2.50 | 2.00 | Y | 1.70 | 4.80 |
| 87098008 | M-9 | 8 | 2.37 | 2.02 | Y | 3.41 | 4.72 |
| 87098008 | M-9 | 9 | 2.50 | 2.20 | Y | 3.52 | 5.11 |
| 87098008 | M-9 | 10 | 2.50 | 2.09 | Y | 4.83 | 6.09 |
| 87098009 | M-10 | 1 | 3.10 | 2.35 | Y | 5.27 | 7.60 |
| 87098009 | M-10 | 2 | 2.73 | 1.94 | Y | 3.83 | 6.51 |
| 87098009 | M-10 | 3 | 2.76 | 2.02 | Y | 2.78 | 5.17 |
| 87098009 | M-10 | 4 | 3.09 | 2.34 | Y | 5.19 | 7.05 |
| 87098009 | M-10 | 5 | 2.67 | 2.09 | Y | 6.00 | 6.92 |
| 87098009 | M-10 | 6 | 2.94 | 2.17 | Y | 5.54 | 6.57 |
| 87098009 | M-10 | 7 | 2.55 | 2.01 | Y | 4.34 | 6.51 |
| 87098009 | M-10 | 8 | 2.83 | 2.26 | Y | 6.70 | 6.55 |
| 87098009 | M-10 | 9 | 2.73 | 2.04 | Y | 6.49 | 5.26 |
| 87098009 | M-10 | 10 | 2.47 | 2.12 | Y | 3.36 | 5.01 |

| SAIC Sample # | MRC Sample # | # Individuals | Total Shell Length (inches) | Shell Length to Notch (inches) | Gonads Y/N | Gonad Mass (wet g) | Muscle Mass w/o Gonads (wet g) |
|---|---|---|---|---|---|---|---|
| 87098010 | M-11 | 1 | 3.06 | 2.24 | Y | 4.17 | 8.63 |
| 87098010 | M-11 | 2 | 2.21 | 2.09 | Y | 4.04 | 5.95 |
| 87098010 | M-11 | 3 | 2.82 | 2.12 | Y | 4.48 | 6.65 |
| 87098010 | M-11 | 4 | 2.72 | 2.27 | Y | 3.20 | 5.69 |
| 87098010 | M-11 | 5 | 3.04 | 2.30 | Y | 4.60 | 6.56 |
| 87098010 | M-11 | 6 | 2.82 | 2.10 | Y | 5.57 | 7.63 |
| 87098010 | M-11 | 7 | 2.25 | 2.00 | Y | 3.17 | 5.52 |
| 87098010 | M-11 | 8 | 2.70 | 2.04 | Y | 5.10 | 6.62 |
| 87098010 | M-11 | 9 | 2.55 | 2.10 | Y | 2.63 | 4.78 |
| 87098010 | M-11 | 10 | 2.74 | 2.04 | Y | 5.09 | 6.59 |
| 87098011 | M-12 | 1 | 2.78 | 2.17 | Y | 5.06 | 4.59 |
| 87098011 | M-12 | 2 | 3.16 | 2.30 | Y | 5.93 | 6.69 |
| 87098011 | M-12 | 3 | 2.94 | 2.36 | Y | 4.78 | 6.36 |
| 87098011 | M-12 | 4 | 2.82 | 2.00 | Y | 3.16 | 1.05 |
| 87098011 | M-12 | 5 | 2.79 | 2.24 | Y | 5.83 | 6.01 |
| 87098011 | M-12 | 6 | 2.57 | 2.06 | Y | 3.86 | 5.29 |
| 87098011 | M-12 | 7 | 2.26 | 2.03 | Y | 2.38 | 3.10 |
| 87098011 | M-12 | 8 | 2.68 | 2.20 | Y | 5.83 | 5.12 |
| 87098011 | M-12 | 9 | 2.68 | 1.98 | Y | 3.98 | 5.74 |
| 87098011 | M-12 | 10 | 2.81 | 2.20 | Y | 6.28 | 5.15 |
| 87098012 | M-13 | 1 | 2.88 | 2.01 | Y | 2.36 | 5.18 |
| 87098012 | M-13 | 2 | 2.78 | 2.02 | Y | 2.84 | 5.25 |
| 87098012 | M-13 | 3 | 2.74 | 2.03 | Y | 1.60 | 3.93 |
| 87098012 | M-13 | 4 | 2.65 | 2.13 | Y | 1.37 | 3.84 |
| 87098012 | M-13 | 5 | 3.03 | 2.31 | Y | 4.17 | 7.74 |
| 87098012 | M-13 | 6 | 2.69 | 2.09 | Y | 1.23 | 3.80 |
| 87098012 | M-13 | 7 | 2.73 | 2.15 | Y | 2.12 | 4.59 |
| 87098012 | M-13 | 8 | 2.95 | 2.28 | Y | 2.21 | 5.14 |
| 87098012 | M-13 | 9 | 2.70 | 1.90 | Y | 2.51 | 3.93 |
| 87098012 | M-13 | 10 | 2.39 | 2.06 | Y | 1.35 | 3.89 |
| 87098013 | M-14 | 1 | 2.83 | 2.18 | Y | 5.45 | 5.24 |
| 87098013 | M-14 | 2 | 2.77 | 2.16 | Y | 3.42 | 5.46 |
| 87098013 | M-14 | 3 | 2.59 | 1.98 | Y | 3.78 | 4.51 |
| 87098013 | M-14 | 4 | 2.75 | 2.22 | Y | 4.51 | 6.43 |
| 87098013 | M-14 | 5 | 2.50 | 2.20 | Y | 3.88 | 5.60 |
| 87098013 | M-14 | 6 | 3.25 | 2.28 | Y | 4.22 | 5.82 |
| 87098013 | M-14 | 7 | 2.71 | 1.97 | Y | 1.76 | 4.13 |
| 87098013 | M-14 | 8 | 2.70 | 2.10 | Y | 2.96 | 5.14 |
| 87098013 | M-14 | 9 | 2.62 | 1.98 | Y | 3.07 | 5.85 |
| 87098013 | M-14 | 10 | 2.60 | 1.93 | Y | 2.77 | 5.09 |
| 87098014 | M-15 | 1 | 2.61 | 1.98 | Y | 3.63 | 5.59 |
| 87098014 | M-15 | 2 | 2.49 | 2.13 | Y | 3.03 | 5.02 |
| 87098014 | M-15 | 3 | 2.84 | 2.37 | Y | 2.94 | 6.81 |
| 87098014 | M-15 | 4 | 2.44 | 1.77 | Y | 2.32 | 5.12 |
| 87098014 | M-15 | 5 | 2.77 | 2.23 | Y | 2.06 | 5.63 |

Tissue Masses and Shell Length Measurements (Page 4)

| SAIC Sample # | MRC Sample # | # Individuals | Total Shell Length (inches) | Shell Length to Notch (inches) | Gonads Y/N | Gonad Mass (wet g) | Muscle Mass w/o Gonads (wet g) |
|---|---|---|---|---|---|---|---|
| 87098014 | M-15 | 6 | 2.24 | 2.04 | Y | 1.57 | 3.77 |
| 87098014 | M-15 | 7 | 2.69 | 1.76 | Y | 1.48 | 3.81 |
| 87098014 | M-15 | 8 | 2.69 | 2.19 | Y | 4.38 | 5.92 |
| 87098014 | M-15 | 9 | 2.68 | 2.08 | Y | 4.12 | 5.37 |
| 87098014 | M-15 | 10 | 2.57 | 1.99 | Y | 3.91 | 6.48 |
| 87098015 | M-16 | 1 | 2.87 | 2.24 | Y | 5.60 | 6.95 |
| 87098015 | M-16 | 2 | 2.82 | 2.12 | Y | 5.38 | 5.87 |
| 87098015 | M-16 | 3 | 2.64 | 2.16 | Y | 4.81 | 6.23 |
| 87098015 | M-16 | 4 | 2.56 | 2.10 | Y | 3.54 | 5.69 |
| 87098015 | M-16 | 5 | 2.61 | 2.03 | Y | 2.38 | 4.52 |
| 87098015 | M-16 | 6 | 2.71 | 2.15 | Y | 4.77 | 6.34 |
| 87098015 | M-16 | 7 | 2.97 | 2.18 | Y | 4.26 | 7.73 |
| 87098015 | M-16 | 8 | 2.37 | 1.96 | Y | 3.56 | 4.88 |
| 87098015 | M-16 | 9 | 2.54 | 1.91 | Y | 3.73 | 5.54 |
| 87098015 | M-16 | 10 | 2.78 | 1.98 | Y | 3.56 | 5.39 |
| 87098016 | M-17 | 1 | 2.75 | 1.94 | Y | 4.48 | 5.63 |
| 87098016 | M-17 | 2 | 2.79 | 1.99 | Y | 4.45 | 5.97 |
| 87098016 | M-17 | 3 | 2.53 | 2.02 | Y | 3.24 | 5.85 |
| 87098016 | M-17 | 4 | 2.80 | 2.03 | Y | 4.41 | 6.14 |
| 87098016 | M-17 | 5 | 2.37 | 2.00 | Y | 2.72 | 3.46 |
| 87098016 | M-17 | 6 | 2.99 | 2.29 | Y | 2.54 | 6.67 |
| 87098016 | M-17 | 7 | 2.71 | 2.01 | Y | 4.12 | 5.92 |
| 87098016 | M-17 | 8 | 2.33 | 1.98 | Y | 2.12 | 3.18 |
| 87098016 | M-17 | 9 | 3.02 | 2.26 | Y | 4.47 | 7.25 |
| 87098016 | M-17 | 10 | 2.82 | 2.22 | Y | 4.38 | 5.95 |
| 87098015 | M-16 | 1 | 2.68 | 2.02 | Y | 4.19 | 5.45 |
| 87098015 | M-16 | 2 | 2.74 | 2.32 | Y | 3.73 | 5.41 |
| 87098015 | M-16 | 3 | 2.90 | 2.28 | Y | 3.69 | 7.22 |
| 87098015 | M-16 | 4 | 2.53 | 2.09 | Y | 2.57 | 4.29 |
| 87098015 | M-16 | 5 | 3.03 | 2.02 | Y | 3.05 | 6.92 |
| 87098015 | M-16 | 6 | 2.89 | 2.18 | Y | 4.60 | 5.28 |
| 87098015 | M-16 | 7 | 2.55 | 2.06 | Y | 3.83 | 4.95 |
| 87098015 | M-16 | 8 | 2.80 | 2.30 | Y | 8.11 | 6.06 |
| 87098015 | M-16 | 9 | 2.92 | 2.22 | Y | 4.50 | 7.10 |
| 87098015 | M-16 | 10 | 2.81 | 2.12 | Y | 3.02 | 4.43 |

# REFERENCES

Perkin-Elmer, 1976. Analytical Methods for Atomic Absorption Spectrophotometry #303-0152.

Perkin-Elmer, 1977. Analytical Methods for Atmoic Absorption Spectrophotometry Using the HGA Graphite Furnace, #993-9312.

Risby, T. H., 1979. Ultra Metal Analysis in Biological Science and Environment. American Chemical Society, Washington, D.C., 263 pp.

# Appendix C: Map of sampling locations and metal concentrations detected in water and sediment samples collected by SCE from 1975-1979. From SCE (1980).

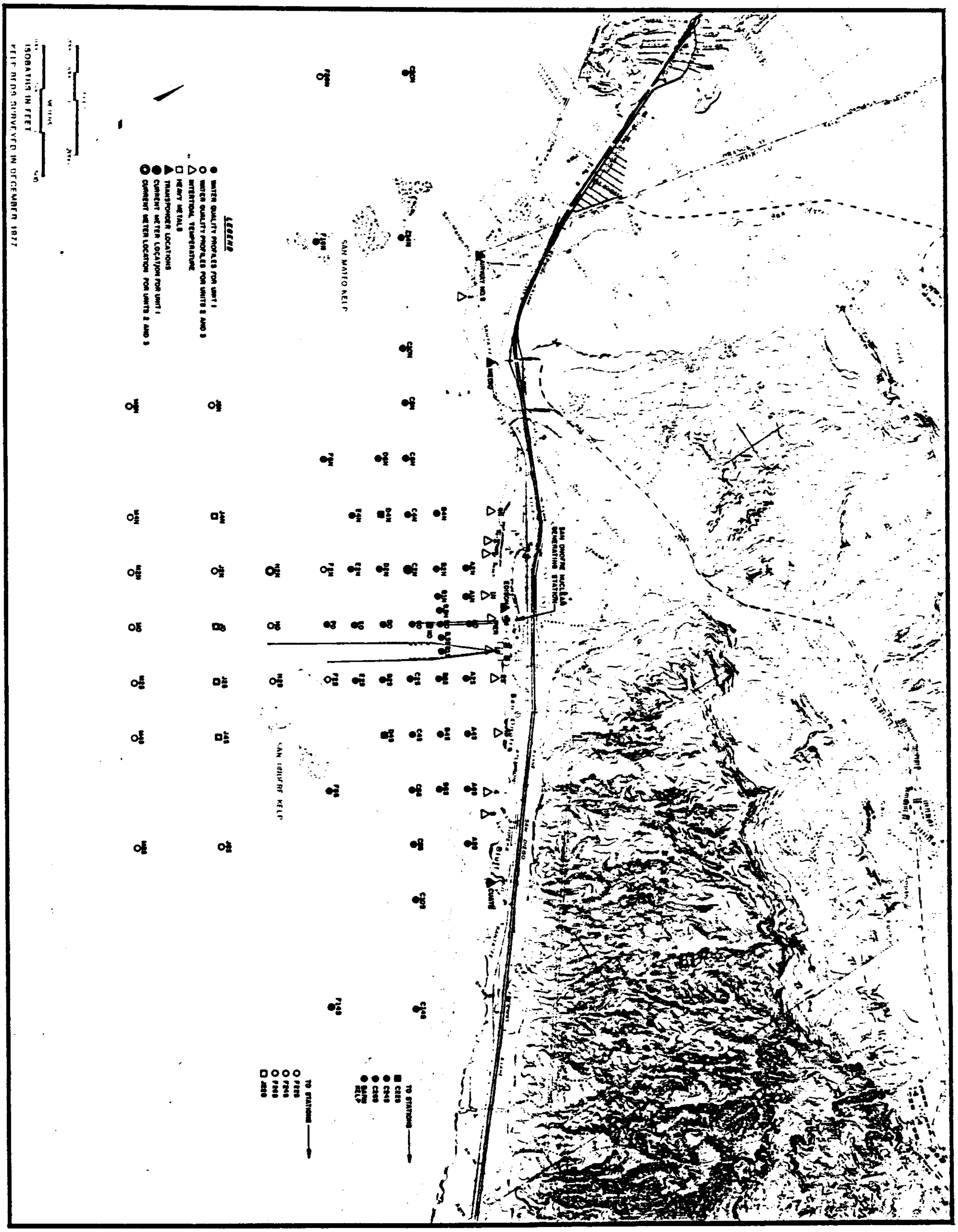

Figure 2A-2. Location and identification of oceanographic sampling stations.

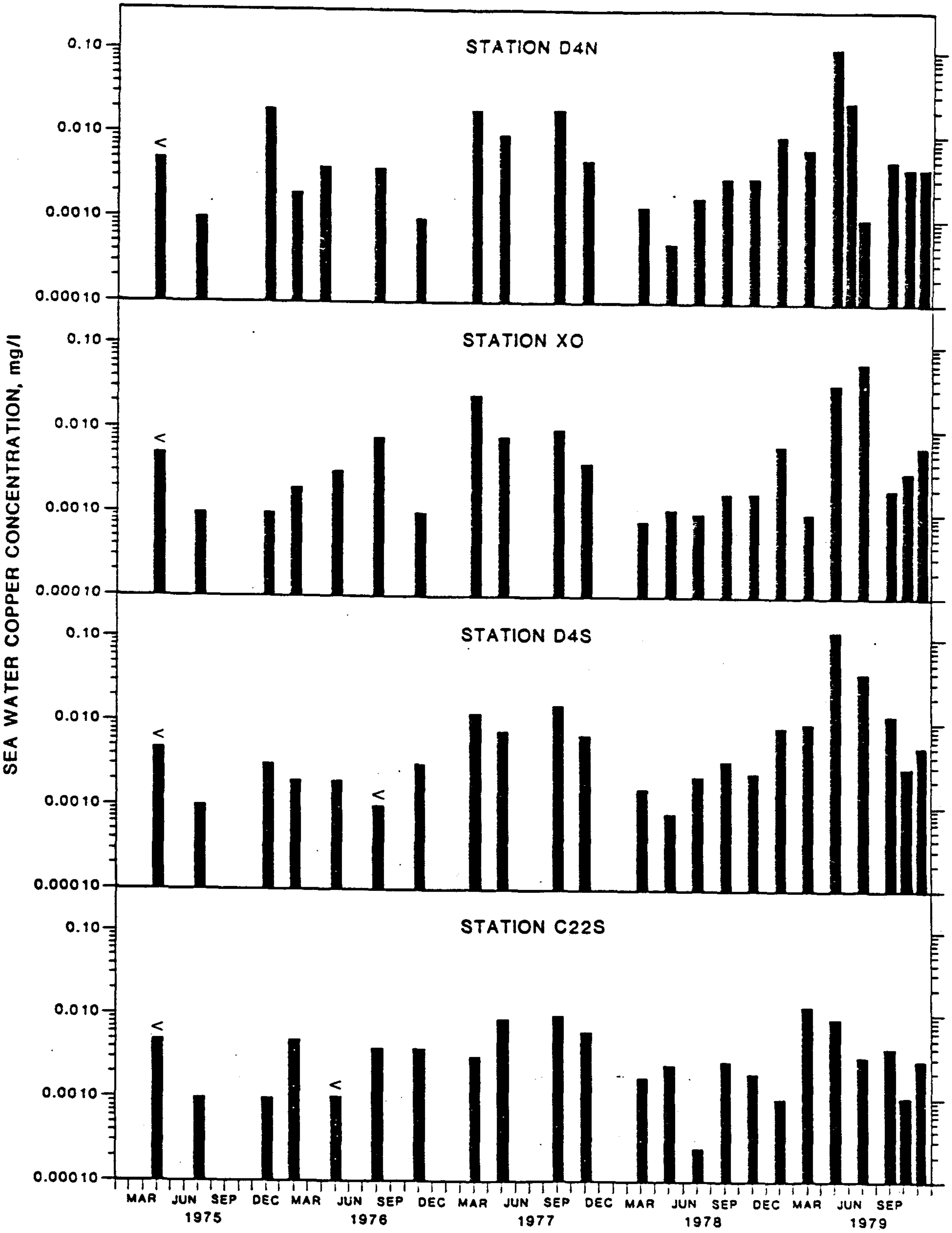

Figure III-1. Copper concentration in seawater from 1975 through 1979 at SONGS 1 stations.

