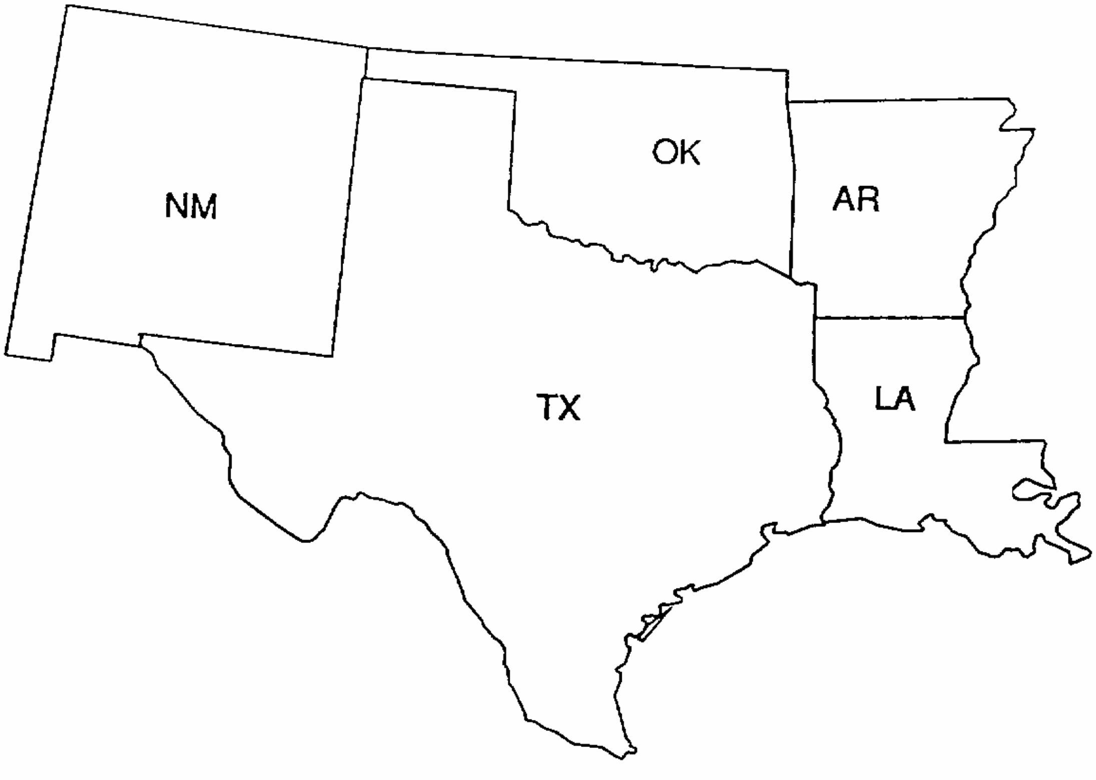
RRT VI
IN-SITU BURN PLAN
PART II
(INFORMATION SECTION)



FEDERAL RESPONSE TEAM REGION VI
IN-SITU BURN PLAN
INFORMATION SECTION

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I. SAFETY CONSIDERATIONS

A. Training

Each responder involved with the controlled burning of oil at sea should complete classroom and hands-on training. That training will be appropriate for the type and level of responsibility assigned to the individual. Typical areas of instruction will include:

- Response organization/management (including specific job assignments);
- Government regulations and permitting procedures;
- Communications;
- Strategies and priorities for response;
- Basic combustion theory;
- Safe handling procedures (vessels, Fire Boom, igniters, etc.);
- Personnel protection equipment and first aid;
- Backup response strategies (identification of potential emergency conditions and appropriate response procedures); and
- Avoidance/minimization of environmental impacts.

Training will be conducted frequently, with an emphasis on the potential effects of burning on all personnel and equipment (e.g., thermal effects, transport of soot and other combustion products, etc), as well as all natural resources communities and facilities where thermal and/or smoke-related impacts could be experienced. As with any other type of spill response, training will also include safe operating practices for vessels, aircraft, fueling operations, the loading and transfer of heavy equipment, etc. All training and actual response activities will be conducted in a controlled, safe manner that complies with appropriate federal and state regulations. Such regulations will include federal Occupational Safety and Health Administration (OSHA) which regulates operations to protect a worker's health and provide a safe working environment. In addition, OSHA regulations require that personnel involved in oil spill response also receive Hazardous Waste Operations and Emergency Response (HAZWOPER) training. The HAZWOPER training alone will normally require from 40 to 80 hours of instruction, depending upon the nature and location of the work to be conducted.

B. Boom Handling

The key to a successful and safe deployment of fire containment boom (as with nearly any piece of equipment) is the planning and practicing of those procedures that are simple and least sensitive to environmental and operational constraints. Experience has shown that booms can be deployed quickly and safely if the following considerations are recognized and planned for in advance:

- The storage of boom in protected containers as close as possible to the potential area of use. This will minimize personnel exposure and response time for last-minute maintenance and transport of the boom.

- Preparation of the boom so that the most effective length is stored with all connectors secured, tow bridles in place, and proper lengths of tow line already connected or immediately available. This will reduce the need for personnel to work on the boom or its support systems while it is under tension and/or in the water.

- Stacking of the boom in its container so that it can be pulled out quickly without snagging or twisting. A single twist of the boom can render it nearly useless for oil containment at or near the twist, and it can be dangerous attempting to untwist the boom by hand once the boom is in the water.

