

SAN ONOFRE NUCLEAR GENERATING  
STATION (SONGS)  
AS A SOURCE OF METALS AND CONCENTRATIONS  
OF METALS IN SAND CRABS

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## INTRODUCTION

An action item on the June 13, 1985 MRC Business Meeting requested investigation of SONGS as a possible source for metals entering the marine environment. Determination of the mass emission of metals discharged by SONGS, and the subsequent dilution and transportation of those metals is an important step towards linking SONGS to metal concentrations in sand crabs or other organisms. Previous studies have suggested that populations of the sand crab Emerita analoga on beaches  $\pm$  12 km from SONGS differ in several attributes from sand crabs occurring on other southern California beaches (Auyong, 1981; Wenner, 1982; and MEC, 1984; Bence, 1986). Sand crabs near SONGS had a higher incidence of prematurely ruptured eggs in association with viable eggs during the late summers of 1983 and 1984 (MEC, 1984; Bence, 1986). Sand crabs may not overwinter, may recruit later to beaches, and may be lower in abundance near SONGS than on other southern California beaches (Wenner, 1982; MEC, 1984). In addition, females may be reproductively mature at a smaller size (Auyong, 1981; Wenner, 1982), as well as grow at a slower rate (Auyong, 1981). Mean size of males and females may be smaller close to SONGS (Auyong, 1981). These reported characteristics in sand crabs collected on beaches near SONGS could be attributed to the presence or operation of SONGS, and/or be explained by differences in the physical parameters among beaches (MEC, 1984). A forthcoming review of all the related MRC sand crab studies by Jim Bence will result in testing the persistence of the above patterns among those studies.

Chemical analyses detected relatively higher concentrations of chromium, manganese, and iron, although not significantly higher for all beaches, in July and/or August 1983 in sand crabs collected from beaches  $\pm$  12 km from SONGS compared to crabs from beaches farther away (Parker, 1985a). The concentrations of these metals in sand crabs are significantly correlated to percentage of females (greater than 13 mm) with completely spent eggs during either July or August 1983 (August: chromium  $R^2 = 0.80$ ,  $P \leq 0.02$ ; manganese  $R^2 = 0.73$ ,  $P \leq 0.04$ ; July: iron  $R^2 = 0.75$ ;  $P \leq 0.04$ ; Parker, 1985b). The spent egg condition may be attributed to premature rupture of eggs (indicated by the presence of spent eggs and viable eggs in a clutch) or synchronous release of larvae (indicated by close to 100% spent eggs in a clutch) (Bence, 1986). In fact, both spent egg conditions appear to be present at a higher incidence near SONGS during the late summer of 1983 (MEC, 1984). Sublethal effects, such as disruption in reproduction are known to occur in marine invertebrates exposed to metals in seawater and sediments at higher concentrations than those which are found in nature (Mearns, et al. 1976; Cunningham, 1979).

This report provides information relevant for two hypotheses. Hypothesis one: SONGS discharges metals, particularly chromium, at high enough concentrations to be transported and incorporated into the tissues of sand crabs at the measured concentrations in crabs on beaches  $\pm$  12 km from the plant. Hypothesis two: the concentrations of the metals in sand crabs  $\pm$  12 km from SONGS are high enough to induce sublethal effects such as impaired reproduction. In order to evaluate

these hypotheses several questions are posed which constitute the organization of this report: I. What metals are discharged from SONGS? II. What are the concentrations and/or mass emissions of metals, particularly chromium released by SONGS? III. Can metals be transported from a point discharge to distances of 12 km? What is the dilution factor for metals in the water column reaching beaches  $\pm$  12 km from SONGS? IV. What evidence exists for incorporation and concentration of metals in marine invertebrates? and ~~IV~~. At what concentrations are metals known to produce sublethal effects in marine invertebrates?