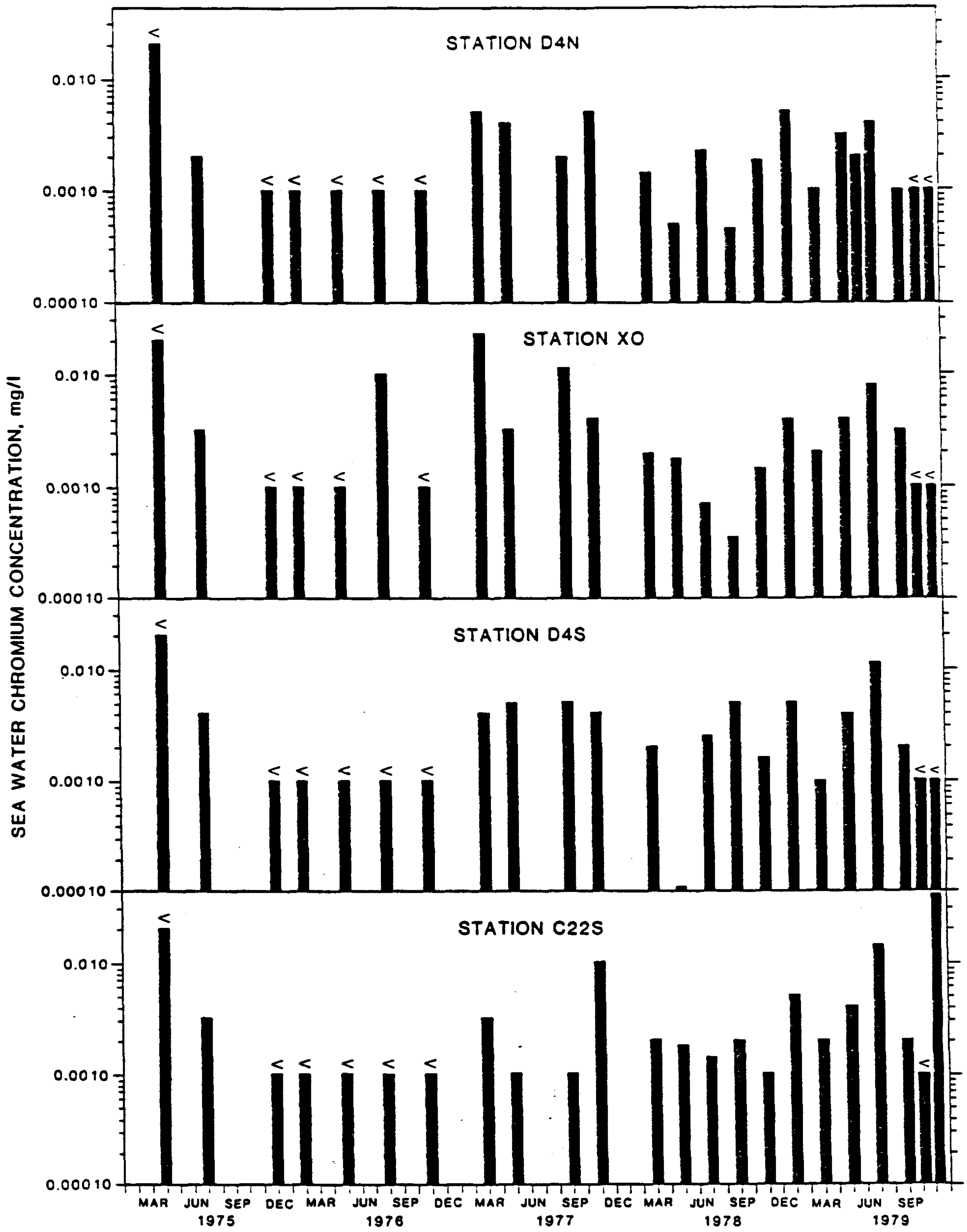

Figure III-2. Chromium concentration in seawater from 1975 through 1979 at SONGS 1 stations.

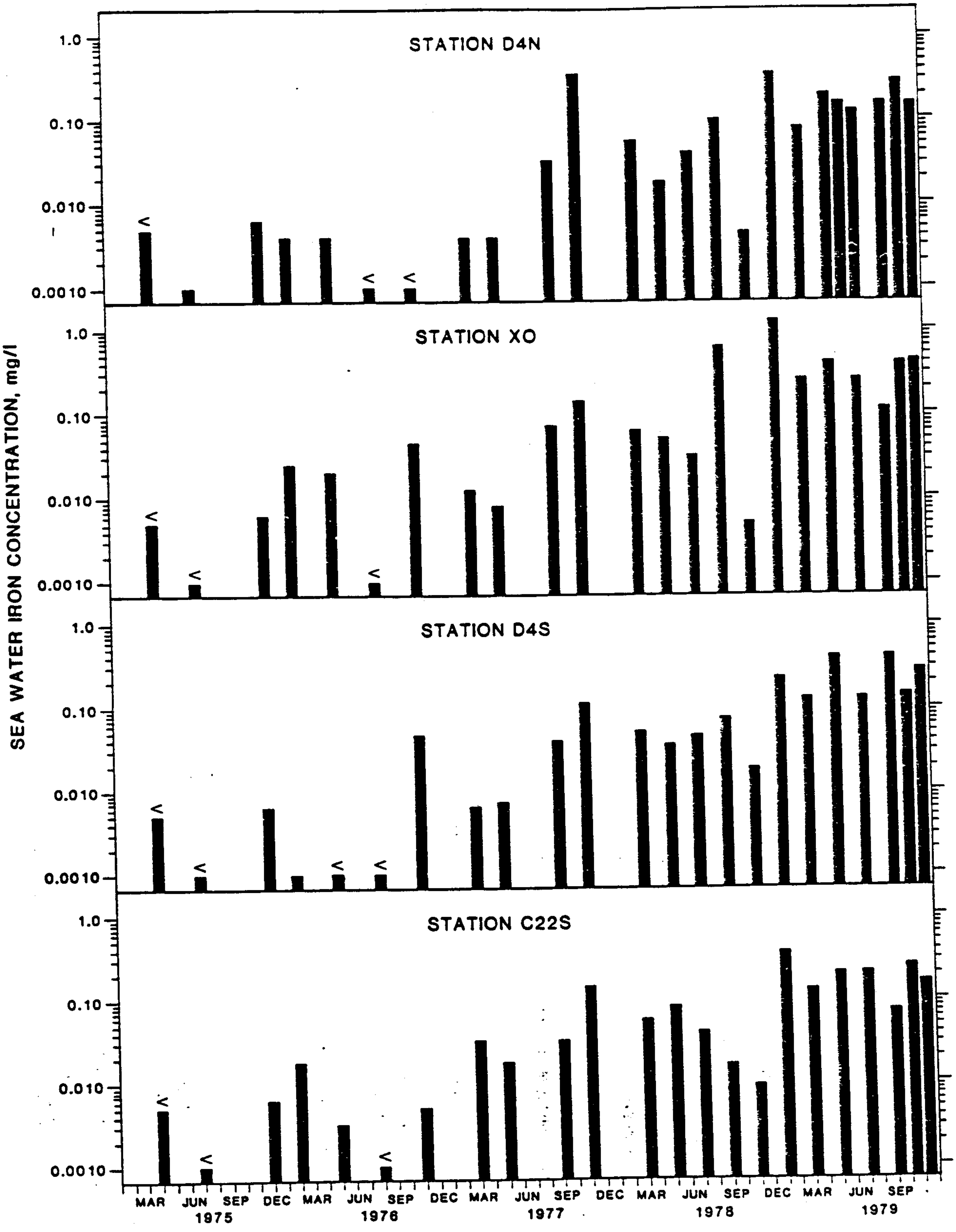

Figure III-3. Iron concentration in seawater from 1975 through 1979 at SONGS 1 stations.

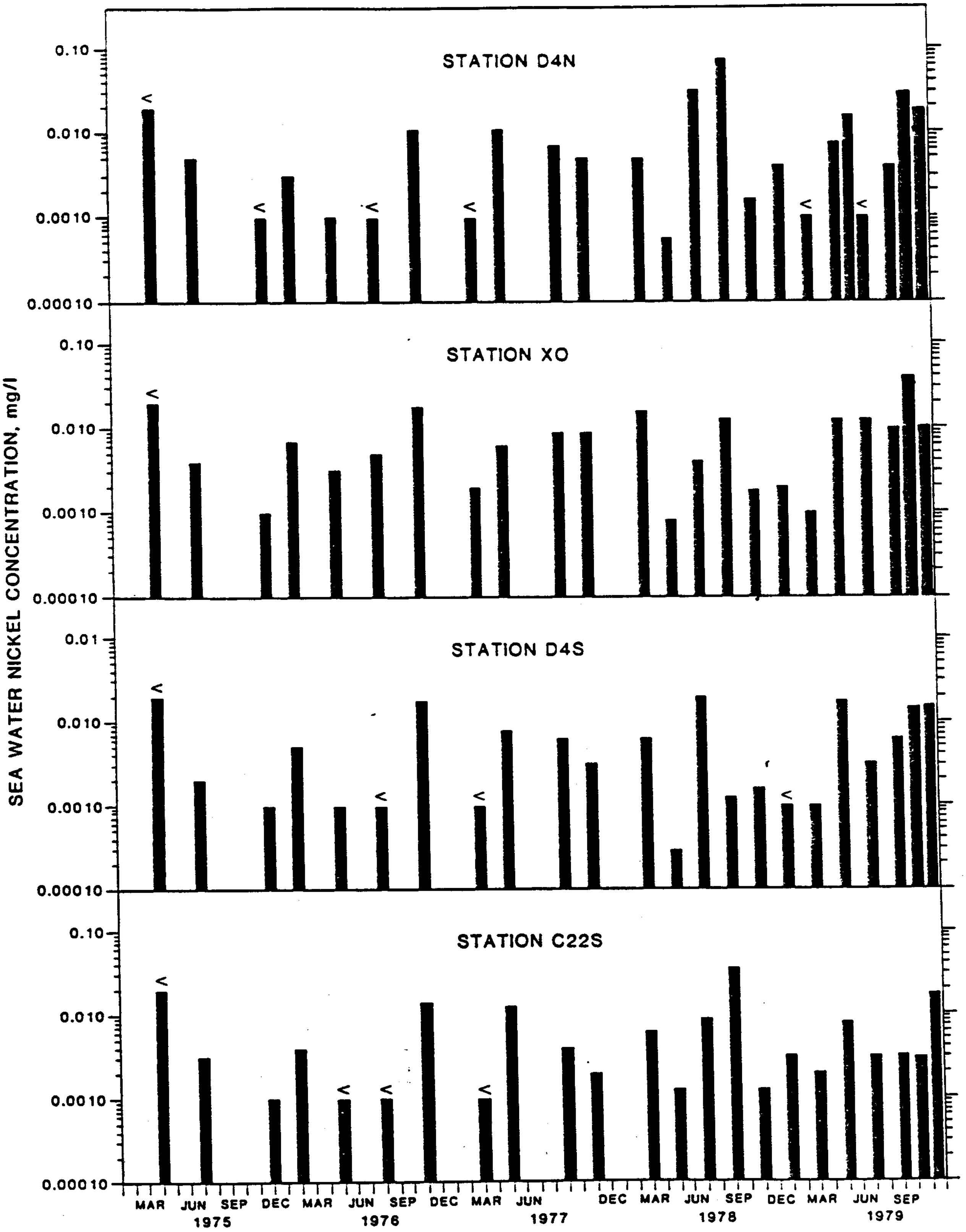

**Figure III-4.** Nickel concentration in seawater from 1975 through 1979 at SONGS 1 stations.

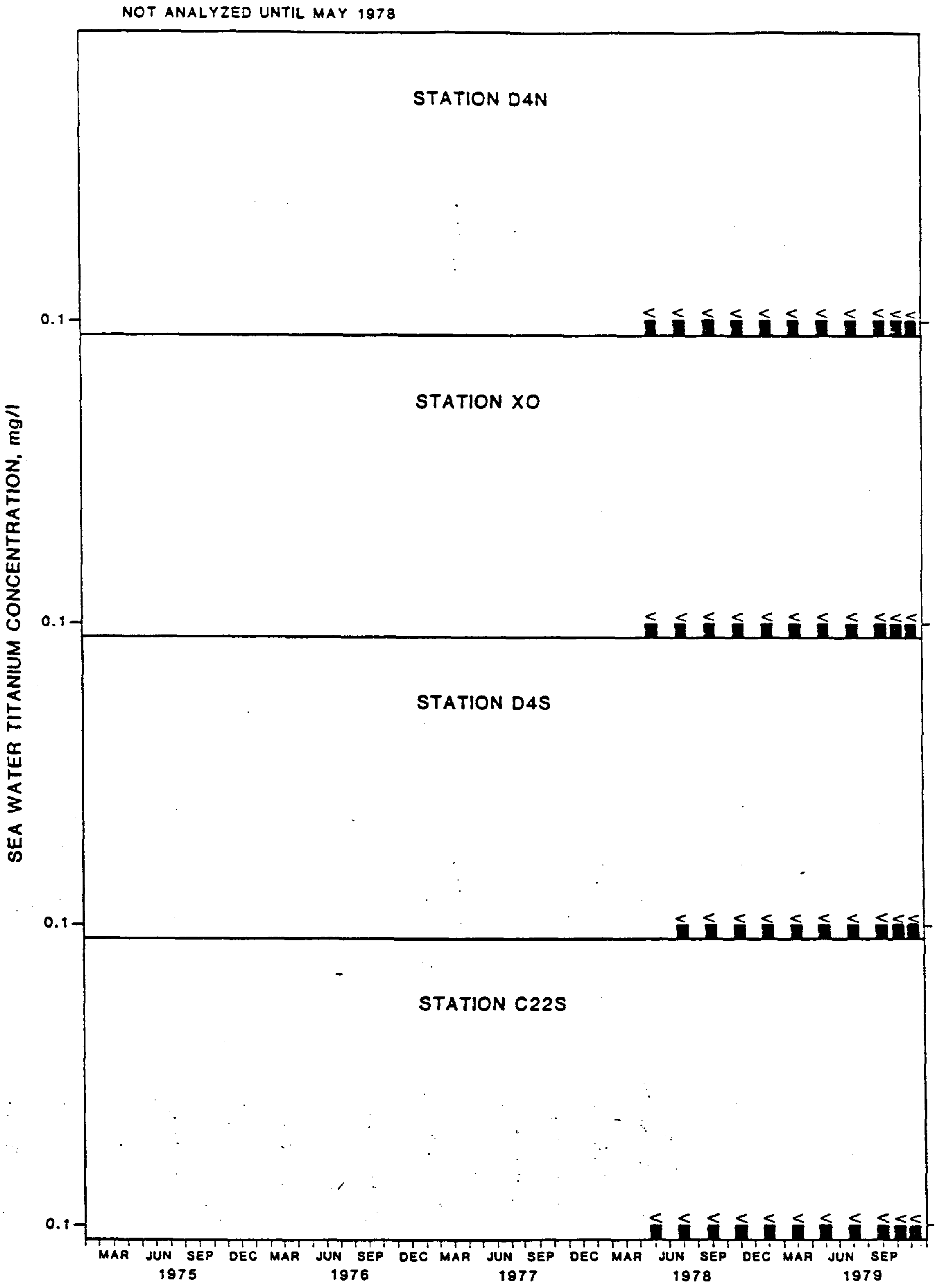

Figure III-5. Titanium concentration in seawater from 1978 through 1979 at SONGS 1 stations.