- If the boom must be held in place (i.e., partially deployed) in order to add sections of boom or make adjustments, anticipation of the drag forces from vessel induced or natural currents. One should avoid standing on or holding the boom during such adjustments-use proper tie-downs and anchor points to eliminate tension in the portion of boom being worked on. Selection of tie-downs, tow lines, tow posts, etc., should be made with due consideration of the average and peak drag forces that may be experienced during deployment and use of any fire containment boom. Some guidelines are provided in Part I, Section 11.13, Specific Response Procedures.

- The provision of adequate communications between personnel on the boom towing vessels and those tending the movement of boom out of its container. Personnel should agree in advance on an alternate communications plan involving a few basic hand signals to be used if radio contact is lost. Standard safety considerations will also be used during the towing of any boom under open-ocean conditions. Refer to Part I, Section 111.13 for these and other factors related to the use of fire containment boom. From a safety standpoint, however, the following factors will be emphasized for the planning and implementation of any at-sea bum

- Responders should at a minimum use the guidelines provided in Part I, Section II.B regarding the type and length of tow lines. Adequate line will be used to provide a safe distance and reaction time for the full range of potential bum situations that could develop. .

- As discussed in other sections of this plan the vessels towing fire containment boom will be positioned during all phases of an at- sea bum so that there is an absolute minimal chance of being surrounded by, or contacting, concentrations of oil that could pose a threat due to deliberate or accidental ignition. The positioning of the boom-towing vessels will take into account the size, thickness, and volatility of any nearby slicks, as well as any vapor clouds that could involve the vessels, the contained burning oil, and/or any other potential ignition sources.

- Prior to ignition, all personnel on site will be positioned upwind or crosswind from the target slick so that they are well outside the anticipated path of the smoke plume. Personnel on vessels near the burn site will be prepared to move indoors and/or don protective face masks should their vessel unexpectedly be caught in a portion of the smoke plume. Such exposures should be minimal or nonexistent with proper attention to wind conditions and vessel location.

- Should a particular spill situation involve the potential use of fire containment boom in an anchored or attached mode very close to the spill source, personnel and equipment will be kept at a safe operating distance from an unexpected explosion or premature ignition of oil at or within the source.

- Responders should ensure that any contained oil is ignited only after all "predetermined" bum requirements -are-met and confirmed via radio link with all key participants. As with any marine spill response operation, the safety of personnel on location depends on both a clear and concise plan of operations and on reliable communications.

Once the contained oil is ignited, the operator of each boom-towing vessel will maintain a burn watch and follow the procedures described in Part I, Section 11. Proper attention to the status of the burn, the speed and positions of the towing vessels, and the proximity of the burn operations to other vessels, slicks, etc., will allow the operator of each vessel to respond quickly to any unexpected events. The operators of the towing vessels will have a pre-approved and agreed upon plan of action if it becomes necessary to modify the size, and therefore the rate, of the bum; to provide assistance to the sister towing vessel; or to terminate the bum. All personnel on each vessel will be aware of those potential actions in order to minimize reaction time, confusion, and risk of exposure to unsafe conditions.

The key to a successful and safe in-situ bum program is good communications. It is essential that the operators of the boom- towing vessels and all other personnel directly involved with the control of the bum have a dedicated radio link for their own communications on the status of the bum. A separate communications link will be established for information flow between the operators of the towing vessels and other non-control participants (e.g., aerial spotters, monitoring and sampling personnel, etc.).

The operational information discussed in Part I, Section II.B will be considered carefully as it relates to vessel speeds, boom configuration, and the proximity of the burn to other vessels, slicks, etc. With properly sized tow lines and a continuous monitoring of the burn status, the elimination of oil by burning is one of the safest and most effective modes of spill control.

C. Unwanted Ignition And Secondary Fires

The unwanted ignition of oil might involve the accidental or premature ignition of floating oil contained within the fire containment boom or oil that had collected elsewhere to sufficient thickness for ignition and sustained combustion. Such ignition is highly unlikely with proper consideration of the proximity of all potential ignition sources to any slicks that could burn. During the early phases of a spill response, when oil may be relatively fresh and volatile, the usual care given to vapors and ignition sources would, of course, be necessary. Up until the time of deliberate ignition, the concern for unwanted ignition would be no different than that for conventional oil containment efforts.

Before any deliberate ignition, the wind and/or direction of tow will be considered to ensure that no one is within or near any potentially large concentrations-of petroleum vapor. Numerous experimental test bums with fresh and slightly weathered oils have revealed that even the lightest breeze is sufficient to limit the size of any initial vapor flash upon ignition of slicks contained within open test tanks and booms. If an oil layer is to be ignited under very still air conditions (where vapors could accumulate over a large area and/or to a significant height), special care should be taken to ensure that the ignition system is released from a safe distance. Part I, Section 111.8 addresses guidelines on aerial and surface ignition techniques.

Globules of burning gelled fuel from a Heli-torch can be released from heights of several hundred feet if necessary, hand-held igniters can be released from vessels many hundreds of feet upstream/upwind of the target oil, and flare guns can be used as well from hundreds of feet away if the oil to be ignited is fairly fresh. In most situations, the problem with containment and burning of oil spilled at sea is not normally unwanted ignition; it is usually the difficulty of achieving wanted ignition. Within minutes to a few hours, most crude oils in a choppy sea will be sufficiently weathered that substantial heat will be needed to produce enough vapors for sustained combustion.