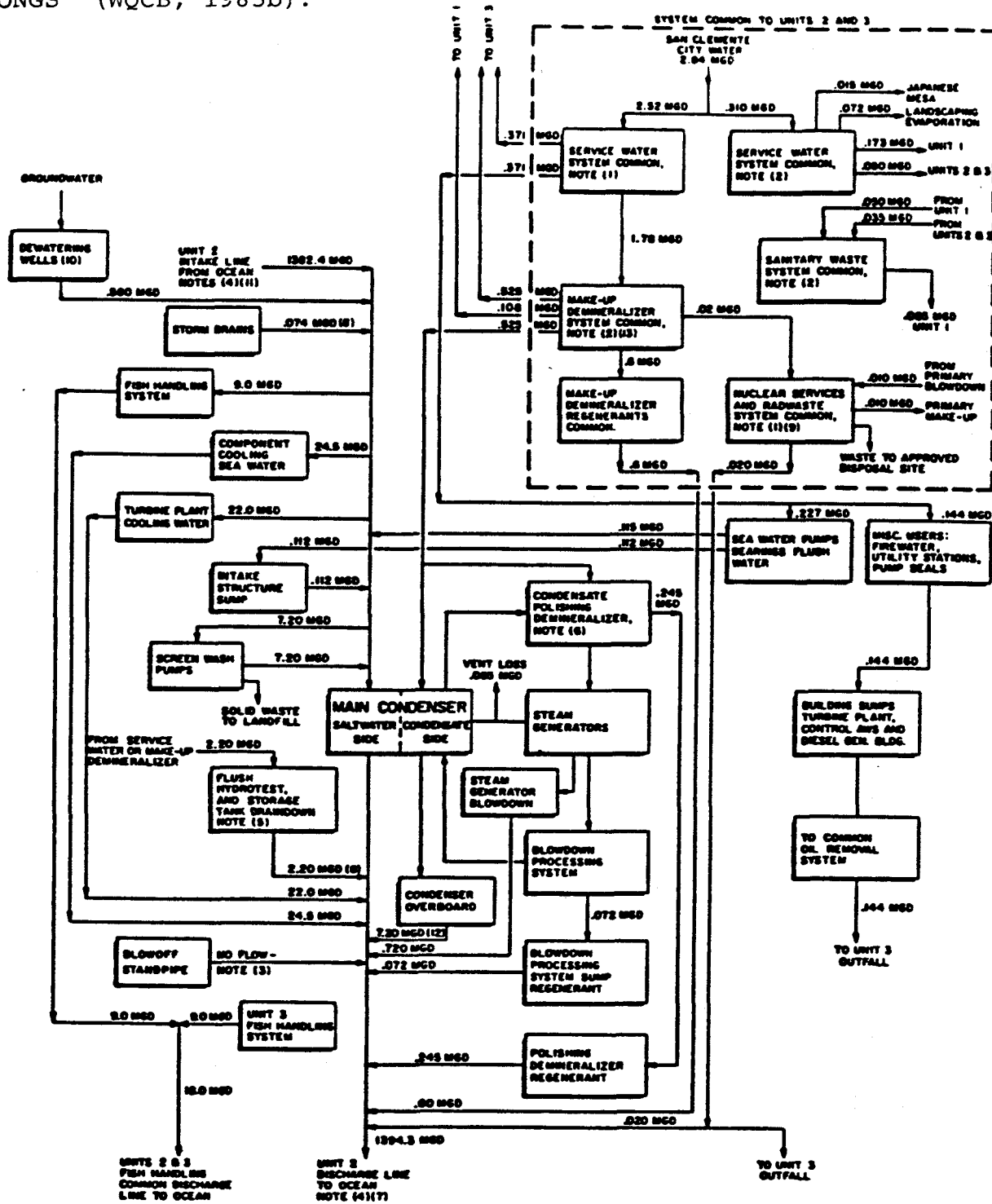
#### **I. Metals discharged by SONGS**

SONGS discharges at least 24 different metals including the ones of most interest to the MRC, specifically chromium, manganese, and iron as radioactive and nonradioactive isotopes (Nuclear Regulatory Commission (NRC), 1983; Water Quality Control Board (WQCB), 1984; 1985a) (Table 1). Nonradioactive metal wastes can be particularly important in a closed-loop system such as SONGS (Eichholz, 1985). The SONGS Unit 2 discharge consists of at least seventeen different in plant streams (WQCB, 1985b) (Fig 1). Wastes are discharged intermittently and peak flows can be ten times greater than the average flow. Most nonradioactive in-plant wastes are diluted in the discharge stream to concentrations that meet local water quality standards (Eichholz, 1985).