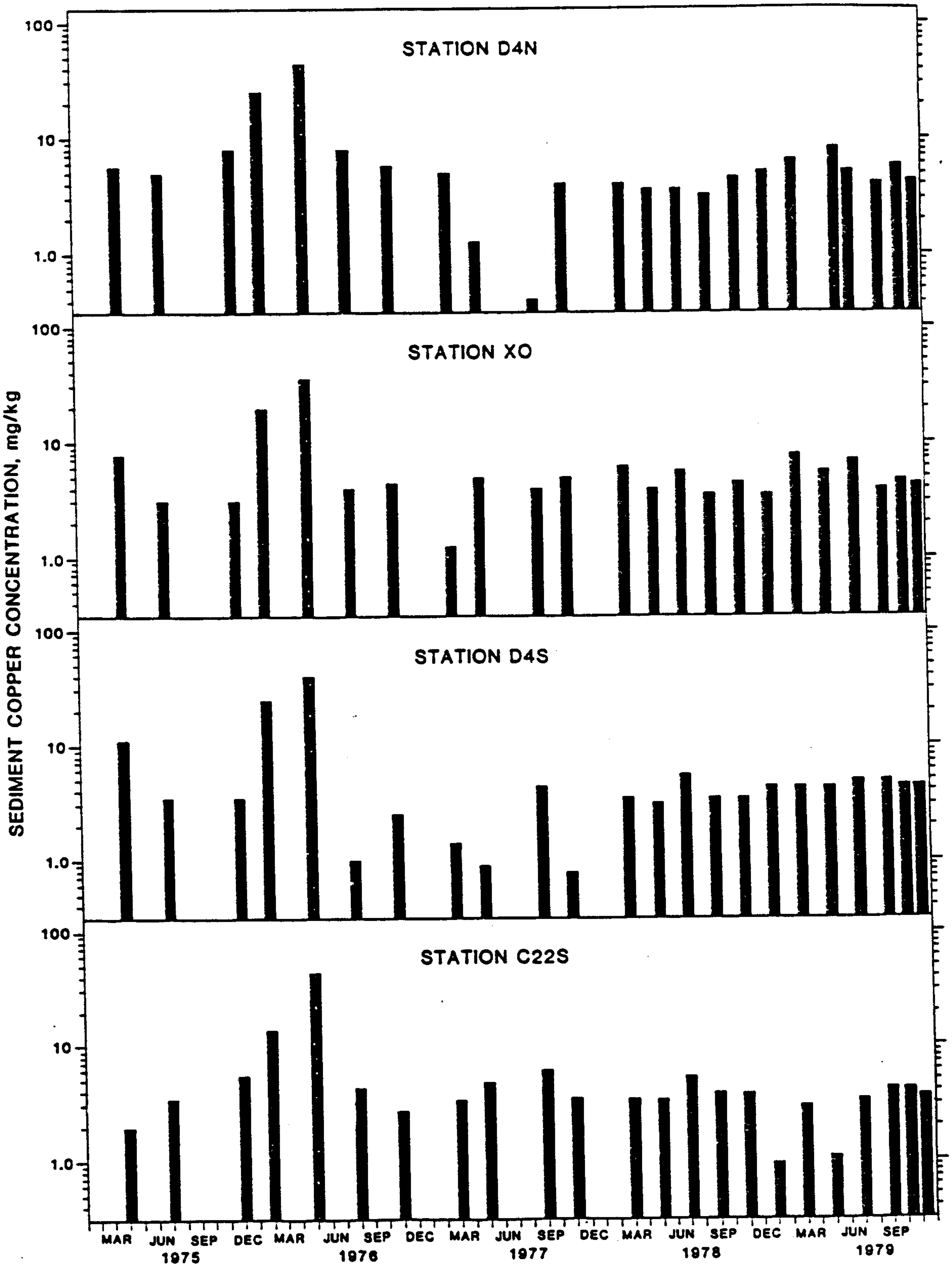

Figure III-6. Copper concentration in sediment from 1975 through 1979 at SONGS 1 stations.

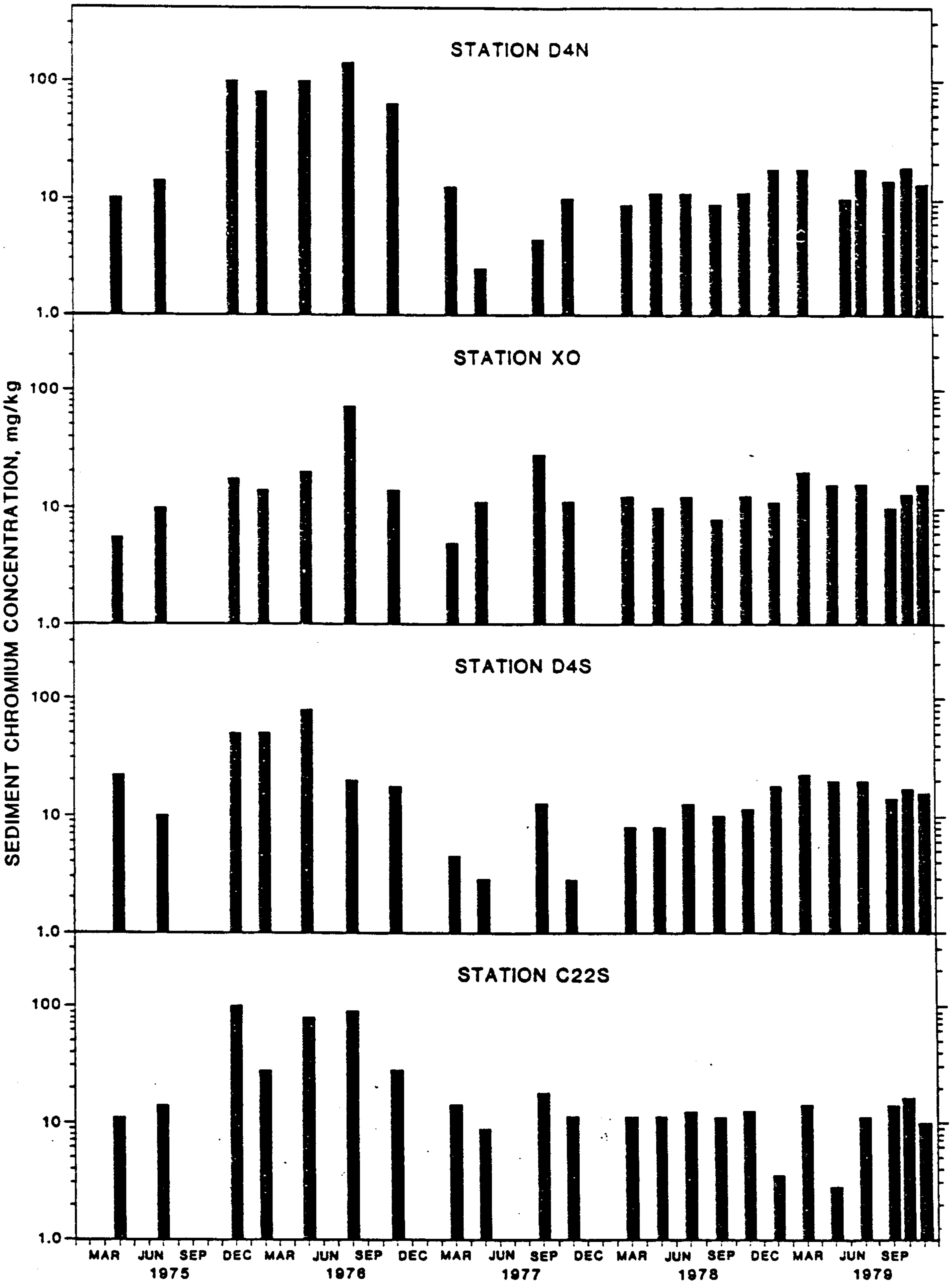

Figure III-7. Chromium concentration in sediment from 1975 through 1979 at SONGS 1 stations.

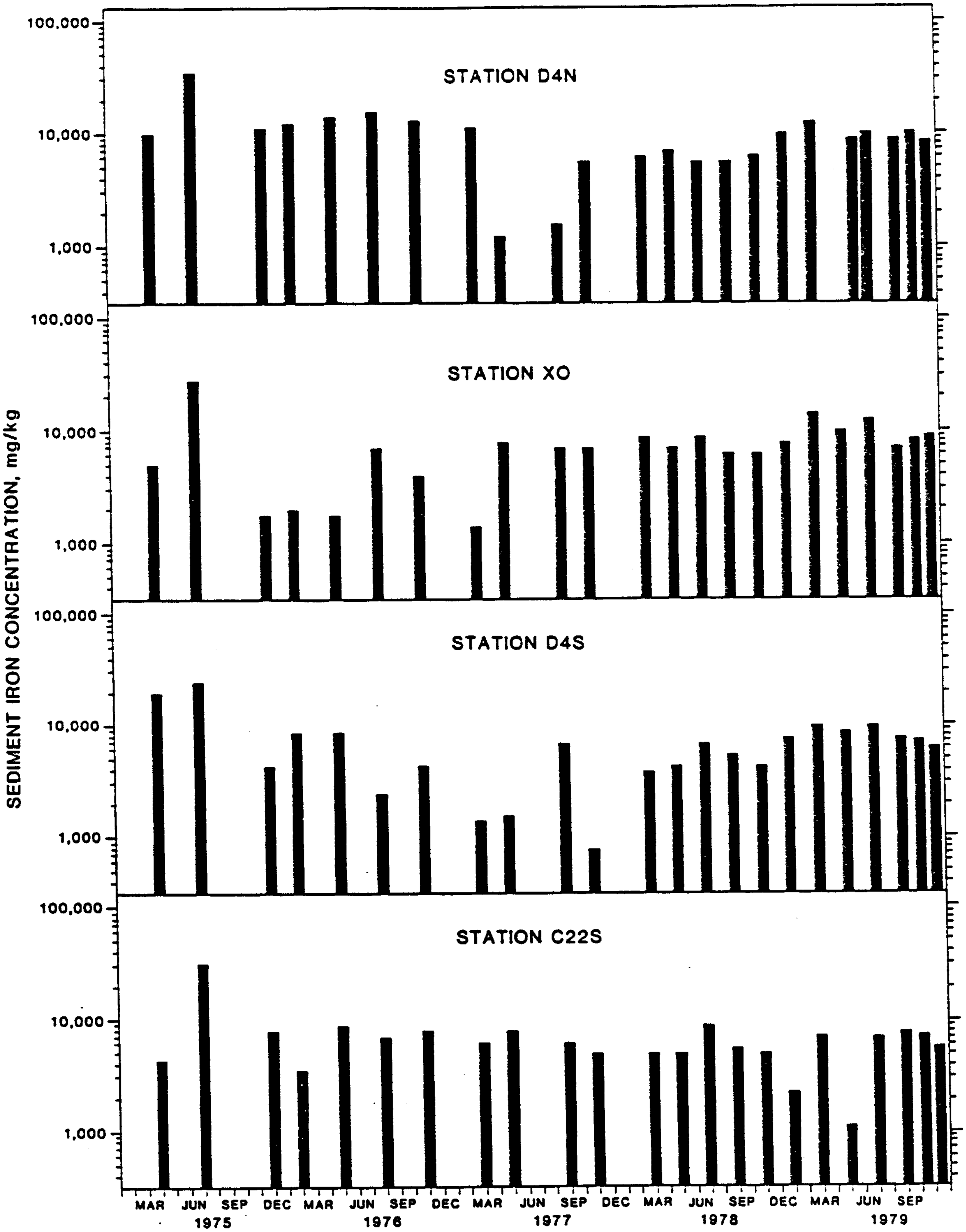

Figure III-8. Iron concentration in sediment from 1975 through 1979 at SONGS 1 stations.

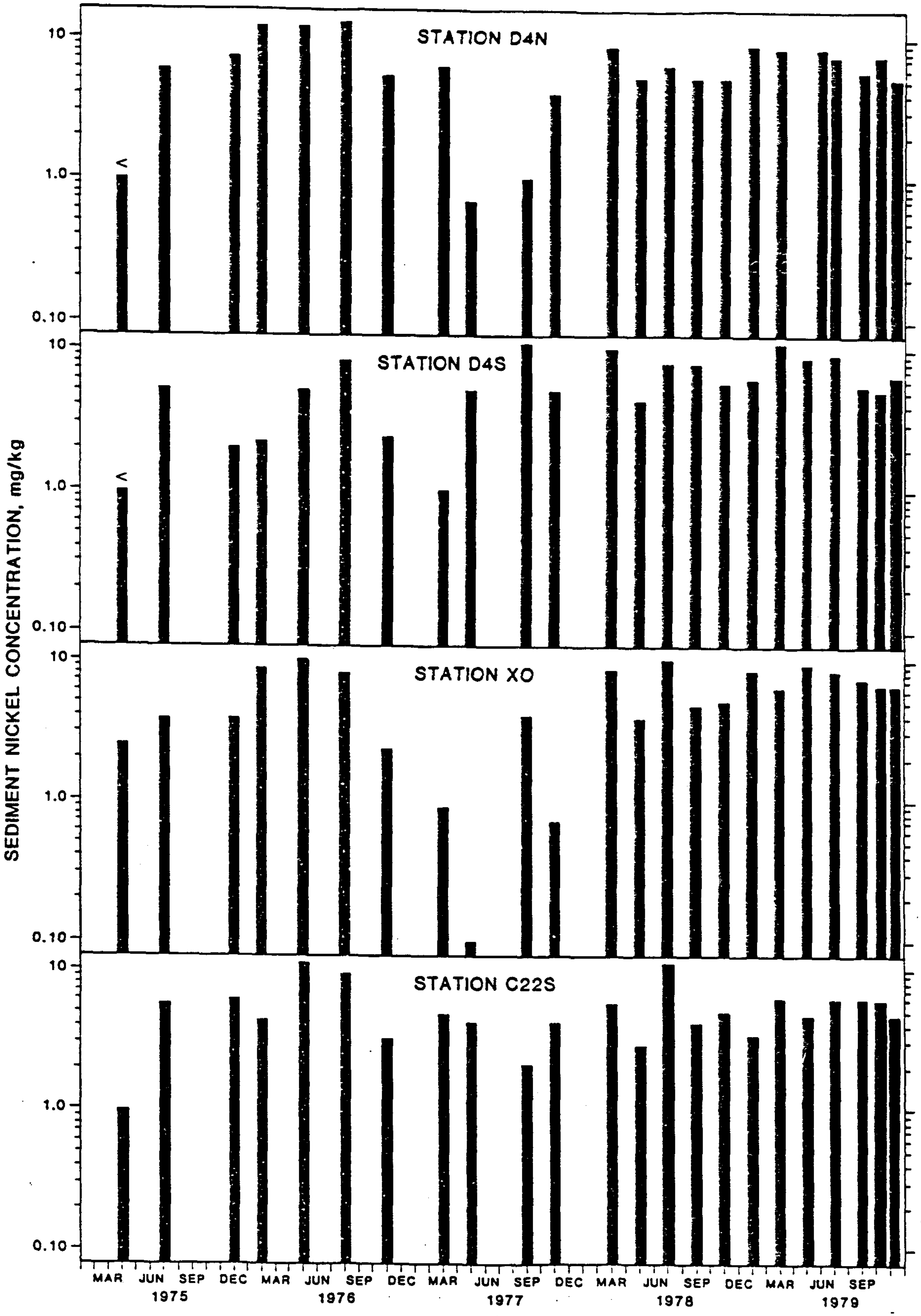

Figure III-9. Nickel concentration in sediment from 1975 through 1979 at SONGS 1 stations.

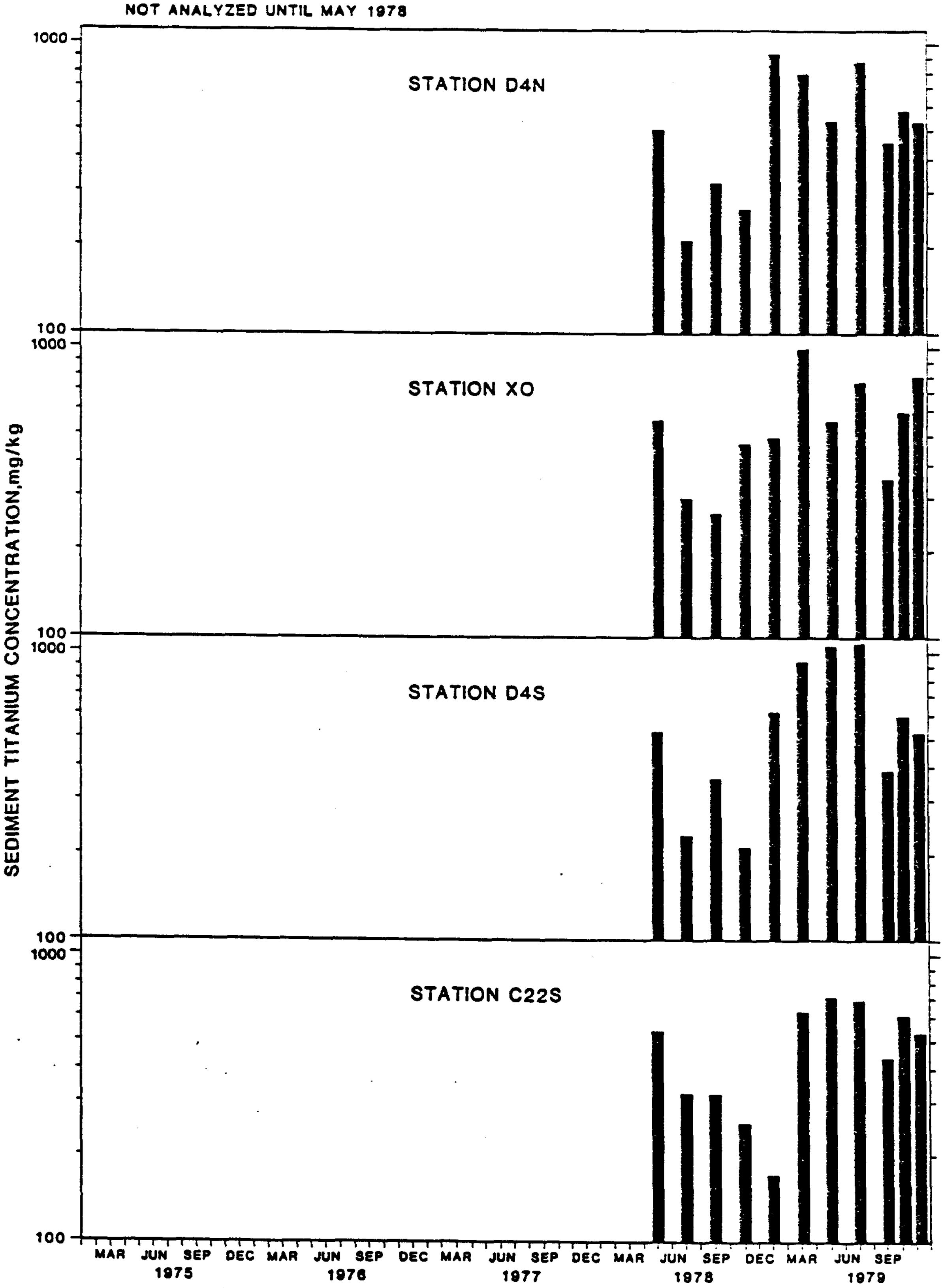

Figure III-10. Titanium concentration in sediment from 1978 through 1979 at SONGS 1 stations.