Because of the difficulty of igniting weathered floating oil layers, the concerns for unwanted ignition and secondary fires are normally minimal. If, on the other hand, a deliberate burn were planned near shore, along a shoreline or river bank, in a marsh, or onshore, the potential for secondary fires would have to be considered carefully. The proximity of ignitable vegetation, trees, docks, and other facilities would need to be examined with respect to the initial movement of vapors (prior to ignition) and the potential movement of burning oil. Such near shore, inshore and onshore burns are not addressed within this response plan.

D. Personnel Exposure

Care will be taken throughout any in-situ burn operation to ensure that all personnel and equipment are protected from any harmful exposure to heat and/or combustion products. Anyone that could be exposed will be provided with adequate personal protective equipment (e.g., respirators, masks, goggles, protective clothing, etc.). Federal OSHA standards for the assessment of hazards will be used for the selection of proper personal protective equipment.

During in-situ burning operations at sea, it is normally quite easy for vessels and aircraft to remain well outside any zone of potentially dangerous exposure to heat or combustion products. However, because of the brief exposures that could result due to wind shifts, vessel power failures, oil and emission sampling procedures, etc., personnel will be trained in how to avoid such exposures and what to do or wear should exposure be unavoidable.

With respect to heat exposure, Part I, Section II.B addresses typical safe operating distances for the separation of operating personnel and a contained fire. An example is provided where 500 feet (152 meters) of fire containment boom could be worked safely with 500 feet of tow line behind each towing vessel. This configuration would normally place personnel on the vessels approximately 600 to 700 feet from a contained fire within the boom. During the offshore bum conducted on the second day of the Exxon Valdez oil spill, 500-foot tow lines were used along with a 450 foot-long 3M Fire Boom. Personnel on the towing vessels could feel the heat of the fire; however, even at the peak of intense burning (flames >200 feet high), the radiated heat was quite comfortable. The distances described here are consistent with the often-used rule of thumb that personnel should be at least five fire diameters away from an open burn.

E. Proximity Issues

During accidental fires involving petroleum on water, burning oil slicks will often threaten boats, docks, and other facilities located on or near the water. Numerous marine petroleum fires have caused enormous losses of personnel and equipment/facilities. In most cases, these losses were experienced because there was no way to safely and effectively contain the burning oil or to divert the oil away from such sensitive areas. Now with the development of fire containment boom, it is possible to plan for and implement marine fire-protection activities that could save lives, equipment, facilities, and other natural resources.

Consideration of the combustion of floating oil as a deliberate response technique for the control and elimination of spilled oil must include a thorough assessment of all potential exposure risks associated with the proposed bum. The guidelines for such a risk assessment should include as a minimum:

- The expected size and duration of burn based on estimated oil volumes, burn rates, burn-area control measures, etc.;

- The location of the burn and any possible change in location due to currents, equipment failure, the towing of containment boom, etc. (this should include the possible movement of personnel, animals, boats, etc. to areas outside possible exposure to excessive heat and/or combustion products);

- The movement and duration of burn for any oil that might be released (accidentally or in response to an emergency) from within an area of controlled burning; and

- The location and type of fixed equipment/facilities (e.g., moored vessels, docks, bridges, etc.) that could conceivably be exposed to burning oil or heavy concentrations of combustion products.

As discussed in several other sections of this response plan, the safety of response and 'non-response personnel will strongly depend on the availability and proper use of reliable communications equipment prior to and throughout any in-situ burn program. Such communications will be needed to warn all participants, observers, government representatives, and the general public about the intent to burn oil. Proper notification will help prevent the unexpected movement of aircraft and vessels into pre-designated restriction zones. In addition, routine status reports to airplanes, boats, radio and television stations, etc. will help reduce the kinds of over-reaction and misinterpretation that often occur during such highly visible and controversial activity.

A specific plan will be in place for rapid notification of appropriate personnel in case a sudden change in wind direction threatens to push smoke toward populated areas. For example, the responsible party will work with local police, Coast Guard, and port authority representatives, as well as the media, to ensure that people in or beneath the path of a smoke plume are warned about its arrival time, cause, likely duration, and potential impacts. If atmospheric conditions are such that the smoke plume could expose people directly to any of the products of combustion, clear directives will be issued regarding the need to remain indoors or to wear appropriate protective masks/equipment if it is necessary to be outside. If the burn program is planned and carried out correctly, with due consideration for such potential exposures, it is highly unlikely that such protective measures would ever be needed.

It is very important that the subject of in-situ burning be presented as early as possible to the public and government agencies in any area where burning could be used for the control of spilled oil. It is important to make every effort to inform the general public about the impacts and trade-offs of various types of spill control techniques. It is important that people, particularly those in coastal communities, know the advantages and disadvantages associated with such control measures as mechanical removal, chemical dispersants, and in-situ burning. Through this process of information exchange prior to an oil spill, meaningful and timely decisions can be reached regarding a community's priorities for the minimization of environmental impact from oil spills and from the various response techniques that might be employed.

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II. BACKGROUND

A. Role Of Burning During Oil Spill Response

In-situ burning has been recognized for many years as an effective way to eliminate large quantities of spilled oil. Prior to the early 1980's, however, most attempts to bum spilled oil had to be carried out without the aid of fire-resistant booms. As a result, the effectiveness of such burns depended on the availability of other structures or forces (e.g., vessels, docks, shorelines, winds; ice, etc.) to keep the spilled oil thick enough to support combustion.