With respect to the seventeen waste streams, the potential major sources for metal wastes are: (1) The secondary cooling water system may contain metals leached from piping; (2) The blowdown processing system which demineralizes the steam generator and provides high quality condensate back to the main condenser; and (3) Other demineralizer systems. Steam upon passing the turbine is condensed back to water and is demineralized prior to returning to the steam generator. This demineralizer system is designed to remove ions entering the system from small leaks which may develop in the main condenser and associated piping. The makeup demineralizer (MUD) system produces deionized water for various in-plant systems. Upon neutralization (pH) the regeneration wastewater is piped to the condenser cooling water system for subsequent discharge at Unit 2 (WQCB, 1985b).

Radioactive corrosion products arise as a result of neutron bombardment of the cladding material enclosing the nuclear fuel (uranium-238) that heats the primary cooling loop. This coolant loop is enclosed with materials including stainless steel, zircaloy, inconel, carbon steel and other steel and copper alloys. The most common radioactive isotopes formed by neutron bombardment in this system are Fe-59, Cr-51, Mn-54, Co-60, and Zr-95 (Eichholz, 1985). The primary coolant stream is decontaminated by the coolant radwaste system (CRS) which consists in part, of an on-line filter and ion exchange system. Radioactive corrosion products are released and monitored in the SONGS' effluents, air, ocean, sediments, and in organisms semiannually by Southern California Edison (SCE) under the

Fig. 1. Flow diagram of discharged wastes from Units 2/3 of SONGS (WQCB, 1985b).



- NOTES:
- (1) COMMON SYSTEM, SERVES UNITS 2 & 3.
  - (2) COMMON SYSTEM, SERVES UNITS 1, 2 & 3.
  - (3) EMERGENCY USE ONLY; NOT PART OF NORMAL OPERATION.
  - (4) MGD = MILLION GALLONS PER DAY.
  - (5) FLUSH & HYDROTEST WASTEWATER VOLUME IS FOR STARTUPS. NORMAL OPERATION WILL BE LOWER. DISCHARGE TO UNIT 1 OUTFALL IS AN ALTERNATE MEANS OF DISCHARGE.
  - (6) CONDENSATE POLISHING DEMINERALIZER WILL NOT BE INSTALLED UNTIL AFTER INITIAL PLANT OPERATION.
  - (7) FLOWS GIVEN ARE ESTIMATED DISCHARGE VOLUME IN GALLONS, PER AVERAGE DAY.
  - (8) THESE FLOWS ARE NOT DAILY INTERMITTANT DISCHARGES, HOWEVER THEY ARE INCLUDED IN THE DAILY FLOW BALANCE.
  - (9) ALL LOW-LEVEL RADIOACTIVE WASTE IS DISPOSED OF IN ACCORDANCE WITH THE NUCLEAR REGULATORY COMMISSION'S REGULATIONS.
  - (10) INTERMITTANT DISCHARGE ASSOCIATED WITH CONSTRUCTION PERIODS. DURING CONSTRUCTION THE FLOW WILL BE CONTINUOUS.
  - (11) FLOW BASED ON MAXIMUM DISCHARGE RATE OF THE MAIN CIRCULATING COOLING WATER PUMPS (240,000 GPM).
  - (12) ESTIMATED VOLUME DISCHARGED IF ENTIRE SECONDARY SYSTEM WAS SHUTDOWN DURING SCHEDULED OR UNSCHEDULED OUTAGES.

MAXIMUM WATER FLOW FOR UNIT 2  
SOUTHERN CALIFORNIA EDISON CO. AND  
SAN DIEGO GAS AND ELECTRIC CO.  
CAMP PENOLETON, SAN DIEGO COUNTY, CA  
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Fig. 1. (continued)