# Appendix D: Original reports from two firms contracted to estimate or predict the magnitude of metal releases by SONGS.

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# POTENTIAL SOURCES OF TOXIC METAL INPUT FROM SONGS TO THE MARINE ENVIRONMENT

## PHASE I: INFORMATION GATHERING

Prepared by:

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September, 1986

# SONGS TRACE METALS STUDY: PHASE I
# INFORMATION GATHERING TASK

## 1.0 INTRODUCTION

Many environmental studies have been performed at the San Onofre Nuclear Generating Station (SONGS) during the last 20 years. One such study conducted in 1985 by SAIC, under contract to the MRC, involved chemical analyses of marine sediment and tissues (sand crabs). These results indicated relatively elevated concentrations of Chromium (Cr) and Manganese (Mn). In order to assess whether SONGS represents a potential source of Cr, Mn and/or other toxic metals, the MRC has contracted SAIC to conduct Phase I, Information Gathering, of a potential two phase program. Phase II, if deemed necessary would consist of making qualitative and quantitative estimates of trace metal discharges from SONGS based on existing data. The Phase I effort was performed by nuclear, chemical and mechanical engineers and marine chemists from SAIC (Oakridge, TN and La Jolla, CA). Specific tasks included a computerized library search, a review of selected references pertaining to the types of chemicals used or potentially used by SONGS during plant operations, identification of potential sources of metals (particularly Cr and Mn) contamination, and a listing of references that may contain qualitative or quantitative data for use in Phase II estimates.

This report presents the results from the Phase I study, specifically documenting potential contamination sources such as various cooling water components and low volume wastes. The former sources contain the greatest discharge volumes and are comprised of condensor, component and turbine plant cooling water along with the washings from screen, storm drains and seawater pumps. The low volume wastes are comprised of flash evaporator and steam generator blowdowns, various demineralizer systems, rad waste system and other drain systems.

This Phase I report is organized into two main sections: Potential Sources of Selected Chemical Contaminants (Section 2.0), and Data Base Searches (Section 3.0).

## 2.0 POTENTIAL SOURCES OF SELECTED CHEMICAL CONTAMINANTS

This section presents information on the reports reviewed to document SONGS operations (2.1) general discharge sources (2.2) and sources of Mn and Cr (Section 2.3).

### 2.1 SONGS OPERATIONS DOCUMENTATION

This section lists the references utilized to document SONGS operations for this Phase I report. A review of the SONGS Environmental Impact Statements was conducted to identify potential uses of compounds containing chromium, manganese and other toxic metals and liquid effluents that might contain these elements.

The following EIS's were reviewed:

- SONGS Unit 1, Applicant's Environmental Report Operating License Stage, August 1972.
- SONGS Unit 1, Final Environmental Statement, October 1973.
- SONGS Unit 2 and 3, Draft Environmental Statement, November 1972.
- SONGS 2 and 3, Final Environmental Statement, March 1973.
- SONGS 2 and 3, Final Environmental Statement, April 1981.

The current NPDES permits for Units 1, 2 and 3 were also obtained for review from the California Regional Water Quality Control Board. These consist of:

- Order No. 82-13, NPDES No. CA0001228, Waste Discharge Requirements for SONGS 1.
- Order No. 85-11, NPDES No. CA0108073, Waste Discharge Requirements for SONGS 2.
- Order No. 85-13, NPDES No. CA0108181, Waste Discharge Requirements for SONGS 3.

## 2.2 GENERAL DISCHARGE SOURCES

Table 1 presents the waste stream discharge sources along with their discharge volumes for Units 1, 2 and 3.

For all units, the component cooling water, turbine plant cooling water, low volume wastes and sewage treatment plant effluents enter the once-through condenser cooling water stream and the combined flows are discharged to the Pacific Ocean through the discharge structure via the discharge conduit.

Wastes are discharged intermittently and peak flows are in some cases greater than ten times average flows. Flush and hydrotest water may alternately be discharged to Outfalls 001 and 002. Makeup demineralizer is a system common to Units 1, 2 and 3 and may be alternately discharged at Outfalls 001, 002 or 003. Building sump wastes are discharged to an oil removal system that is common to Units 2 and 3 and may be alternately discharged to Outfalls 002 or 003.

The once-through condenser cooling water contains waste heat and residual chlorine, and may contain metals leached from piping. Component cooling water and turbine plant cooling water also containing waste heat and metals leached from piping.

Circulating pump bearings are lubricated by a once-through flow of domestic water, most of which is discharged to the condenser cooling water discharge stream.

The main purpose of the flash evaporator for Unit 1 is to supply demineralized water to the steam generator. Chemical composition of the blowdown is similar to that of the source water (municipal supply) except that it is concentrated by a factor of two. Sulfuric acid is added to the flash evaporator feed water to control pH; pH is maintained at 6-8.

## TABLE 1. WASTE STREAM SOURCES AND MAXIMUM DISCHARGE VOLUMES AT THE SONGS

| SOURCE STREAM | DISCHARGE VOLUMES (MGD[a]) | |
|---|---|---|
| HIGH VOLUME | UNIT 1 | UNITS 2 & 3 (each) |
| Once-through condenser cooling water | -504 | 1382.4 |
| Component cooling water | ---- | 24.5 |
| Turbine plant cooling water | ---- | 22.0 |
| Seawater Pumps Bearing flush water | ---- | 0.185 |
| Storm drains | ---- | 0.074 (unit 2)<br>0.168 (unit 3) |
| Screen wash | ---- | 7.2 |
| LOW VOLUME | | |
| Yard drains | 0.087 | 11.75 |
| Circulating pump bearing lubrication | 0.024 | ---- |
| Flash evaporator blowdown | 0.173 | ---- |
| Steam generator blowdown | 0.175 | ---- |
| Plant drains | 0.022 | ---- |
| Radwaste system | 0.086 | ---- |
| Flush, hydrotest storage tank draindown | ---- | 0.33 |
| Sewage plant effluent | 0.05 | ---- |
| Blowdown processing system demineralizer | ---- | ---- |
| Makeup demineralizer | ---- | ---- |
| Building sumps | ---- | ---- |
| Intake structure sump | ---- | ---- |
| Construction dewatering groundwater | ---- | ---- |
| Approximate average total discharge to ocean | 504 | 1449 |

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[a] MGD - Million Gallons per day

Flush hydrotest wastewaters are generated primarily during the start-up phases of Units 2 and 3. The source water consists primarily of demineralized water to which hydrazine, pH control chemicals, cleaning agents, antifoaming agents and dyes are added. During its use, this water may become contaminated with small amounts of oil and grease and suspended particles. Storage tank draindown also consists primarily of demineralized water. In some cases, chemicals, such as boron, may have been added.

Hydrazine and ammonia are used to control the oxygen concentration and pH, respectively, in the demineralized steam generator feedwater. They form gaseous products, mainly nitrogen, which do not significantly affect the chemical characteristics of the blowdown. Steam generator blowdown is processed by demineralization in Units 2 and 3 to recycle condensate to the steam generators. Spent regenerants from demineralization (sulphuric acid and caustic soda) are neutralized prior to discharge. Unit 1 blowdown is not recycled but is discharged to the circulating water outfall.

The liquid radwaste system consists of (a) the coolant radioactive waste processing system and (b) the miscellaneous liquid waste system. The liquid waste processing system collects and treats liquid waste from the chemical and volume control system, blowdown discharge, equipment leaks and drains, laboratory drain, personnel decontamination showers and floor drains. Treatment facilities include a series of holdup tanks and demineralizers, filters, monitor tanks, flash tank and gas stripper. Units 2 and 3 facilities include evaporators. All liquid waste discharged from the coolant radioactive waste system and the miscellaneous liquid waste system are discharged to the circulating water discharge. Prior to release, samples are analyzed to determine the types and amounts of radioactivity present; on the basis of these results the waste is recycled for reuse in the plant, retained for further processing or discharged to the ocean via the circulating water outfall.

With the exception of the intake structure sump, all drains and sumps pertaining to the conventional portion (nonradioactive) flow by gravity to the oily waste sump. Any oil is removed by the oily waste flotation separator prior to discharge.

Figures 1 and 2, reproduced from the applicant's environmental impact statements, show the water use at San Onofre Units 1, 2, and 3 with respect to ocean water intake and effluents. Ocean water is used at maximum rates of 350,000 gallons per minute (gpm) by Unit 1,846,000 gpm by Unit 2, and 846,000 gpm by Unit 3.

## 2.3 SOURCES OF MANGANESE AND CHROMIUM

None of the three units are required to monitor for discharges containing manganese. There is a minute amount of manganese discharge resulting from activation and corrosion products in the liquid radwaste stream. Under worst case conditions of a steam generator leak, $7.8 \times 10^5$ uCi/yr of Mn-54 and 7.0 uCi/yr of Mn-56 are estimated to be released (approximately $7.8 \times 10^{-4}$ gms/yr and $7.0 \times 10^{-9}$ gm/yr, respectively), these levels represent a negligible source of Mn.

Tables 2 and 3 present the maximum limits for all three units for discharges of Cr and other pollutants to the cooling water effluent.

The maximum Unit 1 limit of 85 lb/day Chromium using a discharge volume of $504 \times 10^6$ gallons/day calculates to a concentration at the diffuser of 0.02 mg/l (ppm). The actual discharge of Chromium from Unit 1 is estimated to be 1-6 lb/day or 0.00024-0.0014 ppm. Actual field measurements from Southern California Edison Company (1978)[1] found water column chromium levels ranged from a yearly average of 0.0007 ppm (away from the outfalls) to 0.0015 (near the outfalls). Ocean concentrations of chromium typically range from a low of 0.00016 ppm (offshore) to 0.00025 ppm (near shore) (Cranston and Murray, 1978).[2] From these data, a worst case situation would involve a discharge concentration, without considering a zone of initial dilution, (ZID) of only 0.0014 ppm. This

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[1] Southern California Edison Annual Operating Report: San Onofre Nuclear Generating Station, Volume I (1978)

[2] Cranston, R.E. and J.W. Murray. The determination of chromium species in natural waters. Analytica Chimica Acta. Vol. 99. pp.275-282 (1978).

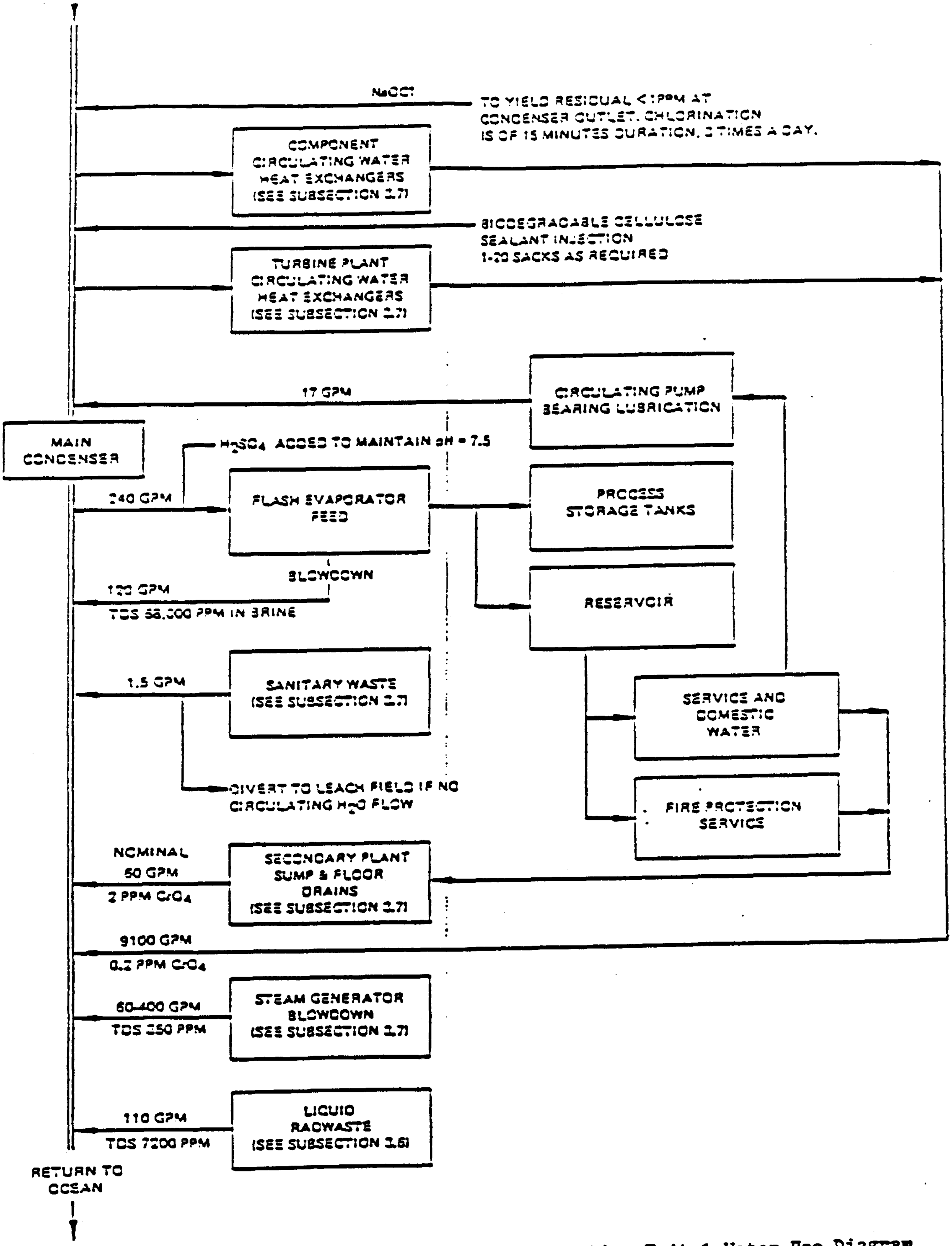
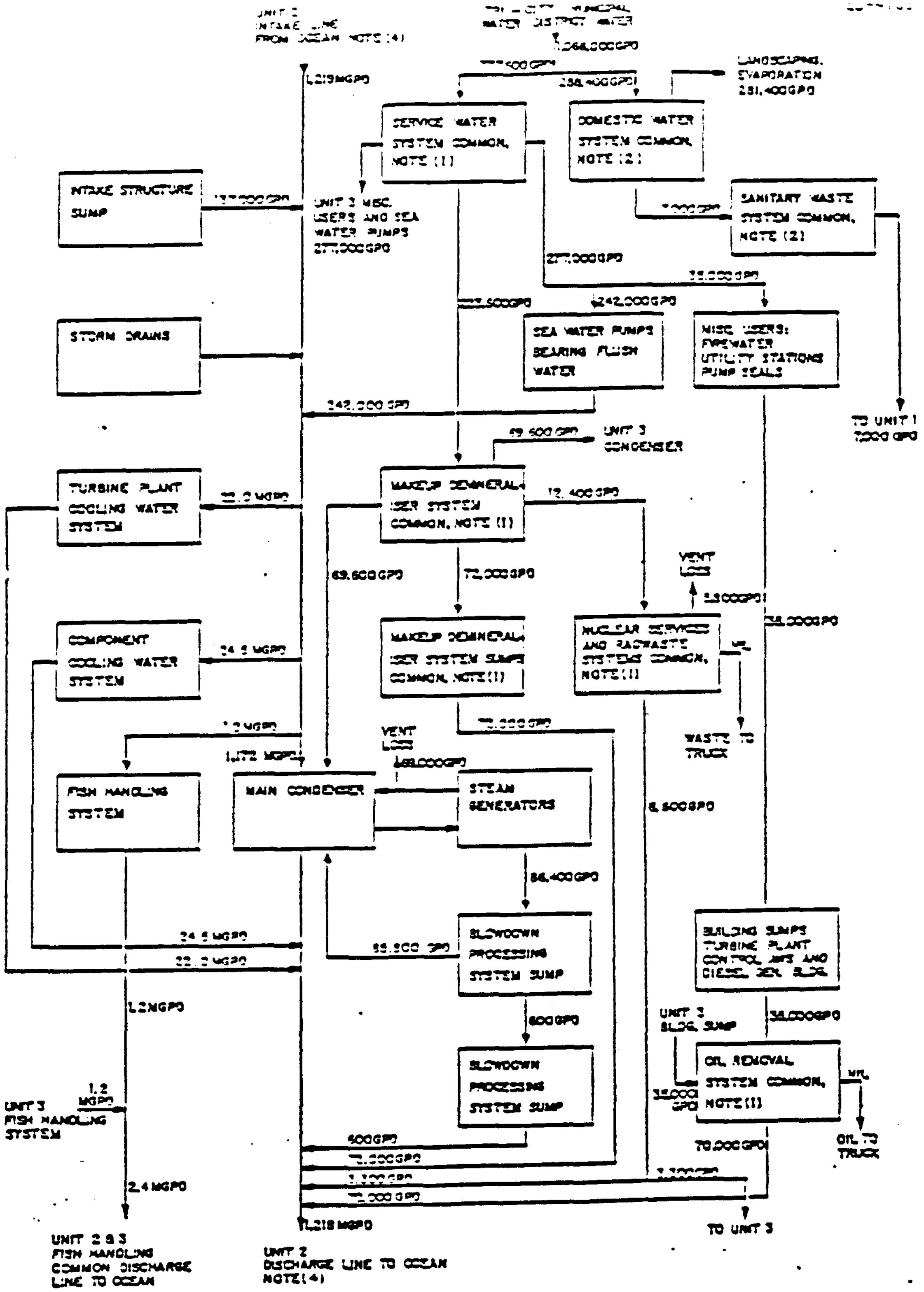