As discussed in Section II.C, Basic Combustion Theory, the effective, sustained combustion of oil on water requires that the oil be at least 2 to 3 millimeters (about 0.1 inch) thick. Without fire containment boom to maintain an adequate thickness, the combustion of unconfined oil will be extinguished quickly when the oil reaches an average thickness of approximately 1 millimeter. For this reason, most accidental and deliberate burns of spilled oil at sea suffer from the effects of winds and waves, which spread any unconfined oil quickly to a thickness that will not sustain combustion. Under such conditions, burning is usually limited to the region immediately adjacent to the source of spillage, the lee of the vessel/facility involved, and/or the structure, shoreline, or debris against which the burning oil is herded by the wind or currents.

Now, with the development of fire containment booms, there are numerous situations where controlled in-situ burning of spilled oil can be carried out quickly, safely, and efficiently. In Part I, Section 11.13, Specific Response Procedures, addresses many potential spill situations where controlled burning could involve offshore exploration and production operations, marine pipeline accidents, and tanker accidents.

Significant advancements have been made during recent years in the development of techniques and equipment for the safe and effective ignition and controlled burning of spilled oil. And, while many states are now recognizing and including burning in their spill response plans, it is important to emphasize that the combustion of spilled oil is not seen as a substitute for the containment and physical removal of spilled oil. Conventional booming and skimming operations should always be conducted wherever they can be implemented safely and with a reasonable degree of effectiveness.

The potential for in-situ burning (as well as the use of chemical dispersants) should be considered on a case-by-case basis to establish whether it should be used in conjunction with, or as a temporary alternative for, other, more conventional cleanup techniques. A careful comparison of response techniques (Allen, 1988) reveals that there are often situations where burning (and/or chemical dispersants) may provide the *only* means of eliminating large quantities of oil quickly and safely. In some situations, mechanical recovery, burning, and chemical dispersants can be used simultaneously for combating various portions of a spill. The objective should be to find the right mix of equipment, personnel, and techniques that will achieve the least overall environmental impact.

B. Summary Of Prior Burn Experience

Table II-1 provides a summary of the history of in-situ burning both in tests and in actual spills. This table is from the *Alaska Clean Seas Proposed Plan for 1992 Full-Scale In-Situ Bum Test, Beaufort Sea, Alaska*, *(Alaska Clean Seas, 1991).* The table and its references provide information on representative tests and spills involving in-situ burning (see Section VIII, Bibliography, for the references cited in the table).

Additional information can be found in the proceedings of the Arctic and Marine Oil Spill Program (AMOP) technical seminars, sponsored by Technology Development Branch, Environment Canada; the proceedings of the International Oil Spill Conference, sponsored by the U.S. Coast Guard, American Petroleum Institute, and the Environmental Protection Agency in the United States; in preliminary results from the New Foundland (Aug. 1993) Bum Experiment; and in the many other publications listed in the bibliography.

One of the earliest major spill incidents involving burning was the grounding of the *Torrey Canyon* off the coast of Cornwall, England, in 1967. Nearly 95,000 tons of crude oil were released over approximately 12 days, and numerous attempts to burn the oil were made with a variety of bombs, rockets, and other combustion promoters. The rapid loss of volatile fractions, the wind and sea states, the violent methods of ignition, and the lack of containment during burning all led to a relatively unsuccessful burn. During the years that followed, several spill incidents involved attempts at, or at least serious consideration of, burning. These include:

- The tanker Arrow in Chedabucto Bay, Nova Scotia (1970);
- The *Othello/Katelysia* collision in Tralhavet Bay, Sweden (1970);
- The *Urquiola* grounding off LaCoruna Bay, Spain (1976)
- The *Argo Merchant* grounding off Nantucket Island, Massachusetts (1976); and
- The *Amoco Cadiz* grounding off France (1978).

The limited success of in-situ combustion during many oil spills in the 1970's was normally restricted to the burning of oil in isolated thick pools (i.e., concentrations adjacent to the source or in pockets trapped by ice, shorelines, etc.).

In the 1980's the same kinds of results were experienced during accidental fires at sea; however, toward the middle of the decade, it had become clear that burning could be successful if proper ignition procedures and controlled containment during the combustion process were used. Numerous experiments in the United States and Canada focused on new techniques for the aerial ignition of oil slicks

(Energetex Engineering, 1978; Dickins, 1 979; Twardawa and Couture, 1 983; Spiltec, 1986a; Spiltec, 1987; etc.), and for the containment of burning oil using fire-resistant booms (Buist and McAllister, 1981; Spiltec, 1986b; Allen and Fischer, 1988).

The above experiments included static tank tests with continuous exposures of fire containment boom to burning crude oil for up to 24 hours. In 1988, an open-water burn test was conducted by 3M and SINTEF (Trondheim, Norway) involving the deliberate ignition of 500 gallons (about 1,900 liters) of Statfjord crude oil contained within 300 feet (91 meters) of 3M Fire Boom. The Fire Boom was towed in a U-configuration-while a Heli-torch (from Simplex in Portland, Oregon) was used to ignite the contained oil. The field trial was quite successful, resulting in the elimination of 95% of the oil in approximately 30 minutes.