OUTFALL NUMBER	OPERATIONS CONTRIBUTING FLOW	DURATION PER OCCURRENCE		OCCURRENCE PER DAY		FREQUENCY a.DAY/MK b.PD/yr		A. FLOW RATE		TOTAL VOLUME		
		Av. (Min.)	Max. (Min.)	Av.	Max.	a.	b.	1. LONG TERM AVERAGE (gpm)	2. MAXIMUM DAILY (gpm)	LONG TERM AVERAGE (gpd)	MAXIMUM DAILY (gpd)	
002	Screen Wash	30	1440	6	1	7	12	5000	5000	0.9x10 <sup>6</sup>	7.2x10 <sup>6</sup>	
	Flush, Hydrotest Storage Tank Brain Drain (1)	720	1440	1	1	7	12	500	1500	360,000	2.2x10 <sup>6</sup>	
	Condenser Hotwell Overboard	360	1440	1	1	7	12	500	5000	180,000	7.2x10 <sup>6</sup>	
	Steam Generator Bleeddown	625	1440	1	1	7	12	500	500	312,500	720,000	
	Bleeddown Process. System Drain. Regenerants (2)	1.5	45	1	4	7	12	400	400	600	72,000	
	Full Flow Condensate (3) Polish Drain. (FFCPO)	245	245	1	2	7	12	500	500	122,500	245,000	
	Makeup Drain. (MUD) (3) (6)	60	60	4	5	7	12	1800(4)	2000	500,000	600,000	
	Radwaste Sys.	85	170	1	1	7	12	120	120	10,000	20,000	
	Building Sumps(5)	330	1440	3	1	7	12	100	100	99,000	144,000	
	Intake Structure Sump	175	560	4	2	7	12	100	100	70,000	112,000	
	Construction Dewatering Groundwater	1440	1440	1	1	7	12	400	400	580,000	580,000	
	003	Screen Wash	30	1440	6	1	7	12	5000	5000	0.9x10 <sup>6</sup>	7.2x10 <sup>6</sup>
Flush, Hydrotest & Storage Tank Brain Drain(1)		720	1440	1	1	7	12	500	1500	360,000	2.2x10 <sup>6</sup>	
Condenser Hotwell Overboard		360	1440	1	1	7	12	500	5000	180,000	7.2x10 <sup>6</sup>	
Steam Generator Bleeddown		625	1440	1	1	7	12	500	500	312,500	720,000	
Bleeddown Process. System Drain. Regenerants (2)		1.5	45	1	4	7	12	400	400	600	72,000	
Full Flow Condensate Polish Drain. Regenerants. (FFCPO) (3)		245	245	1	2	7	12	500	500	122,500	245,000	
Radwaste Sys.		85	170	1	1	7	12	120	120	10,000	20,000	
Building Sumps(5)		330	1440	3	1	7	12	100	100	99,000	144,000	
Intake Structure Sump		175	560	4	2	7	12	100	100	70,000	112,000	
Construction Dewatering Groundwater		1440	1440	1	1	7	12	400	400	580,000	580,000	
004		Fish Handling System (7)	30	1440	10	1	7	12	60,000	60,000	18.0x10 <sup>6</sup>	86.4x10 <sup>6</sup>

NOTES

- (1) Intermittent flow however can be continuous during startup and construction periods or equipment failures.
- (2) Average occurrence, once per 30 days, operation time is 45 min., maximum is 4 times daily.
- (3) All values are engineering estimates. FFCPO and new MUD are yet to be constructed.
- (4) Gravity drain line.
- (5) These sumps discharge to common oil removal system.
- (6) Common system for Units 1,2&3.
- (7) Common system for Units 2&3

jurisdiction of the NRC (NRC, 1982; 1983; 1984).

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Table 1. A partial list of metals (based on available information) discharged by SONGS' Units 1, 2, and 3 (NRC, 1982;1983;1984; WQCB, 1984; 1985a). \*=stable isotopes (concentration range of 0.0004 to 0.60 mg/l (ppm)), @= unstable isotopes ( $10^{-6}$  to 1.0 curies ( $3.7 \times 10^{10}$  disintegrations/second)/3 mo.)