FIGURE 1. San Onofre Nuclear Generating Station Unit 1 Water Use Diagram



Notes:(1)Common system, serves Units 2&3
(2)Common system, serves Units 2&3, AWS bldg
(3)MGPD, millions of gallons per day
(4)Unit 3 flows are same as Unit 2
(5)To convert GPD to liters per day, multiply by 3.7854

FIGURE 2. San Onofre Nuclear Generating Station Units 2 and 3 Plant Water Use

TABLE 2. Pollutant Limitations for Combined Discharge from SONGS Unit 1

| Parameter | Units | 6-Month Median | Monthly Average | Weekly Average | Daily Maximum | Instantaneous Maximum |
|---|---|---|---|---|---|---|
| Arsenic | lb/day | 220 | -- | -- | 1,200 | 3,300 |
| Cadmium | lb/day | 130 | -- | -- | 510 | 1,300 |
| Total Chromium | lb/day | 85 | -- | -- | 340 | 850 |
| Copper | lb/day | 130 | -- | -- | 770 | 2,000 |
| Lead | lb/day | 340 | -- | -- | 1,400 | 3,400 |
| Mercury | lb/day | 3.6 | -- | -- | 21 | 57 |
| Nickel | lb/day | 850 | -- | -- | 3,400 | 8,500 |
| Silver | lb/day | 13 | -- | -- | 70 | 180 |
| Zinc | lb/day | 540 | -- | -- | 3,100 | 8,100 |
| Cyanide | lb/day | 210 | -- | -- | 850 | 2,100 |
| Phenolic Compounds | lb/day | 1,300 | -- | -- | 5,100 | 13,000 |
| Ammonia (as N) | lb/day | 25,000 | -- | -- | 100,000 | 250,000 |

Reproduced from Order No. 82-14.

TABLE 3. Limits for Combined Discharge from all SONGS Unit 2 In-Plant Waste Sources to the Cooling Water Flow*
(Applicable Also to Unit 3)

| Parameter | Units | 6-Month Median | Daily Maximum |
|---|---|---|---|
| Arsenic | lbs/day | 675 | 3,745 |
| Cadmium | lbs/day | 384 | 1,535 |
| Chromium (Hexavalent) | lbs/day | 256 | 1,023 |
| Copper | lbs/day | 407 | 2,326 |
| Lead | lbs/day | 1,023 | 4,093 |
| Mercury | lbs/day | 11 | 65 |
| Nickel | lbs/day | 2,558 | 10,233 |
| Silver | lbs/day | 39 | 212 |
| Zinc | lbs/day | 1,628 | 9,303 |
| Cyanide | lbs/day | 640 | 2,558 |
| Ammonia (expressed as nitrogen) | lbs/day | 76,750 | 307,000 |
| Phenolic Compounds (nonchlorinated) | lbs/day | 3,838 | 15,350 |
| Chlorinated Phenolics | lbs/day | 128 | 512 |
| Aldrin and Dieldrin | lbs/day | 0.26 | 0.51 |
| Chlordane and Related Compounds | lbs/day | 0.38 | 0.77 |
| DDT and Derivatives | lbs/day | 0.14 | 0.26 |
| Endrin | lbs/day | 0.26 | 0.51 |
| HCH | lbs/day | 0.51 | 1.0 |
| Toxaphene | lbs/day | 0.9 | 1.7 |

*Reproduced from Order No. 85-11.

is approximately six times the natural concentration in near shore seawater. However, considering the discharge volume is diluted several times by the ocean, at the diffuser, the measurable concentration above natural levels should be negligible.

A similar chromium situation exists for Units 2 and 3. The reported concentration of chromic acid in the cooling water discharge is 0.005 ppm; this is equivalent to 0.003 ppm chromium at the outfall. Once mixing/dilution occurs with the ocean, it is doubtful that chromium measurements would be significantly above ambient levels.

In summary there is no known manganese discharge from SONGS into the marine environment. Chromium discharge is present and has been documented; however, the levels of chromium discharge from all 3 units appears to be negligible when compared to ambient concentrations. Therefore, although qualitative and quantitative estimates of metals (chromium in particular) discharges from SONGS into the marine environment could be determined (Phase II), it is not recommended, at the present time, that this study be conducted due to the relatively low levels of input into the ocean.

## 3.0 DATA BASE SEARCHES

As part of the Phase I effort to identify and collect data pertaining to trace element discharges from SONGS, an extensive computer search was conducted of four data bases: Energy Data Base (EDB), Oceanic and Oceanic absracts tracts, Water Resources Abstracts and NSC. For each data base a key word search was conducted and all pertinent references recorded. References specifically related to SONGS that could be reasonably accessed were reviewed and incorporated into the Phase I report (Sections 1.0 and 2.0); these references include the SONGS EIS's and NPDES. Orders listed in Section 2.0. The remaining references, representing information and data on other power plants that might be comparable to SONGS, SONGS reports, and data that could not be accessed or which might be appropriate for Phase II, are presented in this section.

## 3.1 ENERGY DATA BASE (EDB)

Key Words: Decontamination Agents

We postulated that SONGS could be a potential source of manganese (Mn) effluent if the plant uses certain permanganates in the maintenance-related and exposure-reduction-related decontamination operations. The search identified the use of such decontaminating agents in experimental programs and routine operations in foreign reactor programs. However, the use of potassium permanganate is being replaced with the use of less corrosive decontamination agents. No direct references to the use of potassium permanganate in U.S. reactor decontamination operations was identified in EDB.

Several references may provide additional information on the use of permanganates for power reactor decontamination as it might apply to SONGS:

1. Acc. No. 84Y0107236, J. Helske, R. Jaernstroem, Experience from Loviisa Nuclear Power Station Concerning the Decontamination of Steam Generated and Primary System Components, VGB Conference on Chemistry in Power Plants, Essen, F. R. Germany, October 1981 (in German).
2. Acc. No. 84J0001654, Y. V. Balaban-Irmenin, a. L. Teplitskii, Deactivation of Nuclear Power Plant Equipment with VVER-440 Reactors, Soviet Power Engineering, April 1981.
3. Acc. No. 85C0112764, J. C. W. Comley, Coolant Circuit Decontamination Experience at WSGHWR, International Conference on Decontamination of Nuclear Facilities, Niagara Falls, Canada, September 1982.
4. Acc. No. 85C0094044, M. J. Sanders, R. D. Bond, Use of High-Pressure Water Jetting to Remove the Corrosion Deposit from Samples of the WSGHWR Primary Circuit Pipework, International Symposium on Jet-Cutting Technology, Ottowa, Canada, June 1984.
5. Acc. No. 84J0119155, J. Alexa, Multiple Use of Alkaline Decontamination Solution Containing Potassium Permanganate, November 1983 (in Czech).
6. Acc. No. 8460063187, J. Fell, Technical Studies in Support of the Winfrith SGHWR, Proceedings of the 9th JUICE Meeting on Heavy Water Reactors, Tokyo, Japan, March 1982.

7. Acc. No. 82C0019682, Operational Experience and Experimental Work on the Winfrith Reactor Relating to Activity Retention on Coolant Circuit Surfaces, Conference on Water Chemistry of Nuclear Reactor Systems 2, Bournemouth, U.K., October 1980.

Key Words: Cr, Mn, Corrosion, and Pollution at Nuclear Power Plants

The search indicated that chromic acid (representing a potential source of chromium) is used by the Japanese as a corrosion inhibitor. Very little information is available on specific effluent rates pertaining to Cr or Mn levels from power plant corrosion, although such corrosion is known to occur.

Key Words: Decontamination, Not Decommissioning, USA, Nuclear Power Plants or Reactors

This search identified some references that might name the routine chemicals used in decontamination of nuclear power plant components. Relevant information may be found in several references:

1. Acc. No. 85C0112735, C. McCracken, NRC Regulations and Positions Concerning Decontamination, International Conference on Decontamination of Nuclear Facilities, Niagara Falls, Canada, September 1982.
2. Acc. No. 84J0156906, Igscc Prompts Recirculation Pipe Replacement in American BWRs, Nuclear Engineering International (England), March 1984.
3. Acc. No. 84C0084654, J. E. Lesurf, et al., Decontamination Following Dilute Chemical Decontamination, 3rd International Conference on Water Chemistry of Nuclear Reactor Systems, Bournemouth, U.K., October 1983.
4. Acc. No. 76C0064398, T. M. Hall, United Nuclear Industries, Inc., Practical Application of ALARA (ALAP) Philosophy, Conference on Remote Systems Technology, Washington, D.C., November 1976.

Key Words: Liquid Wastes, Mn, Cr, U.S. Nuclear Power Plants

This search identified radioactive effluents; two references contain potentially relevant information:

1. Acc. No. 81C0021363, B. Kahn, Composition and Measurement of Radionuclides in Liquid Effluent from Nuclear Power Stations, Conference of the American Society for Testing Materials, Johnson, VT,

USA, July 1978.

2. Acc. No. 77J0029876, New U.S. Regulation on Radioactive Effluent Releases, Radioprotection (France), 1975 (in French).

Key Words: Liquid Wastes, Toxic Metals, U.S. Nuclear Power Plants

No additional relevant information was identified from this search.

## 3.2 OCEANIC AND WATER RESOURCES ABSTRACTS/OCEANIC ABSTRACTS

Key Words: Mn, Cr, Effluent or Liquid Waste, Nuclear Reactors

Isotopes of Mn, Cr and other metals are identified as effluents requiring treatment (using resin beds) (Reference 3).

Reference 4 provides a summary of information from environmental impact statements assessing the impact of radionuclides released to the environment in LWR liquid effluents. Typical releases, using chemicals and concentrations presented in a waste discharge permit application to EPA for a 1130 MWE nuclear power plant, are listed in Reference 5.

A reference to accumulation of Mn and Cr in crabs was identified in Reference 6.

These and other references include:

1. 74-00657, S. C. Doret, et al., Characteristics of Condenser Water Discharge on the Sea Surface (Correlation of Field Observations with Theory), Mass. Institute of Technology, MIT-SG-73-12, June 26, 1973.
2. 71-03050 71-2D-00165, J. N. Reeves, Effects of Thermal Discharge from the San Onofre Nuclear Generation Station (monitoring survey), Water and Sewage Works, Chicago, December 1970.
3. 152211 W81-04575, R. Couderc, et al., Ion Exchange in Nuclear Power Applications, Effluent and Water Treatment Journal, September 1980.
4. 095275 W76-04836, R. S. Booth, et al., A Radiological Assessment of Radionuclides in Liquid Effluents of Light Water Nuclear Power Stations, Oak Ridge National Laboratory, ORNL-TM-4762, June 1975.

5. 043418 W72-09683, R. R. Garton, *Biological Effects of Cooling Water Blowdown*, 71st Meeting of American Institute of Chemical Engineers, Dallas, Texas, February 1972 (May identify typical releases).

6. 036937 W72-02662, D. A. Tennant, et al., *Seasonal Variation and Distribution of 652N, 34 MN, and S1Cr in Tissues of the Crab Cancer Magister Dana*, Health Physics Journal, June 1969.

7. 085166 W76-04835, R. S. Booth, *A Compendium of Radionuclides found in Liquid Effluents of Nuclear Power Stations*, Oak Ridge National Laboratory, ORNL-TM-3811, March 1975.

## 3.3 NSC DATA BASE

Key Words: Water Quality, San Onofre, Effluent and Mn, or Cr and PWR

The power plant at Indian Point had two events with discharges of 8 lb and 12 lb, respectively, of chromium in the form of chromates. These releases were caused by a leak from a corroded air compressor and heat exchanger tube leakage in the CCW heat exchanger, and may be indicative of the amounts of chromium discharged during a (typical) failure.

This search also identified the SONGS environmental reports and responses to questions during the licensing stage. These references include:

1. Acc. No. 75583 - Applicants' Environmental Report, Operating License Stage, Vol. 1 and 2. San Onofre, Aug. 31, 1972, Southern California Edison Co. and San Diego Gas and Electric Co.

2. Acc. No. 63091 - Applicants' Environmental Report, Construction Permit Stage (San Onofre 2 and 3), July 28, 1970.

3. Acc. No. 76762 - Draft Environmental Statement by DRL for San Onofre 2 and 3, Nov. 1972, U.S. Atomic Energy Commission, Directorate of Licensing.

4. Acc. No. 58094 - Response to Question 1.8-2AE, Environmental Monitoring, September 16, 1970, Southern California Edison Company.

Other references of potential relevance to a Phase II study address elements from corrosion products of stainless steel under pressurized water reactor conditions, and manganese increases in lobsters at Millstone 2 (References 1 and 2, respectively).

1. Acc. No. 00J0162942, G. Sachse, H. Schlenkrich, Investigation on the Activity Buildup in the Primary Coolant Circuit of Pressurized Water Reactors Part 3: Laboratory Studies on Transport and Solubility of Corrosion Products Under the Conditions of Primary Coolant Circuit (in German), May 1980.

2. Acc. No. 00Z0108290, Concentration of Manganese Increases in Lobsters at Millstone 2, Northeast Energy 6, Hartford, Connecticut, November 1975.

Key Words: Decontamination Operations

Decontamination operations were further investigated to identify possible sources of manganese from power plant operations. Two foreign language papers on the use of Mn compounds for decontamination were cited, but do not appear to provide information regarding such practices in the U.S.

1. Acc. No. 00X0036746, J. M. Aucharpt, J. F. Gaudier, Decontamination of Irradiated Fuel Processing Waste Using Manganese Dioxide Hydrate, Commissariat a L'energie Atomique, France, June 1969 (in French).

2. Acc. No. 00X0031533, G. H. Furnica, Decontamination of Radioactive Waters by Coprecipitation with $Ca(MnO_4)_2$ and Active Earths, Institute for Hygiene and Labor Protection, Bucharest, April-June 1966.

The key word search on San Onofre and effluents identified several references, which included the environmental impact statements, references on radioactive effluents from operating nuclear plants, and the impacts of San Onofre on the marine environment. These references in addition to the environmental impact statements listed in Section 2.0 include:

1. Acc. No. 00Z0098067, San Onofre Technical Specifications, U.S. AEC, November 1974.

2. Acc. No. 00Z0082682, Monitoring of Radioactive Effluents at San Onofre 1, U.S. AEC, June 1973.

3. Acc. No. 00X0066328, B. Kahn, et al., Environmental Experience with Radioactive Effluents from Operating Nuclear Power Plants, EPA, Cincinnati, Ohio, September 1971.

4. Acc. No. 00X0017552, W. R. Gould, J. B. Moore, Regional Environmental Considerations in the Evolution of and Operating Experience with the Southern California Edison Company Generating System, International Atomic Energy Agency Symposium on Environmental Aspects of Nuclear Power Stations, New York, August 1970.

One final reference identified in NSC may be helpful in describing the concentrations of heavy metals in seawater (nuclear power plants in Sweden):

1. Acc. No. 00X0137677, I. Gustavsson, Concentration of Heavy Metals in the Receiving Waters off the Nuclear Power Plants in Sweden, Stockholm, Sweden, September 1976.