On March 25, 1989, during the evening of the second day following .the grounding of the *Exxon Valdez* in Prince William Sound, Alaska, an estimated 15,000 to 30,000 gallons of North Slope crude oil were eliminated using in-situ combustion techniques (Allen, 1990). The oil was collected with 3M Fire Boom towed in a U-configuration through slightly emulsified oil patches in the downwind region of the spill. Working with 500-foot tow lines, a 450-foot length of boom was towed at about 0.5 to 0.75 knot (0.26 to 0.52 meters/second) until the downstream portion of the "U" was filled. A small hand-held igniter of gelled fuel was released from one of the tow boats so that it would drift back into the contained oil. Shortly after ignition, the entire area of oil within the boom caught fire and burned for about 1 hour and 15 minutes. The intense portion of the burn lasted about 45 minutes, during which time the towing vessels could control the size of the fire by altering their speeds as desired. Upon completion of the bum, it was estimated that about 300 gallons of stiff, taffy-like, easily recovered bum residue existed within the boom. Using three different approaches to calculate the volume of oil burned, it was estimated that from 15,000 to 30,000 gallons of oil were eliminated, resulting in a burn efficiency of at least 98%.

TABLE II-I
SUMMARY OF IN-SITU BURNING:
REPRESENTATIVE TESTS AND USE ON SPILLS

DATE	TYPE/ LOCATION	DESCRIPTION	TYPE/AMOUNT OF OIL	ENVIRONMENTAL COMMONS	BURN EFFICIENCIES	REFERENCES
1967	Tanker accident (Torrey Canyon)	Attempts were made to burn oil on water with bombs, napalm and other materials	_	_	Limited success	Evans 1989
1970	Accident n Deception Bay. Quebec	Onshore spill reached intertidal ice. Oil pumped to ice surface and burned: some oil at ice and contained by nearshore ice burned	Diesel and Gasoline, 400,000 gallons	Solid ice cover	_	Barber 1971; McLeod & McLeod 1974; Ramseier, n.d.; Peterson et al. 1975
1970	Accident in Chedabucto Bay (Arrow)	Some isolated slicks were burned	Bunker C, approx. 3.8 million gallons spilled	Water temp. 32° to 36°F	Limited success	Barber 1971; McLeod and McLeod 1974
1970	Vessel collision in Tralhavet Bay. Sweden March (Othello and Katelysia)	Spill was trapped to pack ice and a silica wicking agent (Cab-O-Sil ST-2-0) was used burn. Conditions precluded mechanical containment and recovery.	Between 14.3 million and 23.9 million gallons of Bunker C spilled	Low water Temperature; pack ice	“Large” amount burned	Evens 1989
1974-75	Experimental Spill, Balaena Bay, Canadian Beaufort Sea	Oil spilled under ice was burned in spring as a accumulated in meltpools of the ice surface	Crude, 12,000 gallons	Oil allowed to become contained in the ice as it grew	More van 90% of oil available for burning was eliminated	Pallister 1978
1976	Accident in Lake Huron (Imperial St. Clair)	Oil became incorporated in ice, and numerous burns conducted as oil melted out of ice	Diesel and Gasoline, 57,000 gallons spilled	Fresh water/ice	_	Beckett 1979
1977	Accident m Buzzards Bay, Massachusetts	A pool of 3,600 gallons in broken ice was ignited with igniters dropped from helicopter	No. 2 fuel oil, 84,000 gallons spilled	Shorefast and rafted ice	Approximately 50% of 3,600-gallon pool burned	Schner & Eidam 1979: Baxter et al. 1978
1979	Tanker Collision (Atlantic Empress and Aegean Captain) in Caribbean Sea	Two fully laden VLCC's collided (accidental)	Crude oil, 134 million gallons total on both vessels	Summer, tropical seas	Most oil burned as uncontained slick	Horn & Neal 1981
1979-80	Experimental release	Oil release with air under first-year sea ice to simulate blowout under ice	Prudhoe Bay crude, 5,000 gallons	Oil encapsulated in under-ice cavities in several-hundred-yard radius	125 burns were conducted on meltpools with 77% to 82% efficiency	Buist et al. 1981
1980	Tests of Port Mellon, B.C.	Static test of Dome Petroleum's stainless steel fireproof boom with burning crude oil	Redwater crude oil, 400 gallons	On water, December	99.87%	Buist et al. 1983
1981	Tests at EPA OHMSETT test tanks	Test of Dome Petroleum's boom with burning crude oil and waves in test tank (22 tests)	Circo 4X light oil and Murban crude	Water test tank with swells	_	Buist et al. 1983
1983	Tier 2 burn test in Prudhoe Bay test pit (Task 1)	Four tests conducted with uncontained oil spilled in broken ice conditions	Fresh, degassed Prudhoe Bay crude: Tests 1 & 3: 36 gallons, Tests 2 & 4: 244 gallons	Broken ice in onshore fresh want pit (3-5 oktas) Test 1 & 2: grounded ice Tests 3&4: floating ice	55% to 85%	Industry Task Group 1983b
1983	Tier 2 burn tests in Prudhoe Bay test pit (Task 2)	Burning of oil inside fire containment boom in test pit (single burn and continuous burn): follow-up tests conducted in test tank	Single burn: 34 gal fresh, degassed Prudhoe Bay crude Continuous burn: 1 hr @ 2.5 gpm	Fresh water in test pit 33°F; no ice	Single burn: 90% Continuous burn: 95%	Industry Task Group 1983b