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Lead	*	Cesium	@
Cadmium	*	Lanthanum	@
Copper	*	Ruthenium	@
Mercury	*	Strontium	@
Chromium	*@	Antimony	@
Manganese	*@	Barium	@
Iron	*@	Cerium	@
Nickel	*@	Molybdenum	@
Silver	*@	Niobium	@
Zinc	*@	Rubidium	@
Cobalt	*@	Technetium	@
Tungsten	@	Zirconium	@

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## II. Mass Emissions of metals from SONGS

Concentration measurements of stable chromium and iron in the major waste streams at SONGS are required by regulation, whereas there is no requirement for detection of manganese (WQCB, 1985b,c). Chromium concentrations are determined semi-annually by taking one grab sample in the combined effluents, as well as in the in-plant waste stream for Units 2/3, and only in the in-plant waste stream for Unit 1. Iron concentration is measured semi-annually by taking one grab sample in the in-plant waste stream only at Unit 1. The one sample concentration values are



reported in the WQCB reports as the daily maximum and as the 6-month median. The sensitivity for concentration measurements is at 0.01 mg/l. Water samples are collected by SCE, and sent to Environmental Engineering Laboratories, San Diego to be analyzed. SCE submits the required reports to the WQCB in San Diego. In addition, SCE has reported preoperational (Units 2 and 3) metal concentrations for copper, chromium, iron, nickel, and titanium in water and sediment samples collected at Unit 1 outfall to 7550 km downcoast during 1978 to 1980 (SCE, 1981lab). Presently, the sampling program is being repeated to obtain operational metal concentrations (personal communication, R. Grove).

In the January-June 1985 Semiannual WQCB report chromium was measured at 10.0 ug/l (or ppb) on May 29, 1985 in the combined discharge in Units 2/3. Since the chromium level could be at or about the limit of sensitivity in concentration measurements, it is impossible to calculate an accurate value in MT/yr (metric tons/year) of chromium discharged from SONGS. There is a difference of 37 MT/yr chromium in yearly mass emission depending upon whether or not chromium is discharged at 10.0 or 1.0 ug/l (Table 2).

Table 2. Metric tons per year chromium calculated from a range of chromium concentrations and based on the June 1985 volume of flow from Units 1,2, and 3 at SONGS.

**Volume of flow: (millions of liters/day)**

June 1985					
Unit 1	1689				(87% of maximum daily combined
Unit 2 & 3	4614 each				discharge flow rate)

Assuming a Cr					(ug/l or ppb)
concentration of: 10.0	5.0	2.5	1.25	0.62	
metric tons/yr	39.8	20.0	10.0	5.1	2.6

John Palmer (handout at MRC Business Meeting of June 13, 1985) estimated that the cooling systems at SONGS 1-3 discharge 0.28 MT/yr chromium into the ocean. That estimate is based upon a circulating volume of 12588 millions of liters/day, and a median concentration difference between effluent and influent calculated by Young, et al. (1977). The median difference in concentration is based on sampling during 1977 at eight of SCE's coastal generating stations, including SONGS' Unit 1 at the beginning and end of the intake and discharge structures, respectively. This estimate for the mass emission of chromium may be biased towards the low side for the following reasons:

(1) The objective of the report was to measure metal input only from the secondary cooling systems. Arrangements were made with SCE on the day of sampling that no retention basin water (in-plant wastes from sources such as acid-cleaning, fireside boiler

wash water and floor drainings) was to be released into the effluents (Young, et al. 1977). However, concentrations of chromium from in-plant wastes can be relatively high. In-plant release of chromium was measured at 20.0 ug/l on October 19, 1984 with a stream flow of 2.15 millions of liters/day; and (2) Although the flow volume for Units 2 and 3 was included in the calculations, actual concentration measurements of chromium were not available because Units 2 and 3 were not operational in 1977. Whether concentrations of chromium are higher in Units 2 and 3 compared to the concentrations at other SCE generating stations is not known.

In summary, the yearly mass emission of chromium from SONGS Units 1, 2, and 3 is 0.28 MT/yr using the most conservative estimate, or 39.6 MT/yr based on the level of sensitivity in concentration measurements required by the WQCB. Even so, the 0.28 MT/yr chromium estimate is twice as large as the rate of chromium released from the nearest sewage discharge, SERRA at Dana Point (Schafer, 1984).