MHB TECHNICAL ASSOCIATES
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RECEIVED JUL 27 1987

July 24, 1987

Mr. Hans Kasper
Executive Director
Marine Review Committee, Inc.
531 Encinitas Blvd., Suite 105
Encinitas, CA 92024

Dear Hans:

Enclosed herein are MHB's findings and conclusions on Phase I of the investigation into potential sources of toxic metals from San Onofre Units 2 and 3 (SONGS 2/3). The purpose of Phase I of the study was primarily to determine whether the available information, together with our knowledge of nuclear plant operations, was sufficient to identify the origins and rates of release and to identify the information needed to more precisely estimate releases. Secondary purposes were to identify other potential sources and to present a range of release rates, based on the available data, even if incomplete.

In our efforts to be efficient, we did not duplicate the SAI Study prepared for the MRC, September 1986. We did, however, conduct additional data searches and we spoke at length with the regulatory agencies and analyzed regulatory correspondence.

Through our research effort, we were able to identify potential sources of heavy metals and calculate a range of release rates of chromium, copper, and iron. However, much of the additional information needed to refine these findings is not in the public domain and is held by SCE. We did not analyze radioactive releases, as they were outside our scope. These releases are continuously monitored and are reported to be relatively minor. In order to arrive at a different conclusion, one would have to assume that the plants are being operated negligently or illegally, or that scientific opinion on the effects of radioactivity is incorrect by a wide margin. We, of course, cannot answer either of those questions in this limited study.

Below, we provide some background on the technical issues, findings and conclusions, and recommendations. We will send you a revised proposal for completing Phase II of the project after you have had time to review this report. If you should have any questions regarding the content of this letter, please do not hesitate to call.

Very truly yours,

Dale G Bridenbaugh for

Peter M. Strauss

PMS:bb
Enclosure

## Background

Discharges of heavy metals into the marine environment could originate from three sources: the direct addition of chemical agents which contain metals as an active ingredient (e.g., anti-corrosion agents); erosion and corrosion of metals that are used in the plant; and, through the concentration and discharge of naturally occurring metals in water (e.g., makeup-water flush). The first two are likely to be the major sources of heavy metals released at San Onofre. For the first category, there is sufficient information in the literature to form the basis for an estimate, although many assumptions are made and need verification. For the second category, critical information is held by the operator of the facility.

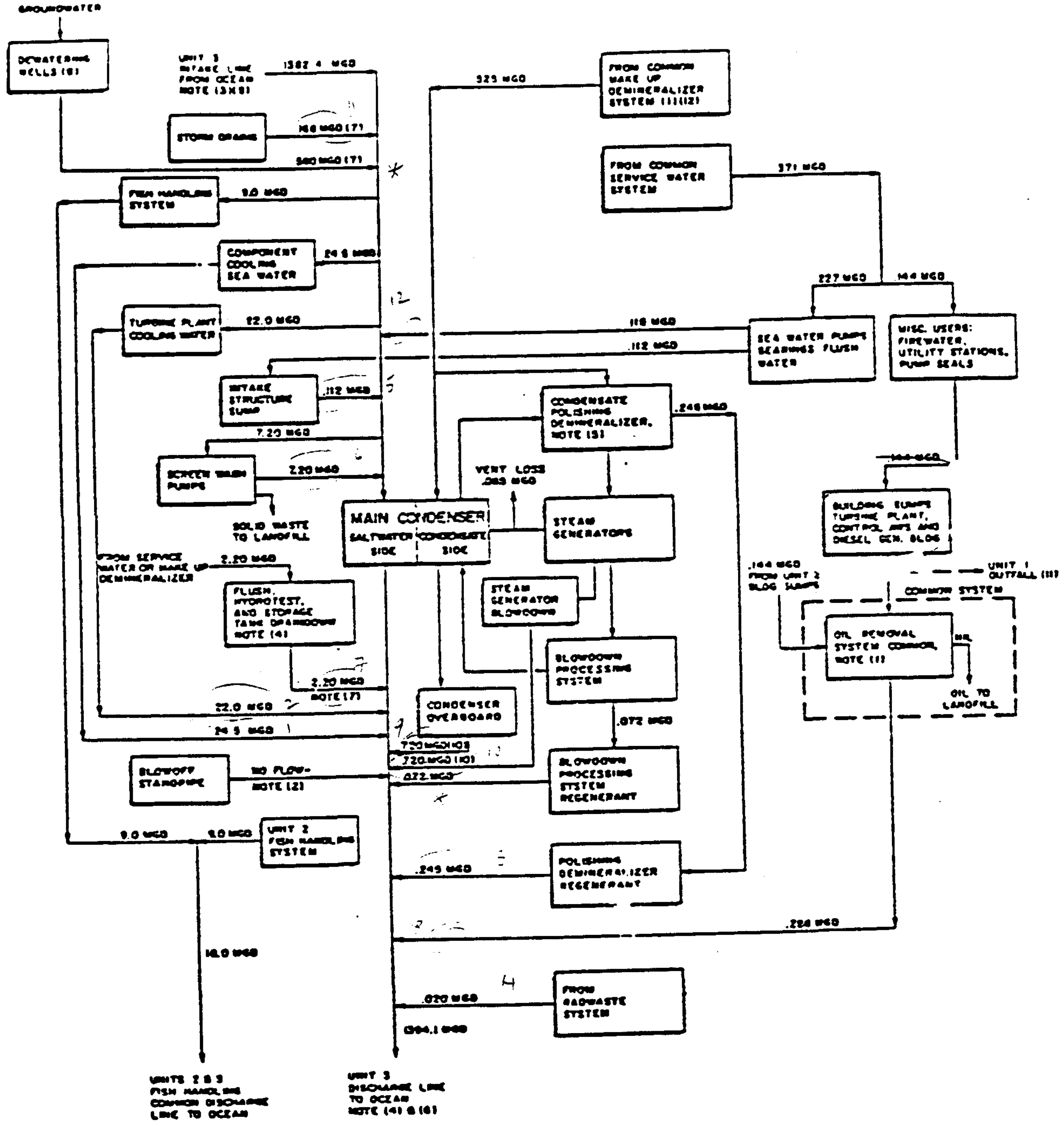
There are 15* potential points for each Unit where a release could originate. These points are shown in a schematic of water flow for Unit 3, Figure 1.** They all discharge into the once-through saltwater cooling system. Quantities discharged are shown on Table 1. The reported quantities, and for that matter, the number of potential points, were not consistent in all of the documents reviewed. The Environmental Statement, the Application for NPDES Permit by SCE, and the NPDES Permit vary slightly. Quantities given in Table 1 are based on MHB's best judgement about the reasonableness of the quantities and the backup data provided.

---

* Sixteen points exist if the once-through coolant flow through the conduits and condenser is considered to be a source.

** Source: NPDES No. CA 018181, Order 85-13, CA RWQCB.

# FIGURE 1



NOTES:

(1) COMMON SYSTEM, SERVES UNITS 2 & 3.

(2) EMERGENCY USE ONLY; NOT PART OF NORMAL OPERATION.

(3) MGD = MILLION GALLONS PER DAY.

(4) FLUSH & HYDROTEST WASTEWATER VOLUME IS FOR STARTUPS. NORMAL OPERATION WILL BE LOWER. DISCHARGE TO UNIT 1 OUTFALL IS AN ALTERNATE MEANS OF DISCHARGE.

(5) CONDENSATE POLISHING DEMINERALIZER WILL NOT BE INSTALLED UNTIL AFTER INITIAL PLANT OPERATION

(6) FLOWS GIVEN ARE ESTIMATED DISCHARGE VOLUME IN GALLONS, PER AVERAGE DAY.

(7) THESE FLOWS ARE NOT DAILY INTERMITTANT DISCHARGES. HOWEVER THEY ARE INCLUDED IN THE DAILY FLOW BALANCE.

(8) INTERMITTANT DISCHARGE ASSOCIATED WITH CONSTRUCTION PERIODS DURING CONSTRUCTION THE FLOW WILL BE CONTINUOUS

(9) FLOW BASED ON MAXIMUM DISCHARGE RATE OF THE MAIN CIRCULATING COOLING WATER PUMPS (240,000 GPM)

(10) ESTIMATED VOLUME DISCHARGED IF ENTIRE SECONDARY SYSTEM WOULD BE DRAINED DURING SCHEDULED OR UNSCHEDULED OUTAGES

(11) THE DISCHARGE CAN BE DIRECTED TO UNIT 1 OUTFALL VIA THE TEMPORARY RETENTION BASIN.

(12) ESTIMATED FLOW FOR NEW MAKE-UP DEMINERALIZER SCHEDULED FOR COMPLETION IN 1984

MAXIMUM WATER FLOW FOR UNIT 3
SOUTHERN CALIFORNIA EDISON CO. AND
SAN DIEGO GAS AND ELECTRIC CO.
CAMP PENDLETON, SAN DIEGO COUNTY, CA
PAGE 4 OF 4

CLE 2/4/83

## TABLE 1

## POSSIBLE SOURCES OF HEAVY METAL DISCHARGE TO OCEAN

| Operation | Average Volume | Maximum | Treatment |
|---|---|---|---|
| Main Condenser Cooling | 1,200 MGD 1/ | --- 5/ | Ocean Discharge |
| Screen Wash | 0.9 MGD | 7.2 MGD | Ocean Discharge |
| Pump Bearing Flush | .24 MGD | 2.4 MGD | Ocean Discharge |
| Flush, Hydrotest and Storage Tank Draindown | 0.4 MGD | 2.2 MGD | Ocean Discharge |
| Steam Generator Blowdown Processing Sys. | 600 MGD | 0.7 MGD 2/ | Ocean Discharge & Neutralization |
| Component Cooling | 24.5 MGD | --- 5/ | Ocean Discharge |
| Turbine Plant Cooling | 22 MGD | --- 5/ | Ocean Discharge |
| Polishing Demineralizer | 0.12 MGD | 0.25 MGD | Ocean Discharge & Neutralization |
| Makeup Demineralizer Sumps | 0.5 MGD | 0.6 MGD 3/ | Ocean Discharge & Neutralization |
| Radwaste System | 0.1 MGD | 0.2 MGD | Ocean Discharge & Neutralization |
| Plant Drains | 0.29 MGD 4/ | --- 5/ | Ocean Discharge & Oil Removal |
| Yard Drains | 5.8 MGD 4/ | --- 5/ | Ocean Discharge |
| Intake Structure Sump | 0.7 MGD | 0.11 MGD | Ocean Discharge |
| Building Sumps, Diesel Gen. Building | 0.10 MGD | 0.14 MGD | Ocean Discharge |

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#/ Footnotes appear on following page.

## TABLE 1 (cont'd)

| Operation | Average Volume | Maximum | Treatment |
|---|---|---|---|
| Condenser Hotwell Overboard | 0.18 MGD | 7.2 MGD 2/ | Ocean Discharge |
| Sewage Operation Treatment (Common) | .007 MGD | | Ocean Discharge |
| Diesel Generator Cooling Water | --- 6/ | --- 6/ | See Footnote |

---

1/ Millions of gallons a day.
2/ When system is fully discharged.
3/ Serves both Units.
4/ NPDES Application prepared by SCE, 4/2/82. Most likely represents capacity with intermittent flow.
5/ Maximum not given. Main condenser, component cooling, and turbine plant cooling do not vary substantially under normal operating conditions.
6/ The Diesel Generator Cooling Systems are closed loop air-cooled (radiator type). Their estimated capacity is 3,200 gallons of treated water.

The chemicals reported to be in use at the plant are listed in Table 2. Potassium chromate, which is reported in several NRC documents is not reported. Whether this was an oversight or whether potassium chromate has been discontinued in closed-loop cooling water systems needs to be addressed. Also, anti-corrosion and anti-fouling paints which may contain zinc, chromate, and copper are not listed.

Of the chemicals listed, chromic acid and potassium chromate are the most important as heavy metal sources. These chemicals are used to inhibit corrosion of metal parts. Inhibiting corrosion is perhaps the largest single non-radiological operations and maintenance issue for a nuclear plant. As was experienced by SCE at SONGS Unit 1, severe corrosion of the steam generator caused several years of shutdown and millions of dollars in extra costs.

Protection of closed recirculating-water systems generally call for both high pH and high inhibitor levels.* Within a relatively narrow pH range (8.5-9.5), the choice of inhibitors is small. Chromates have been the most prevalent and by far the most flexible, but environmental restrictions have limited their use. When they are used, they are applied at concentrations from 200 ppm to as high as 1500 ppm as $CrO_4$ (Chromic Acid). Higher levels have caused rapid pump-seal failures, and so most systems treated with chromate tend towards the lower end of the range.

Substitutes are available, with varying degrees of effectiveness. The most common nonchromate corrosion inhibitor for closed systems is often referred to as boron nitrite. It uses borax as a buffering agent to maintain a pH above 8.5, and usually contains a variety of corrosion inhibitors. However, nitrites feed bacterial growth, which lower pH levels and contributes to slime deposits. Also, air leakage occuring around pump seals converts the nitrite to nitrate. Molybdate-based treatments have found recent use with considerable success. They often contain copper-corrosion inhibitors and occasionally nitrites, along with alkali buffering agents to maintain pH above 8.0. The molybdate is carried at levels of 100-200 ppm.

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* "Cooling Water Treatment," Special Report. Strauss, Puckories, Power, June 1984.

## TABLE 2

## UNIT 2/3 CHEMICAL DISCHARGES*

| | Chemical** | Use | Discharge Control |
|---|---|---|---|
| a. | Chromic Acid | anti-corrosion agent | Controlled to 0.005 mg/l |
| b. | Boric Acid | Used in the primary systems. Prior to discharge the borated water is treated to meet radiological and pH limits | Controlled to 6 to 9 pH |
| c. | Nalco (39 and 2,000) | anti-corrosion agent containing sodium, boron, nitrate and nitrite | Controlled to <1.0 mg/l |
| d. | Sulfuric Acid | pH control of demineralizer regenerants | Controlled to 6 to 9 pH |
| e. | Sodium Hydroxide | pH control of demineralizer regenerants | Controlled to 6 to 9 pH |
| f. | Sodium Hypochlorite | algicide | Controlled to 0.4 mg/l |
| g. | Ammonia | pH control | Controlled to 6 to 9 pH |
| h. | Calgon CS | nitrite based anti-corrosion (replaces chromic-based where saltwater contact is possible) | Not stated |
| i. | Hydrazine | reducing agent to prevent corrosion | Not controlled, estimated at <0.34 mg/l |
| j. | Ethylene Glycol polymers | non-ionic biodegradable surfactant | Not controlled, estimated at <0.1 mg/l |

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* Source: Regional Water Quality Control Board, Order 85-13.

** Additionally, SCE reported that the following pollutants are expected t be used over the next five years: benzene, toluene, 1,1,1-trichloroethane, carbon tetrachloride, and 1,1-dichloroethylene. Potassium Chromate, which is used in several systems as an anti-corrosive agent, is not listed in the permit.

**TABLE 2** (cont'd)

| | Chemical | Use | Discharge Control |
|---|---|---|---|
| k. | Trisodium Phosphate | used as detergent during flushings | Not controlled, estimated at <1.0 mg/l |
| l. | Sodium Flourescein | biodegradable dye used during hydrotesting | Not stated |
| m. | Rodamine | biodegradable dye used during hydrotesting | Not stated |
| n. | Silicon | anti-foaming agent used in conjunction with surfactants | Not controlled, estimated at <0.1 mg/l |

Three systems of significance at SONGS reportedly add Chromates for corrosion inhibition: the Turbine Plant Cooling Water System (TPCW); Component Cooling Water System (CCWS); and the Emergency Diesel Generator Cooling System.

The sea-water side of the TPCW and the CCWS are the largest discharges into the main cooling systems. Because of the volume (combined 47 MGD on each Unit), low concentrations of chromate leakage could result in large mass emissions. Based on the Final Safety Analysis Report (FSAR) that SCE submitted to the NRC, these systems use chromates ($K_2CrO_4$) at concentrations of 450 ± 50 ppm. In SCE's submittal to the RWQCB on April 2, 1982, it described the maximum leakage rate for the Unit 1 systems as 4 gpm. Assuming that leak rates are proportional to flow, Units 2/3 would have a maximum of 28 gpm (Unit 1 TPCW and CCWS have 9,000 gpm normal flow; Units 2/3 combined have a flow rate of 64,000 gpm). Using these figures, we estimated releases of chromium into the once-through main cooling system.

In addition, floor drains for non-radioactive portions of Units 2/3 lead to an oily waste sump, where oily waste is removed and the remaining effluent is discharged into the outfall. Each outfall has a flow rate of 200 gpm. The FSAR for Units 2/3 reports that small leaks around valves and fittings in the TPCW would go undetected and would drain into the turbine building drainage systems. SCE's Environmental Report for Unit 1, prepared in 1972, reported a continuous process concentration of chromate in the floor drain sump at 0.6 ppm, with a flow rate of 60 gpm. Assuming leaks of the same concentration, we were able to estimate annual releases of chromates from floor drains.

The Emergency Diesel Generators also have a closed-cooling water system. There are two generators for each Unit, with a coolant capacity of approximately 800 gallons each. The FSAR reports that the cooling systems add potassium chromate at concentrations up to 3000 ppm.

The technical specifications for SONGS require that whenever repair necessitates that the cooling system is drained, a new batch of coolant must be added. Because waste coolant is most likely classified as a hazardous waste (DHS standards for hexavalent chromium are 5 mg/l or 5 ppm), there should be records of these shipments, as required by law. An internal SCE memo (Art Kneisel to Dr. J.B. Palmer, "Heavy Metal Discharges from San Onofre," 3/13/87), states that the waste coolant is shipped offsite in compliance with the Resources Conservation and Recovery Act (RCRA), which is the enabling legislation for hazardous waste regulation. However, in the time allotted for this study, we have been unable to confirm this statement. There is some question about its accuracy because SCE would be required to notify the U.S. Environmental Protection Agency (EPA) that it is a generator of chromated coolant wastes. Table 3 lists the wastes reported by SCE to EPA, and chromates are not among them.