TABLE II-I (Cont'd)
SUMMARY OF IN-SITU BURNING:
REPRESENTATIVE TESTS AND USE ON SPILLS

DATE	TYPE/ LOCATION	DESCRIPTION	TYPE/AMOUNT OF OIL	ENVIRONMENTAL CONDITIONS	BURN EFFICIENCIES	REFERENCES
1984	Experiments at OHMSETT (New Jersey)	4 tests were run in EPA test tank	Prudhoe Bay crude (fresh and weathered)	Broken ice (45-60%) in test tank	85% to 95%	Smith and Diaz 1985
1985	ACS Kenai 24-four burn tests	Evaluation of 4 types of fire containment boom in test tank with burning oil	Fiesta Cook Inlet crude oil	10' x 40' test tank	_	Spiltec 1986b
1985-1989	Vanous smale-scale tests	National Institute of Standards and Technology tests to study combustion and smoke generation	Various crudes	Various small scale tests	_	Evans et al. 1989 a, b
1986	Experiments at OHMSETT (New Jersey)	Tests in EPA test tank	Prudhoe Bay and Hibernia-A crudes	Broken ice (60-75%) in test tank	65% to 75%	Smith and Diaz 1987
1986	Experimental spills off Nova Scotia	Two spills each 264 gallons ignited after several tours spreading in pack ice	Alberta crude	Pack ice (5 to 9 tenths)	77% to 80%	Buist 1986; Buist & Dickins 1987
1986	ACS Deadhorse Helitorch tests	Tests of ignition of crude oil in test Pans using a Helitorch	Fresh and weathered crude oil (5 gal/pan)	Oil on water with Ice; 24° to 26°F	_	Spiltec 1987
1986	Calgary, Alberta	25 tests in Jan. and Feb. at the Esso Research Ice Basin to test burning in ice leads (2 experiments in brash ice)	Aged Normal Wells crude	Leads cut in ice sheet in test basin	About 70% to 90%	Brown & Goodman 1986
1988	Experimental spill off Spitsbergen	300 feet of 3M Fire Boom used to contain slick, which was ignited with Helitorch	Stratfjord crude, 500 gallons	Ocean in summer	95%	Allen 1990
1988	St. Vincent's Bay, B.C. spill	Burning of spilled diesel on water; winter	2,400 gallons diesel spilled	Diesel burned in trench; air temp. 43°F	_	Robertson 1991
1989	Test burn in Prince William Sound during *Exxon Valdez* spill	450 feet of 3M Fire Boom towed by 2 vessels to collect oil and contain it for burning: the oil had been floating on calm water for 30 to 40 hours before it was burned.	Prudhoe Bay Crude, approx. 15,000 to 30,000 gallons	Calm water	Estimated 98% efficiency, with stiff, taffy-like burn residue of about 300 gallons	Allen 1990, 1991a
1990	Rivers Inlet, B.C.	Fuel burned an water	Approx. 22,500 gallons fuel	November	About 2,640 gallons burned	Robertson 1991
1990	ACS test burns	Purpose was to test 3M Fire Boom for a 48-hour burn in a test tank	Prudhoe Bay crude	Open water in test tank, air temp. -38°F	_	Alaska Clean Seas (B. McKenzie)
1990	Tanker accident (*Mega Borg*), Gulf of Mexico	Fire from senes of onboard explosions on tanker	Light crude oil (5 million gallons)	Summer	Large amount burned or evaporated	Leveitte 1991
1991	Test burns in Mobile, Alabama	Meso-scale tests in water-filled test tank with oil slicks up to 50 feet in diameter inside fire containment boom	Crude oil	Test tank	_	Evens et al. 1991a

NOTE:

This table is adapted from *Alaska Clean Seas Proposed Plan for 1992 Full-Scale In-Situ Burn Test, Beaufort Sea, Alaska,* Alaska Clean Seas, Anchorage, Alaska. December. 1991, and is used by permission.

C. Basic Combustion Theory

1. Ignition and Combustion Requirements for Oil on Water

The successful elimination of spilled oil by burning depends on:

1. The type and condition of oil to be burned,
2. The method used to ignite the oil, and
3. The environmental conditions at the time of the bum.