### **III. Transportation of metals in the marine environment**

#### **A. Distribution and concentration of metals from point source discharges.**

The concentration of some metals is substantially higher in invertebrates living in areas near point source discharges than concentrations in the same species collected at non impacted sites (controls). During 1974, chromium concentrations in the

scallop Hinites multirugoses were seven to eighteen times greater in the sewage outfall area ( $\pm 1$  km) located at Palos Verdes, California than control (non-affected) sites (Young and Jan, 1976). Scallops concentrate chromium in particular organs including the gonad where concentrations are six times higher in scallops near the outfall than the control area (Young and Jan, 1976) (Table 3). The estimated average concentration of chromium discharged in the final effluent was 0.750 mg/l during 1976 (Schafer, 1977).

Table 3. Mean chromium concentrations (ug/wet g)  $\pm$  95% confidence limits at Whites Point and Point Vicente, 1 km off Palos Verdes Peninsula (outfalls) and control sites. Sample size varied between 6 to 8 scallops, (Hinites multirugoses) (Young and Jan, 1976).

<u>Digestive Gland</u>		<u>Gonad</u>		<u>Adductor Muscle</u>	
Outfall Control		Outfall Control		Outfall Control	
41	2.2	2.6	0.39	0.35	0.05
$\pm 19$	1.2	0.73	0.13	0.12	0.06

Accumulation of man-made radioactive isotopes in marine organisms at and about SONGS provides direct confirmation of the source of these elements, as well as a tag to indicate that other substances released from the generating station may be expected to be absorbed by such organisms. Radiological monitoring of the environment at and about SONGS indicates that at least during 1981 to 1983, crustaceans, molluscs, and fish repeatedly contained three to eight different metal radionuclides with

concentrations (Curies/Kg dry) ranging from two to 350 times background levels (Newport Beach) for the same species (NRC, 1982, 1983, 1984). An incorporation factor of two to 350 for metal radionuclides does not necessarily reflect the magnitude for accumulation of stable metals in marine species, but it is strongly suggestive that metals released from SONGS can be transported and incorporated into nearby organisms.

#### B. Transportation of metals

Metals released by nuclear power plants can be detected in marine organisms up to distances of at least 10 km. Co-60 was detected in the algal species Fucus vesiculosus to distances of 10 km away from the Barseback nuclear power plant in Sweden (Mattsson, et al. 1980). The transport of metal radionuclides conforms to the hydrodynamic conditions in the area. A current of 20 to 30 cm/s transported the labeled water 2000-5000 m downstream in periods of 3 to 5 hours.

Sand crabs on beaches  $\pm$  12 km from SONGS during July and/or August 1983 had on the average about three times the concentration of chromium than crabs occurring at distances farther away (Parker, 1985a). A metal continuously discharged from Units 1, 2 and 3 will reach beaches  $\pm$  8 to 10 km from SONGS on the average at an approximately 100 fold dilution (Reitzel, 1985). This prediction is based upon current velocities and estimated rates of dispersion (Reitzel, 1985). For example, chromium released at 9.990 ppb (ug/l) (detection limit of

required measurements) from Units 2 and 3 will reach beaches 8 to 10 km from SONGS at a concentration of 0.099 ppb.

#### IV. Incorporation and concentration of metals in sand crabs

Many marine invertebrates readily assimilate and concentrate metals (Carr, et al. 1982). Body burdens of metals usually are elevated substantially as compared to concentrations observed in seawater and sediments (reviews: Krenkel, 1975; Vernberg, et al. 1979). Transfer factors (X10, X100, X 1000) vary with metal, species, type of feeder, season, and geographic location (Frazier, 1976; Fales, 1978; Frank and Robertson, 1979; Romeril, 1979; Marina and Enzo, 1983). Some examples of transfer factors for marine organisms are reported in Table 4.

The mechanisms for uptake and concentration of metals in marine invertebrates are not known well enough to predict to what degree sand crabs are likely to concentrate chromium or other metals from seawater (Cunningham, 1979). In bivalves, metal uptake occurs from four sources in the environment: (1) dissolved inorganic metal ions; (2) organometallic iron complexes; (3) metal ions preconcentrated on phytoplankton and detritus; and (4) metal ions complexed on inorganic sediment particles. The major pathway for metal absorption in bivalves is through ingestion of food particles by filtration (Phillips, 1977). In contrast, metal uptake in polychaetes is thought to be a passive process attributed to binding of metals with body proteins (Chipman, 1966). Logical pathways for metal uptake in sand crabs are

Table 4. Concentration factors for marine invertebrate species exposed to aqueous chromium at various concentrations. Initial chromium concentration, days of exposure and concentration of chromium in each species are listed.