In addition, drains from the Diesel Generator Building empty into a common (Units 2/3) oil removal system and are discharged into the main cooling system. There is likely to be some chromium discharge due to failed pump seals and miscellaneous packings, although we cannot determine the amount.

The extent of the discharge of metals that have been eroded or corroded from the plant are a function of the materials used in the plant and are influenced by a range of operational variables. Iron, steel, and other alloys are used extensively for piping, pumps, steam generator tubing, condenser tubing, and the turbine generator. Of particular importance are the steam generator tubes made of a high nickel/chromium alloy, the turbine blades made of alloy metals, and iron piping in the secondary loop. Through condenser hotwell overboarding, boiler blowdown, demineralizer failure, or a variety of normal and abnormal variables, eroded and corroded metals accumulate and could enter the main cooling system.

Normal operational variables affect the amount of corrosion and erosion. These include the startup cooldown cycle, routine maintenance and repair, and the normal practice of discharging boiler blowdown and overboarding the hotwell during startup. Abnormal variables refer to a broad range of unplanned occurrances. These may include tube leaks, water hammers, and failure of demineralizer to capture corroded metals. Attached as Exhibit 1 is a description of some of the abnormal events that SCE reported to the NRC which may be linked to discharges of heavy metals.

A number of characteristics of the cooling water influence the rate of corrosion which can be controlled to some extent. The most important ones are:

- Presence of $O_2$;
- Amount of dissolved and suspended solids;
- pH;
- Water velocity;
- Temperature.

The presence of dissolved oxygen is essential to the electrochemical reaction (oxidation). Hydrazine is used to absorb available oxygen. Dissolved solids also increase the electrical conductivity of the water. The more dissolved solids, the greater the conductivity.

Suspended solids influence corrosion by eroding or abrading the metal surface. Some particulates may become entrained in the steam and bombard the turbine blades.

## TABLE 3

## SONGS TOXIC WASTES*

| EPA Hazardous Waste No. | |
|---|---|
| F001 | Tetrachloroethylene, methylene chloride, trichloroetylene, 1,1,1, trichloroethane, clorinated fluorocarbons |
| F005 | Toulene, MEK, carbon disulfide, isobutanol, pyridine |
| U159 | 2-Butanone |
| U226 | 1,1,1, Trichlorethane |
| U133 | Hydrazine |

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* Source: Notification of Hazardous Waste Activity forms, U.S. EPA Form 8700-12 obtained through Freedom of Information Act.

Acidity and low alkalinity promote corrosion by increasing the dissolution rate of the base metal.

Water flow increases corrosion by bringing $O_2$ to the metal and carrying away corrosion products. High velocities erode metal surfaces or protective films. However, when water velocity is too low, suspended solids may accumulate on surfaces and increase corrosion.

Temperature changes cause corrosion rates to double with every 25-50-degree rise up to 160F. (Above 160F, further temperature increase has relatively little effect on corrosion rates in cooling-water systems.) Both temperature and acidity affect the corrosive effect of cooling water on metal. Most of these characteristics are relevant during the cooldown/shutdown/startup cycle. Oxygen is more easily introduced into the system; suspended solids often referred to as "hideout" solids reappear during startup; water velocity changes; and, of course, temperature changes. Table 4 indicates how frequently temperature changes may occur at San Onofre.

It is relatively well documented that iron and copper discharges increase dramatically during power reduction, shutdowns, and startup. The major discharges are believed to be in the steam-generator blowdown and the hotwell-overboard system. A recent research project by EPRI on San Onofre (Return of Hideout Chemicals in PWR Steam Generators During Power and Temperature Reductions, NP-4563) concluded that blowdown concentrations of chemicals and metals increase appreciably during power reductions and shutdowns. However, the report stated that quantification was difficult.

The Environment Report for Units 2 and 3 states that the hotwell is equipped with system that overboards directly to the main cooling system during startups until Total Suspended Solids (TSS) are less than 1 ppm. Some of these solids consist of metal eroded from the turbine and corroded from tube sheets, the water box, and steam generator tubes. An article in Power ("Corrosion: A Special Report," 4/83) reported iron or copper buildup in PWR condensate measured approximately 250 Kg and Copper measured 40 Kg, respectively, over 4,000 hours or 6 months of continuous operation.

SCE, in its Unit 1 Application to the RWQCB, stated that iron exceeded limits (1 mg/l) during startup by a factor of ten, lasting up to 48 hours. SCE reported that this occurrence takes place 5 times per year. If we assume that this is true for Units 2 and 3 as well, and that copper increases by an amount 10 times the daily maximum limit (to 0.2 mg/l), then estimates of "abnormal releases" in blowdown can be made.

# TABLE 4

## REDUCTIONS IN POWER OUTPUT BELOW 50%*

| Year | Unit 1 | Unit 2 | Unit 3 |
|---|---|---|---|
| 1986 | 8 | 9 | 9 |
| 1985 | 6 | 8 | 10 |
| 1984 | 1 (no power for 11 mos) | 9 | 20 |
| 1983 | No Power | 14 | 4 (began operating 9/83 |
| 1982 | 2 (no power for 10 mos) | (never over 50% power) | -- |

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* Source: NUREG-0020, 1/82 - 10/86.

## Findings and Conclusions

Based on the information that we reviewed, we estimated that chromium discharges from Units 2 and 3 range from 4.5 thousand pounds to 16.5 thousand pounds per year. This information is incomplete until we gain a better understanding of how spent coolant from the diesel generators is handled. Assumptions and calculations are attached in Exhibit 2.

There is a substantial difference between our estimates of chromium release and SCE estimates (memo from Art Kneisel to J.B. Palmer, 3/13/87). Since we have requested that SCE respond to our estimate during June 4, 1987 presentation of these findings, I can only conclude that they are reasonable.

We were also able to estimate a minimum iron and copper discharge from steam generator blowdown for Units 2 and 3. However, the quantities are so small (60 lbs. and 6 lbs. per year, respectively) that they are insignificant. Until a better understanding is gained regarding hotwell overboarding, and the efficiency of the demineralizers on the secondary system, meaningful conclusions cannot be drawn. However, because we know that corrosion problems are so pervasive for nuclear power plants, potential discharges of iron and copper may be significant.

We were not able to draw any conclusions regarding other toxic heavy metals. Of particular note is manganese, of which we found no evidence during our review.

It is important to note that the releases identified do not exceed levels permitted by the RWQCB, although the yearly mass emissions seem high. On the average, emissions are only 9% of the Regional Water Quality Control Board's permitted level of discharge. More importantly, we found no evidence to support the permitted levels. Likewise, although a review of SCE's semi-annual monitoring reports indicated chromium exceeded standards on a few occasions, no link has been drawn between these exceedances and environmental damage, and no follow-up studies were undertaken by the RWQCB or SCE. We draw two conclusions from this:

1) The required monitoring program and other terms of the Regional Water Quality Control Board's Permit are in definite need of improvement; and

2) There is not enough information at present on which one can design a meaningful monitoring program.

There are a few other potential sources of heavy metal discharges within the surrounding area. San Onofre Unit 1 estimated discharge of chromium is between 643 lbs. and 2,352 lbs. per year and past practices may have left substantial deposits of heavy metals. Runoff and stream contamination from past practices at Camp Pendelton may also have left deposits of heavy metals. The Navy prepared an Initial Assessment Study of Camp Pendelton, which identified 20 sites where disposal of toxic wastes took place, including machine shop oils and paint wastes containing chromates.

## Recommendations

We recommend that MRC pursue a second phase of study that is designed to more accurately establish the quantities of heavy metal discharges in conjunction with designing a sampling program that will provide meaningful results. For example, the monitoring program needs to be coordinated with cooldown/startup cycles, major repairs, draining coolant, and abnormal occurrences. In addition, some basic operational information is needed. Having open access to the operators and records at the plant would help answer some of the basic operational questions which influence discharge. These questions include:

1. The frequency and duration of hotwell overboarding after startup.
2. When other hotwell overboarding occurs and why.
3. How often turbine building cooling system and component cooling system are drained? What is done with spent coolant?
4. How often diesel generator cooling systems are drained, and what is done with spent coolant?
5. Has full-flow condensate polishing demineralizer system been installed (permit stated it would be installed "sometime after initial operation")? If not, what are the effects?
6. What chemicals are currently in use, and on which systems?
7. Have there been any abnormal leaks in the major cooling system?
8. How much chromic acid is used in the sewage treatment system?
9. What are the average system operation rates for TCWS and CCWS? What are the design leak rates?
10. Are anti-corrosion and anti-fouling paints used?
11. What materials are used to plug tube leaks?

We also recommend that MRC monitor any investigations the Navy is doing as a followup to its Initial Assessment Study. At the very least, it probably is going to yield some meaningful background data.

We also recommend that SCE be requested to verify and/or otherwise explain the apparent discrepancy of not reporting itself as a generator of potassium chromate to the EPA, as it has so stated. In the absence of MRC having access to SCE records, we recommend that MRC follow-up on search of DHS manifests.

## EXHIBIT 1: ABNORMAL EVENTS WHICH MAY BE LINKED TO DISCHARGES OF HEAVY METALS[*]

### UNIT 1

| | |
|---|---|
| 07-30-84<br>LER 84-008-00 | During extended mode 5 outage observed corrosion of structure reinforcing steel raised concerns that structure may not be able to meet seismic design criteria. Extensive inspection initiated. |
| 06-04-79<br>LER 79-008-01 | During maintenance outage 18 defective tubes discovered in steam generator A. Caused by corrosion of area tubesheet. Defective tubes plugged. |
| 06-05-79<br>LER 79-010-01 | Radiography revealed linear indications in steam generator feedwater nozzle during maintenance outage. Caused by stress assisted corrosion. Reducers replaced and welds redone. |
| 05-20-76 | Steam generator B indicated that steam flow started decreasing on slow ramp during full power operation. Caused by leaking blowdown valve on high pressure line to steam flow transmitter. Leak corrected. |
| 07-30-76 | Steam generator radiation monitor indicated high activity on blowdown from steam generator C. Caused by leak in one tube in steam generator C. Tube explosively plugged. |
| 10-12-80<br>LER 80-039-03 | Maintenance inspection revealed worn thrust bearings on all turbochargers on emergency diesel generator 1. Cause under investigation. Bearings returned to manufacturer for repair. |

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[*] This Exhibit is not intended to be inclusive. Rather, its purpose is to demonstrate the type and form of information which is publicly available. Any inferences pertaining to the potential discharge of heavy metals would require a more thorough evaluation of the event.

| | |
|---|---|
| 03-24-80<br>LER 80-012-03 | During normal operations number 2 diesel generator fuel oil transfer pumps G-75A and G-75B tripped on current overload. Caused by failure of sump pumps in transfer pump vault due to high water level in vault. |

### UNITS 2 & 3

| | |
|---|---|
| 03-26-86<br>LER 86-007-00 | During cold shutdown loss of shutdown cooling system flow occurred. Chased by erroneous level indication in tygon manometer ref scale and air bubble in tygon tubing. |
| 10-04-85<br>LER 85-049-00 | Seven pacific scientific snubbers found frozen on shutdown cooling system. Caused by water hammer due to air pockets from inadequate venting. Snubbers replaced and additional venting capability will be added. |
| 07-30-83<br>LER 83-089-03 | Train B salt water cooling system flow rate less than required. Unit declared inoperable while debris cleaned from traveling screen system (TSS). Caused by TSS overload due to high surf. |
| 12-14-82<br>LER 82-170-03 | Review of chart recordings of RCS cold leg temperature indicated heatup-cooldown rate limits exceeded on three occasions. |
| 10-01-82<br>LER 82-125-03 | Shutdown cooling system declared inoperable when pre-existing tube leak in train A component cooling water system HX aggravated. Caused by surge tank filled with solid due to faulty level control switch 2LSN-6498. |
| 10-01-82<br>LER 82-125-03 | While in mode 5 W-RCS drained to midloop decreasing component cooling water system surge tank level indicated leak. Cause not stated. Nine leaking tubes in train A shutdown cooling system plugged. |

# EXHIBIT 2: ESTIMATE OF CHROMIUM DISCHARGE

## HIGH SCENARIO

### Assumptions:

$K_2CrO_4$ = 500 ppm
Leak rate at Unit 1 = 4 gpm
Leak rate at Units 2/3 = 28 gpm
System Operation Rate = 100%

### Calculation for Unit 1

4 gpm X 60 m/h X 24 h/d X 365 d/y = 2.1 X $10^6$ gpy (leakage)

2.1 X $10^6$ gpy = 7.9 X $10^6$ liters/y

7.9 X $10^6$ l/y X 500 mg/l = 3950 X $10^6$ mg/y

(3950 X $10^6$ mg/y) X (2.205 X $10^{-6}$ lbs/mg) = 8710 lbs/year $K_2CrO_4$*

8710 lbs/year $K_2CrO_4$ X .27 = 2352 lbs/yr chromium*

### Calculation for Units 2/3

Multiply results of Unit 1 by 7 (leak rate)

7 X 2352 lbs/y = 16,464 lb/yr Chromium**

### Conversion Factors

1 mg = 2.205 X $10^{-6}$ lbs
1 gallon = 3.785 Liters
1 part per million (ppm) = 1 mg/l
1 pound $K_2CrO_4$ = 27 percent chromium

---

* This translates to 6.4 lbs/day, 8% of the permitted limits for total chromium for Unit 1.

** This translates to 45 lbs/day for each unit, 9% of the permitted limits for Units 2 and 3.

# MEDIUM SCENARIO

## Assumptions Unit 1

$K_2CrO_4$ concentration = 300 ppm
Leak Rate at Unit 1 averages 2 gpm
Leak rate at Units 2/3 averages 14 gpm
System Operation Rate = 90%

## Calculation for Unit 1

(2 gpm X 60 min/hr X 24 hr/day X 365 days/year) (90% operating time) = 946,080 gallons per year = 3.6 X $10^6$ liters per year

300 mg/l (3.6 X $10^6$ l/y) = 1080 X $10^6$ mg/y

1080 X $10^6$ mg/y = 2381 lbs/year $K_2CrO_4$

2381 lbs/y X .27 = 643 lbs/yr chromium

## Calculation for Units 2/3

Multiply results from Unit 1 by seven

7 X 643 lbs/year = 4,501 lbs./yr. chromium

## Conversion Factors

1 mg = 2.205 X $10^{-6}$ lbs
1 gallon = 3.785 Liters
1 part per million (ppm) = 1 mg/l
1 pound $K_2CrO_4$ = 27 percent chromium

# EXHIBIT 3: SOURCES OF INFORMATION

## Publications

1. RWQCB Inspection Reports (1985-87)
2. RWQCB Correspondence File
3. SCE Form 2C (NPDES)
4. NPDES Permits for SONGS 1, 2, 3
5. NRC, Environmental Report, San Onofre Unit 1, 1972
6. NRC, FSAR, Units 1, 2, 3
7. NRC, Environmental Reports, San Onofre Units 2 & 3, 1978
8. NRC, Computer Search of PDR
9. NRC, Technical Specifications, SONGS 1, 2, 3
10. NRC, License Amendments, SONGS 2 & 3
11. EPA, Development Document for Effluent Guidelines for Steam Electric Power Plants
12. SAIC Potential Sources of Toxic Metal Input from SONGS to the Marine Environment, September 1986
13. SCE, Semi-Annual Monitoring Reports
14. SCE, Semi-Annual Environmental Reports, 1982-86
15. SCE, Monthly Operating Reports
16. EPRI, Return of Hideout Chemicals in PWR Steam Generators During Power and Temperature Reductions, NP-4563
17. EPRI, Flushing Steam Boiler is Effective Method of Reducing Scale-Particle Erosion in Boiler, RP-1885
18. EPRI, Condensate Polishers for Brackish Water-Cooled PWRs, NP-4550, July 1986
19. EPRI, Properties of Colloidal Corrosion Products and Their Effects on Nuclear Power Plants, NP-2606, October 1982
20. EPRI, Electrochemistry and Corrosion of Alloys in High Temperature Water, NP-4705, July 1986

21. Department of Navy, Initial Assessment Study, Marine Corp Base Camp Pendleton, California, Preliminary Assessment of Toxic Waste Disposal Practices at Camp Pendleton

22. Young, Jan and Moore, "Metals in Power Plant Cooling Water Discharges," Coastal Water Research Project, pp. 25-31.

23. Power, "Protecting Todays Systems for Long-Term Reliability", Makans, Jason, Special Report, April 1983.

24. Power, "Cooling-Water Treatment", Strauss, Sheldon, Puckorius, Paul, Special Report, June 1984.

## People

1. Dennis Ruddi, EPA, Washington, D.C., Expert on Steam Electric Power Plant Effluents
2. Cheryl Lehr, EPA Region IX, Industrial Assistance
3. Brian Melzian, EPA Region IX, Marine Biologist
4. Madonna Narvez, EPA Region IX, Reviews Monitoring Reports
5. Carla Fisher, EPA Region X, Formerly Handled San Onofre Water Quality Permits
6. Ken Greenberg, EPA Region IX, Environmental Engineer, Water Quality
7. Ida Tulliver, EPA Region IX, FOIA
8. Bruce Postumus, Regional Water Quality Control Board, Region IX, Permit Officer for San Onofre
9. Warner Ziegler, JRB, McLean, VA, Assisted EPA in preparing Water Quality Permit for SONGS
10. Stan Ramulchuck, San Diego Air Quality Management District - no knowledge of chromate-based paints
11. Miles Bryant, Valspar Corporation, NJ, Supplier of paint
12. Art Kneisel, SCE. Wrote memo to Palmer describing chromium releases
13. Cathy Fisher, California Department of Health Services (DHS), Toxics Division
14. Anita Follette, DHS, Manifests
15. Dianne Perry, Consultant

16. John Davies, Skasol, Inc., Chemist for water chemistry firm

17. Jim Betz, NALCO, Sales agent for chemical company.

# Appendix E: Responses from SCE to MRC regarding potential sources within SONGS of metals that could be released into the marine environment.