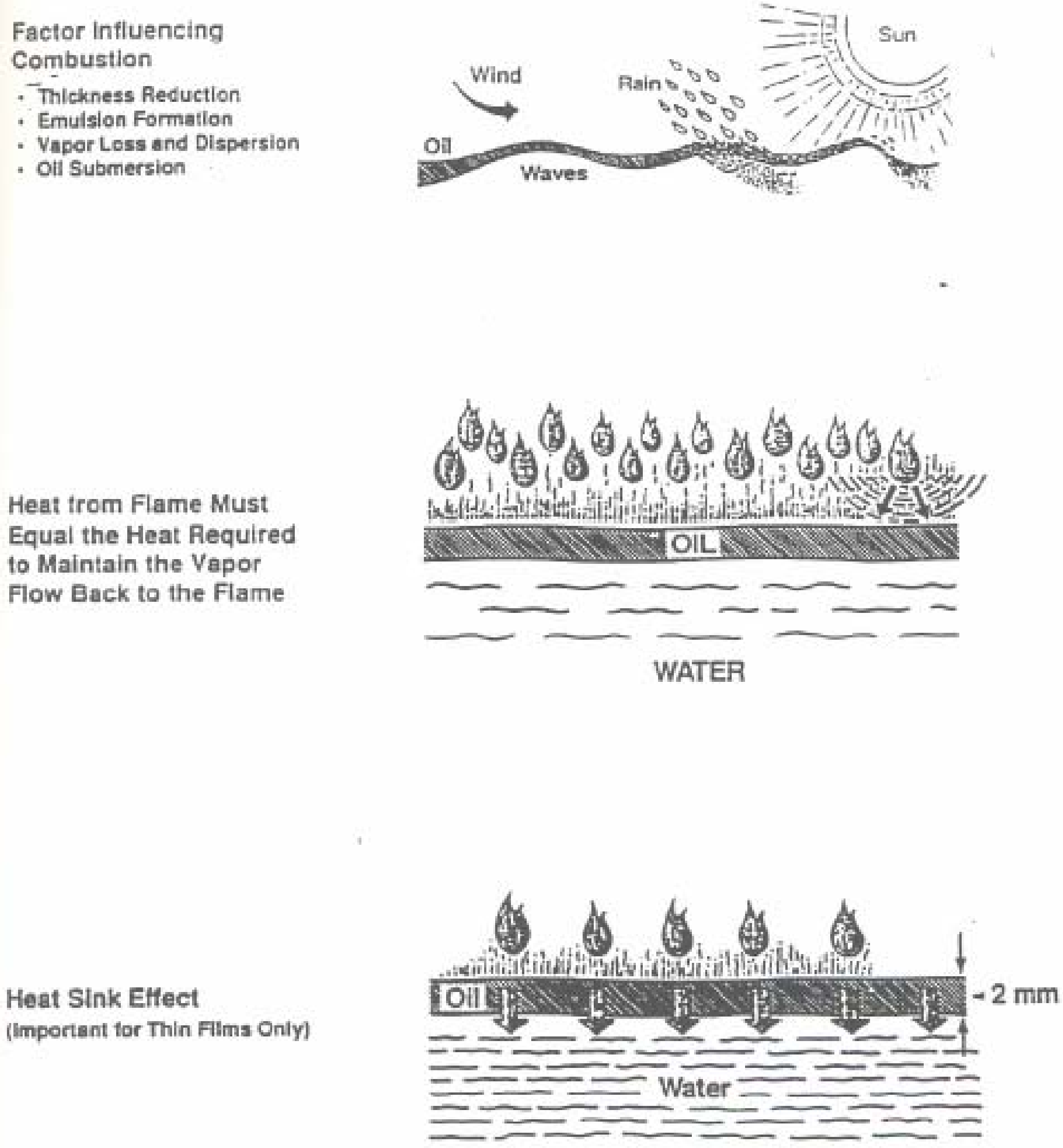
The effects of various environmental conditions on burning are addressed in the Section II.C.2. The first two items, however, should be understood thoroughly before a safe and effective in-situ burn of spilled oil is attempted.

The results of many of the early attempts to burn spilled oil on water were marginal at best. Only in cases where the volume of oil spilled was very large and/or the seas were quite calm, was there much success in maintaining effective combustion. Inappropriate conclusions were often reached involving misconceptions that "oil evaporates too quickly to burn," "oil spreads out and disperses too quickly to bum," and "oil gets too cold on water to burn." These factors, of course, can be significant for a spill that cannot be accessed fairly quickly. They may also be significant for spills that move onto an active water surface (i.e., high winds, waves, or currents). It is important, however, to realize that many oil spills-particularly large-volume batch spills and high-flowrate spills-remain sufficiently thick long enough to retain their lighter volatiles and provide an insulating layer against the transfer of heat from the oil to the water below.

The natural thicknesses of an oil spill very near the spill source may actually be increased by the effects of thermally induced winds that transport surface water and oil toward the fire. In addition, if a barrier such as ice, shorelines, fire containment boom, etc. can be used to trap the oil and thicken it, the window of opportunity for successful ignition and sustained combustion may be increased substantially. The key issue here is oil thickness.

The vast majority of crude and refined oils will burn on water if the average oil layer thickness is at least several millimeters and the ignition area and temperature are great enough to vaporize material for continued combustion. Experience has shown that at least 0.1 inch (about 2 to 3 millimeters) of oil thickness is needed to prevent excessive heat loss from a relatively fresh oil layer to the water below. Nearly all in-situ burn tests with relatively fresh crude oil on water have revealed that combustion will cease quickly when the average film thickness is reduced to approximately 1 to 2 millimeters. This "extinction thickness" will be increased by a factor of 2 to 3 for oils that have become weathered and/or emulsified.

FIGURE II-1
BASIC COMBUSTION THEORY



Source: Allen, 1992

As shown in Figure II-1, the heat radiated back from the flame (typically only 2% to 3% of the heat generated) must equal or exceed the heat required to maintain the vapor flow from the oil back to the flame. If the oil is too thin (usually about 1 to 2 millimeters for fresh oil), the "heat sink" effect of the water will be sufficient to cool the oil to the point where vapor production will be too low to sustain the fire.

The minimum thickness for sustained combustion of an oil layer on water is clearly related to the rate at which heat is transferred through the oil. Equally important, however, is the fire point of the oil. For less volatile oils such as weathered and emulsified crude oils, and Bunker C, the minimum thickness may increase from 1 to 2 millimeters to as much as 8 to 10 millimeters for the heaviest and most emulsified oils.

Another basic but very important -aspect of successful burning is the way in which ignition is attempted. Many efforts to bum spilled oil at sea have failed because high-energy, explosive-like ignition sources were used. Such igniters have often blown the oil layer from the immediate influence of the ignition source, thereby preventing the igniter from heating the oil to its fire point. The most effective oil spill igniters provide a minimal disturbance of the oil layer while creating a gentle exchange of heat to as much of the surrounding oil as possible. The use of gelled fuel (as applied from a Heli-torch) is one of the most efficient ways to ignite oil slicks quickly, safely, and with minimal expense. The Heli-torch and other igniters are covered in Section V.B.5, Ignition and Substained Combustion.