Species	Metal Conc. (ppm)	Exposure (days)	Conc. metal in species (ppm)	Conc. Factor	Author
Grass shrimp <u>Palaemonetes pugio</u>	0.08	7	7.54	94	Carr, et al. 1982
Mussel <u>Mytilus edulis</u>	1.0	28-42	430	430	Capuzzo & Sasner, 1977
Clam <u>Mya arenaria</u>	1.0	28-42	765	765	Capuzzo & Sasner, 1977
Bean clam <u>Donax serra</u>	0.02	21	2.6	130	Watling & Watling, 1983
Gastropod <u>Bullia rhodostoma</u>	0.02	21	2.7	135	Watling & Watling, 1983
Polychaete <u>Neanthes arenaceodentata</u>	0.0098	158	2.18	222	Oshide & Word, 1982

during filter feeding on plankton and/or contact of antennae with sediments bound with metals. Direct absorption is another possibility, but the exoskeleton may act to impede the process. However, accumulation of metals from sediments by sand crabs appears unlikely because sediments on beaches  $\pm$  12 km from SONGS do not have higher concentrations of metals than other southern California beaches (Bence, 1985).

#### V. Sublethal effects of metals on sand crabs

Emerita analoga collected within  $\pm$  12 km from SONGS during late summers of 1983 and 1984 had a higher incidence of prematurely ruptured eggs with viable eggs (partially spent eggs) than sand crabs occurring at other southern California beaches (MEC, 1984; Bence, 1986). The concentrations of chromium, manganese, and iron, in sand crabs are significantly correlated to the percentage of females (greater than 13 mm) with completely spent eggs during either July or August 1983 (Parker, 1985b). The completely spent egg condition may represent a higher degree of synchronous egg release near SONGS than at other beaches (Bence, 1986). However, other sand crab attributes have not been correlated to concentration of metals in sand crabs. Appropriate questions for the MRC to ask are: (1) Whether these metals are known to disrupt reproduction in invertebrates? (2) What is the range in concentrations for each metal known to affect reproduction? (3) Does the partially spent egg condition represent abnormal reproduction in sand crabs? and (4) Are other



biological attributes correlated to metal concentrations in sand crabs?

Exposure to relatively low concentrations, but higher than naturally occurring concentrations, of chromium will result in impaired or disrupted reproduction in some invertebrate species. Exposure to chromium resulted in production of abnormal sea urchin larvae (Pagano, et al. 1983). Changes in mitotic activity during cleavage explained this abnormality. Myint and Tyler (1982) observed a negative combined effect of temperature, nutrition, and exposure to metals on the gametogenic cycle of the mussel Mytilus edulis.

Some of the most comprehensive research on sublethal effects of chromium has been conducted by the Southern California Coastal Water Research Project (SCCWRP) and Dr. Don Reish (for review, see Reish, 1984) using species, particularly polychaetes from the waters of southern California. Oshida and Word (1982) conducted one of the few studies relating the concentration of potential toxins in seawater to metal accumulation in a species with a sublethal response. The polychaete Neanthes arenaceodentata after exposure to 38.2 ug/l hexavalent chromium for 158 days incorporated 8278 ug/Kg wet chromium (Table 5). This exposure regime and subsequent tissue incorporation resulted in a 34% reduction in number of offspring per brood (Table 5).

Table 5. Number of offspring per brood and body tissue concentrations of total chromium of Neanthes arenaceodentata exposed to hexavalent chromium (Oshida and Word, 1982).

Chromium Conc. (ug/l)	# spawning pairs	mean # off-spring/ brood	± SE	mean tissue concentration (ug/wet Kg)	±SE
Control	22	323.3	48.9	70	24
2.6	25	273.9	31.6	458	60
9.8	22	303.3	39.0	2189	414
38.2	22	213.4	32.8	8278	517

The range of mean chromium concentrations in sand crabs (930 to 4570 ug/Kg dry) collected on beaches ± 12 km from SONGS during August 1983 (Table 6) is only 11-55% less than the concentration (8278 ug/Kg wet) found to inhibit reproduction by 34% in the polychaete N. arenaceodentata (Oshida and Word, 1982). Thus, it is reasonable to expect that sand crabs with mean body burdens of 930 to 4570 ug/Kg dry chromium might exhibit impaired or reduced reproduction. The chromium discharged from SONGS may contribute to only a portion of the total body burden in sand crabs. However, the mass emission of chromium from SONGS could be significant by elevating the chromium concentration in sand crabs above the threshold level which produces sublethal effects.