MAILED BY
NUCLEAR SAFETY

APR 26 1988

April 26, 1988

DR. B. J. MECHALAS

SUBJECT: A Follow-up Commentary on Chromate Usage at San Onofre

The Marine Review Committee (MRC) requested MHB Technical Associates, Inc. (MHB) to estimate potential chromate discharges to the marine environment near San Onofre. MHB's estimates of chronic leakage of chromium (in the form of chromates) to the ocean from Unit 1 systems ranged from 643 to 2352 lb/yr, and from Units 2/3 ranged from 4501 to 16,464 lb/yr. According to MHB, another potential source of chromates that could be discharged to the ocean includes anti-fouling paints which have chromates as a minor constituent.

Further concern over the chromates usage at San Onofre was expressed in a memo to the MRC dated March 23, 1988. In short, a request was made to Edison to address MHB calculations, and address the handling of hazardous waste containing chromates.

These issues will be addressed individually with documentation where applicable.

MHB's estimated chronic chromium release rates are grossly overestimated because of incorrect basic assumptions underlying the calculations. Verification that the assumptions were incorrect was based on actual operational information.

MHB Associates, Inc. first assumed that three different cooling water systems at each of the three units are chromated, namely: the Turbine Plant Cooling Water System (TPCW), the Component Cooling Water System (CCW), and the Emergency Diesel Generator Cooling System. In actuality, only the Unit 1 TPCW, the Unit 1 CCW, and the Units 2 and 3 diesel generators have ever been chromated. See Attachment A.

Because the Units 2/3 TPCW and CCW have never been chromated, attention will be focused on MHB's estimates of chronic chromate leakage from the Unit 1 systems.

It was also assumed by MHB that the Unit 1 systems are chromated at approximately 450 ppm, and leak at a rate of 4 gpm. The actual concentrations used varies from system to system. The 4 gpm leak rate for Unit 1 chromated systems listed in correspondence from Edison to the Regional Water Quality Control Board - San Diego Region (RWQCB - SDR) represents a maximum leak rate, as stated, and not one that is going to be routinely encountered in plant operations. In fact, the actual leak rates of chromates from these systems are difficult to determine. Because of this, chromate usage was determined by tracking the monthly consumption rates. See Attachment B. For Unit 1 systems, the monthly consumption of chromates ranged from 0 to 135 lb/yr, averaging 37 lb/yr from 1978 through 1984. This corresponds to a potential release rate of chromium ranging from 0 to 36 lb/yr, averaging 9.9 lb/yr during this same time span.

MHB's estimates of chronic leak rates, ranging from 643 to 2352 lb/yr per Unit 1, are unrealistic. This was first eluded to in the November 1987 Edison communique from J. M. Curran to Dr. B. J. Mechalas. In the memo, the chromium content of the Unit 1 TPCW was calculated to be 33.5 lb. The chromium content of the Units 2/3 diesel generators was calculated to be about 26.3 lb. The goal of the calculations was to show that entire systems would have to be drained many times during the course of the year to reach MHB's estimated chronic release rates. For illustration, the 50,000 gallon Unit 1 TPCW, chromated at 300 ppm, would have to be completely drained at least 19.2 times per year, or roughly every 2.5 weeks to reach MHB's lower estimated yearly chronic release rate of 643 lb/yr of chromium. San Onofre is simply not run in this manner.

The disposition of the "consumed" chromates is limited to re-use in the plant, discharge to the ocean according to NPDES permit limitations, or disposal as hazardous waste. Summaries describing non-radioactive effluent releases to the ocean are submitted routinely to the RWQCB - SDR. Accidental spills of chromates are necessarily reported to the RWQCB - SDR. The disposal of hazardous waste at San Onofre is governed by San Onofre procedures which are written in conformance with Federal and California State requirements. The maximum permissible concentration of chromium in an aqueous solution is less than 500 ppm (category 132). From 1981 to present, the amount of chromium disposed of in the form of aqueous or organic solutions (hazardous waste categories 132, 133, and 341) has ranged from a high of approximately 33 lbs in 1981 to less than 10 lb/yr in subsequent years. See Attachment C for a summary description of chromate solution disposal from 1981 through 1984.

Concern has also been raised over the use and subsequent disposal of paints in the form of paint sludge from San Onofre. Paint is classified as a hazardous material. Used paint is consolidated into a shipping container. The paint container is then crushed and solidified per State and Federal Regulations. The shipping container, once filled, is profiled and sent to a licensed incineration facility.

In summary, the potential release rates of chromium in the form of chromated aqueous solutions or paints to the marine environment is at most minimal, and is a small fraction of the estimated release rates provided by MHB. San Onofre operational data indicate that tens of pounds of chromium may be potentially, but not necessarily, released to the ocean from San Onofre Unit 1 systems. The paints used at San Onofre are disposed of per State and Federal Regulations. The impact of San Onofre operations on the marine environment is thus considered to be minimal with regard to chromate usage and disposal.

J. M. CURRAN

Attachments (3)
JCL:jje:0761E

cc: [redacted]
R. S. Grove
P. H. Penseyres
B. D. Metz
E. S. Medling
J. C. Leslie
ESM Files
NE Files
CDM

Attachment A

## Primary Usage of Chromates at SONGS

| | | |
|---|---|---|
| Unit 1 | TPCW* | Chromated from 1966 to present. |
| Unit 1 | CCW* | Chromated from 1966 to May 1984. |
| Unit 1 | Diesel Generators | Never chromated. Calgon LC-15 (hydrazine) to 1987. Nalco 39 (nitrite/borate) 1987 to present. |
| Units 2/3 | TPCW (2 systems) | Never chromated. Hydrazine to 1983. Calgon CS (nitrite/borate) 1983 to present. |
| Units 2/3 | CCW (2 systems) | Never chromated. Same as the Units 2/3 TPCW. |
| Unit 2 | Diesel Generators | Originally chromated. Converted to Nalco 39 (nitrite/borate) in 1987. |
| Unit 3 | Diesel Generators | Chromated. Conversion to Nalco 39 (nitrite/borate) scheduled in 1988. |

*Abbreviations: TPCW - Turbine Plant Cooling Water System
CCW - Component Cooling Water System

Attachment B

## Chemical Consumption of Chromates
## Unit 1 (lbs.)

| | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 |
|---|---|---|---|---|---|---|---|
| Jan. | - | 0 | 0 | 0 | 0 | 0 | 20 |
| Feb. | - | 0 | 0 | 0 | 0 | 0 | 7.9 |
| Mar. | - | 0 | 0 | 0 | 0 | 0 | 0 |
| Apr. | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | - | 0 | 0 | 0 | 25 | 0 | 0 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 10 | 0 | 2 |
| Aug. | 20 | 0 | 0 | 0 | 0 | 0 | - |
| Sep. | - | 0 | 5 | 0 | 0 | 0 | * |
| Oct. | - | 0 | 0 | 7 | 0 | 0 | - |
| Nov. | 25 | 0 | 0 | 6 | 0 | 0 | - |
| Dec. | 0 | 0 | 0 | 25 | 100 | 0 | - |

Notes: Dashes - Data not available
* - Unit 1 CCW changed to Calgon in Sep. 1984
Similar data is not available for Units 2/3

Attachment C

## Chromate Disposal Records Summary

| Date | Amount | Chromates | Manifest # |
|---|---|---|---|
| 2/14/84 | 4000 gals. | (5 ppm) | 835-48783 |
| 2/7/83 | 5400 gals | (10 ppm) | 009-109642 |
| 2/7/83 | 5400 gals | (10 ppm) | 009-109643 |
| 2/8/83 | 5040 gals. | (10 ppm) | 009-109644 |
| 2/8/83 | 5040 gals. | (10 ppm) | 009-109645 |
| 9/30/83 | 3000 gals. | (5 ppm) | 833-15551 |
| 11/26/83 | 2500 gals. | (5 ppm) | 833-15553 |
| 3/16/82 | 2000 gals. | (.02 ppm) | 009-105253 |
| 3/16/82 | 5400 gals. | (13.2 ppm) | 009-104927 |
| 3/16/82 | 5400 gals. | (13.2 ppm) | 009-108005 |
| 7/15/82 | 5400 gals. | (.03 ppm) | 009-110326 |
| 7/15/82 | 5000 gals. | (7 ppm) | 009-098413 |
| 7/1/81 | 2.35 tons | (.5%) | 370-000532 |
| 7/3/81 | 5040 gals. | (950 ppm) | 009-099632 |
| 7/16/81* | 2.35 tons | (.5%) | 370-000533 |
| 9/15/81* | 2.62 tons | (2500 ppm) | 210-014788 |

*Note: Restricted chromium concentrations (less than 500 ppm) were not required in 1981

NOV 4 1987

November 4, 1987

RECEIVED
NOV 4 1987
B. MECHALAS

DR. BYRON J. MECHALAS

SUBJECT: Commentary on the MHB Technical Associates Report dated July 24, 1987

In the subject report, sources and release rates of various metals are discussed. The most important heavy metal being released to the marine environment according to MHB is chromium in the form chromic acid and potassium chromate. The main sources of these releases are listed as the Unit 1 Turbine Plant Cooling Water System (TPCW), the Component Cooling Water System (CCWS), and the Emergency Diesel Generator Cooling System. Using these release points, chromate concentrations listed in the FSAR and SCE estimates of leak rates, MHB estimates the yearly discharge of chromium to the ocean from Units 1, 2, and 3 to range from 5,144 lbs./yr. to 18,816 lbs./yr. From this study, MHB recommended that MRC further investigate the use, potential generation (through erosion and corrosion), and disposal of chromium at San Onofre.

Our review of this study indicates that MHB's estimate of chromium discharge to the environment is unrealistic and unrepresentative of current plant operating conditions.

As of September 1987, the primary sources of chromium include the use of potassium chromates in the Unit 1 TPCW and in the Unit 3 diesel generators. Taking the average concentration of chromates and the volumes of these systems, the calculated approximate maximum amount of chromium that could be discharged to the ocean is 60 lbs. A calculation based on National Pollutant Discharge Elimination System (NPDES) effluent data for San Onofre for January through June 1987 indicates that the discharge of chromium to the ocean may have been actually below 2 lbs. for that time span. Make-up to the Unit 1 TPCW is about 1 lb. on a yearly basis. When the Unit 1 TPCW is drained, the chromates are trucked offsite as hazardous material. When necessary, the Unit 3 diesel generators are drained to a bladder or to drums temporarily until the chromates can be reintroduced into the system.

Because chromium is classified as a hazardous material, San Onofre is in the process of converting from chromate corrosion inhibitors to other corrosion inhibitors. Conversion of the Unit 1 TPCW to Calgon CS is planned for February 1988. Conversion of the Unit 3 diesel generators to Nalco 39M is scheduled by December 1988.

In summary, the amount of chromium that is discharged from San Onofre to the ocean is considered to be insignificant, in short term. In the long term, the release of chromium is expected to decrease to near zero by 1989. Accordingly, NES&L believes that further expenditure of time and funds to the chromium issue is unwarranted.

J. M. CURRAN

JCL:jje:0590E

cc: J. B. Palmer
E. S. Medling
J. C. Leslie
ESM Files
CDM

Attachment "A"

Calculation of the amount of chromium that <u>could be</u> discharged to the ocean from the Unit 1 TPCW and the Unit 3 Diesel Generators. Make-up rates to the TPCW, DGs not considered.

A. Unit 1 TPCW — 1987 data used (from N. Bihl).

$$300 \text{ ppm} = 300 \times 10^{-6} \frac{g\ K_2CrO_4}{g\ H_2O}$$

$$\frac{300 \times 10^{-6}\ g\ K_2CrO_4}{g\ H_2O} \times \frac{1\ gm}{ml} \times \frac{1000\ ml}{l} \times \frac{1\ liter}{.264172\ gal} \times 50{,}000$$

$$= 5.68 \times 10^{4}\ g \text{ chromates}$$

$$5.68 \times 10^{4}\ g\ K_2CrO_4 \times \frac{51.996\ Cr}{194.191\ K_2CrO_4} \times \frac{1\ lb}{454\ g} = \frac{33.5\ lb}{\text{Chromium maximum}}\ *$$

B. Unit 3 Diesel Generators –

Unit 3 DG NE 3.08 lb Cr maximum
NW 4.64 lb Cr "
SE 7.57 lb Cr "
SW 11.05 lb Cr "
<u>26.34 lb Cr</u> maximum

* make-up to TPCW ≅ 1 lb per year

TO THE OCEAN FROM SONGS IN 1987

hexavalent Chromium

I. MAXIMUM concentration that could have been released based on NPDES permits.

A. Potential sources of release

Unit 1 - TPCW (50,000 gal @ 300 ppm)

Unit 2 - none

Unit 3 - Diesel Generators
- NE 1000 gal @ 1380 ppm
- NW 800 gal @ 2600 ppm
- SE 800 gal @ 4240 ppr
- SW 1000 gal @ 4950 pp

B. million gallons released from Jan - June 1987

| | |
|---|---|
| Thru Unit 1 plant drain | 15.658 mG |
| thru Units 2/3 building sump | 7.789 mG |
| | $23.447 \times 10^6$ gallon |

C. Maximum possible ~~amount of Cr~~ released through these sources.

NPDES semiannual report — hexavalent Chromium concentration less than 0.01 mg/l for Jan - Jun 1987. 1 sample/6

$$23.447 \times 10^6 \text{ gal} \times \frac{1 \text{ liter}}{.264172 \text{ gal}} \times \frac{.01 \text{ mg}}{\text{liter}} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ lb}}{454 \text{ g}}$$

$= \underline{1.95 \text{ lb.}}$

or about 4 lb/yr for 1987 (estimated) maximum

Attachment B

# Chemical Consumption of Chromates
Unit 1 (lbs.)

| | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 |
|---|---|---|---|---|---|---|---|
| Jan. | - | 0 | 0 | 0 | 0 | 0 | 20 |
| Feb. | - | 0 | 0 | 0 | 0 | 0 | 7.9 |
| Mar. | - | 0 | 0 | 0 | 0 | 0 | 0 |
| Apr. | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | - | 0 | 0 | 0 | 25 | 0 | 0 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 10 | 0 | 2 |
| Aug. | 20 | 0 | 0 | 0 | 0 | 0 | - |
| Sep. | - | 0 | 5 | 0 | 0 | 0 | * |
| Oct. | - | 0 | 0 | 7 | 0 | 0 | - |
| Nov. | 25 | 0 | 0 | 6 | 0 | 0 | - |
| Dec. | 0 | 0 | 0 | 25 | 100 | 0 | - |

Notes: Dashes - Data not available
* - Unit 1 CCW changed to Calgon in Sep. 1984
Similar data is not available for Units 2/3

Attachment C

## Chromate Disposal Records Summary

| Date | Amount | Chromates | Manifest # |
|---|---|---|---|
| 2/14/84 | 4000 gals. | (5 ppm) | 835-48783 |
| 2/7/83 | 5400 gals | (10 ppm) | 009-109642 |
| 2/7/83 | 5400 gals | (10 ppm) | 009-109643 |
| 2/8/83 | 5040 gals. | (10 ppm) | 009-109644 |
| 2/8/83 | 5040 gals. | (10 ppm) | 009-109645 |
| 9/30/83 | 3000 gals. | (5 ppm) | 833-15551 |
| 11/26/83 | 2500 gals. | (5 ppm) | 833-15553 |
| 3/16/82 | 2000 gals. | (.02 ppm) | 009-105253 |
| 3/16/82 | 5400 gals. | (13.2 ppm) | 009-104927 |
| 3/16/82 | 5400 gals. | (13.2 ppm) | 009-108005 |
| 7/15/82 | 5400 gals. | (.03 ppm) | 009-110326 |
| 7/15/82 | 5000 gals. | (7 ppm) | 009-098413 |
| 7/1/81 | 2.35 tons | (.5%) | 370-000532 |
| 7/3/81 | 5040 gals. | (950 ppm) | 009-099632 |
| 7/16/81* | 2.35 tons | (.5%) | 370-000533 |
| 9/15/81* | 2.62 tons | (2500 ppm) | 210-014788 |

*Note: Restricted chromium concentrations (less than 500 ppm) were not required in 1981

NOV 4 1987

November 4, 1987

RECEIVED
NOV 4 1987
B. MECHALAS

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$$= \underline{1.95\ \text{lb.}}$$

or about 4 lb/yr for 1987 (estimated) maximum