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Table 6. The range of mean metal concentrations (ug/Kg dry) for chromium, manganese, and iron in the tissues of female sand crabs, Emerita analoga collected  $\pm$  12 km from SONGS during the months of July and August 1983 (Parker, 1985a).

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	Range of mean concentrations (ug/Kg dry weight)		
	Chromium	Manganese	Iron
1983			
July	340-830	28000-62000	120000-370000
August	930-4570	30000-58000	167000-571000

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## DISCUSSION

There is a potential impact by SONGS to sand crabs  $\pm$  12 km from the plant. Sand crabs near SONGS in the late summers of 1983 and 1984 exhibited a pattern of a higher frequency of prematurely ruptured eggs with viable eggs than crabs on beaches farther away (MEC, 1984; Bence, 1986). One explanation for this sublethal response in sand crabs near SONGS is that relatively high body burdens of metals, particularly chromium, could be interfering with reproduction. Several pertinent facts support the view that SONGS may be responsible for the high concentrations of metals in sand crabs, and consequently the disruptive effects of these metals to reproduction.

SONGS is a source of the three metals, chromium, manganese, and iron, which were at relatively higher concentrations during July and/or August 1983 in sand crabs near the plant than in crabs on other southern California beaches. SONGS discharges chromium at twice the rate, using the most conservative estimates, as the nearest sewage outfall. Point source discharges are known to produce a pattern of higher concentrations of some metals in marine invertebrates at distances away from outfalls. Likewise, radioactive labeled metals released from nuclear power plants, as point source discharges, are known to be transported, incorporated, and concentrated into marine species at distances up to 10 km. In particular, marine invertebrate species collected at SONGS' Units 1, 2, and 3 can incorporate three to eight different metal radionuclides at much higher concentrations (Curies/Kg dry) than

for those same species collected at a control site.

Chromium appears to be at least one candidate metal which by its presence in sand crabs could explain the reproductive patterns in crabs near SONGS. At present, quantitative data on the mass emission of manganese are not available because routine concentration measurements are not required. Invertebrates are known to concentrate high levels of iron without sublethal effects, so stable iron is not a likely causitive agent for impaired reproduction in sand crabs.

The worst and best case conditions for the discharge, transport, dilution, and concentration of chromium in sand crabs are presented in Figs. 2ab. Fig. 2c describes what might be expected based on incorporation of chromium in sand crabs under "natural" conditions. Worst and best case conditions are based in part on chromium concentration factors for other marine invertebrate species. Sand crabs may be concentrating chromium to a greater or lesser extent than grass shrimp, mussels, or clams (Table 4). Concentration factors for uptake of chromium by plankton and consequent transfer to planktonic feeders, such as sand crabs are not easily available in the literature. Even though the worst and best case conditions should be viewed as a first look at the problem, several generalizations are apparent. First, under worst case conditions incorporation of chromium into sand crabs directly from the water column would have to occur by a factor of 10,000 to be within the concentration range of chromium in sand crabs on beaches near SONGS (Fig. 2a). A concentration factor of this magnitude is unlikely. However, passage of chromium through plankton to sand crabs under worst

case conditions may be feasible (Fig. 2a) depending upon the exact concentration factors.

Second, SONGS as a source of chromium in sand crabs under best case conditions does not appear reasonable (Fig. 2b) by direct incorporation from the water column or via plankton as a food source. The chromium sediment pathway is not shown in any of the cases because there is no tendency for sediments near SONGS to have elevated concentrations of chromium over beaches farther away even when sediment coarseness is taken into consideration (Bence, 1985). The relatively low concentrations of metals in the 1983 MEC sediment samples collected near SONGS discount natural processes, such as erosion, as a means by which metals would be available in sediments for incorporation in sand crabs.