2. Factors Influencing Combustion

As discussed above, the major influences on the combustion of floating oil are the type and condition of the oil, and its average thickness. Vapor losses, reductions in thickness, the formation of oil-in-water emulsions, and other physical and chemical changes are accelerated in the open ocean due to wind, waves, rain, sunlight, and other natural causes of oil degradation and dispersion.

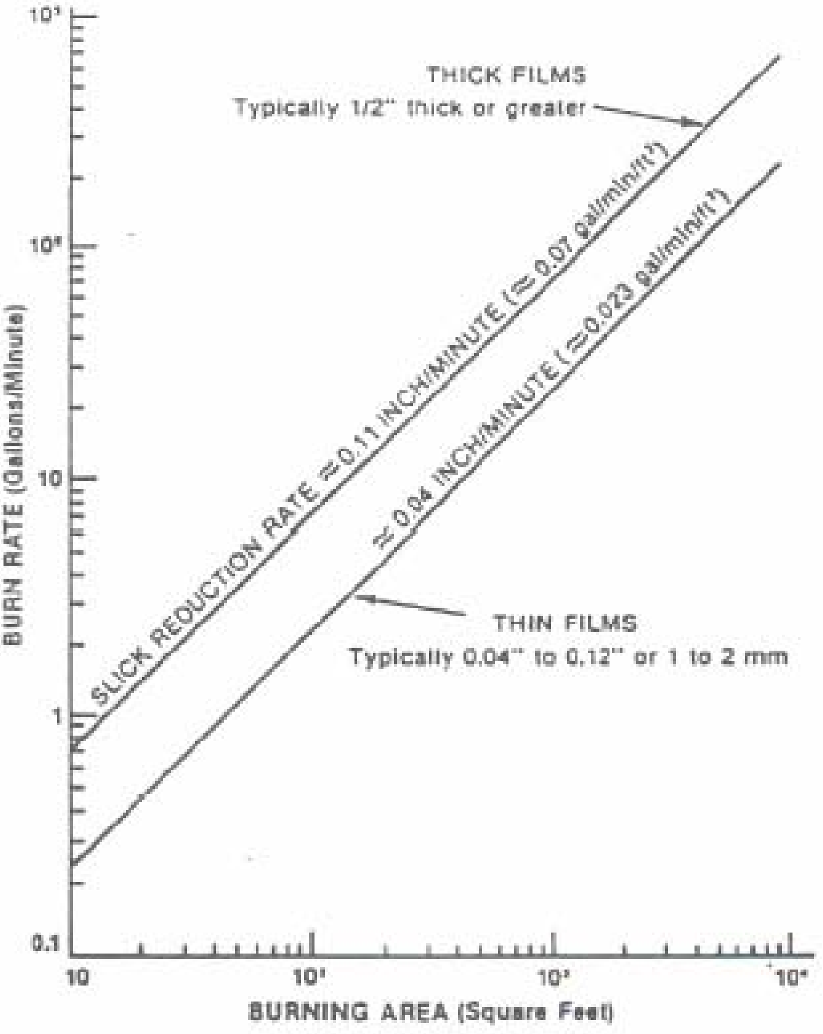
As with other boom-dependent approaches to spill control, excessive winds and waves, currents, and debris can make it difficult or impossible to contain oil with fire containment boom. These same conditions can make ignition and sustained combustion (particularly with aged/emulsified oil) extremely difficult. Poor visibility, including night operations, can be a significant problem; however, once the oil is ignited, station-keeping can be relatively easy when burning at or very close to the spill source. Large quantities of debris, though a serious problem with towed or diversionary booms, can be used to enhance burning without boom if there is enough material to limit the spread of oil and dampen wave action. If used in a drift mode with debris, conventional boom and fire containment boom can be used to limit the spread of oil. The resulting compounds) released to the air are typically only a few percent of the original volume of oil burned (even during such large fires as the recent crude oil fires of Kuwait).

Numerous laboratory investigations and actual large-scale field trials have demonstrated that most relatively fresh oil spills on water can be ignited and burned effectively if they are kept at least a few millimeters thick. When such oils are burned within a confined area, such as the apex of a U-boom configuration under tow, the oil layers commonly burn at about 0.07 gallons per minute per square foot [i.e., with a thickness reduction rate of about 0.1 inch (2 to 3 millimeters) per minute]. In figure II-2, burning rate (in gallons per minute) is plotted as a function of the burning area (in square feet). Typical burn rates are provided for both thick films (about 0.5 inch or greater) and thin films (those just barely thick enough to sustain combustion). It can be seen that a fire covering only about 2,000 square feet (e.g., an area about 45 feet square) could eliminate about 100 gallons of oil per minute.

The efficiency of removal during such burning will depend on the thickness of the oil at the start of combustion and the final thickness when the burn is completed. Figure II-3 provides an example in which two starting oil layer thickness of about 4 inches (100 millimeters) and 0.4 inch (10 millimeters) are burned down to a minimum thickness required for sustained combustion (about 1 or 2 millimeters). The thicker layer experiences a thickness reduction of 98% to 99% of the original volume of oil. The thinner layer results in the elimination of 80% to 90% of the original oil thickness; the burn therefore represents an efficiency of removal of 80% to 90% of the original volume.

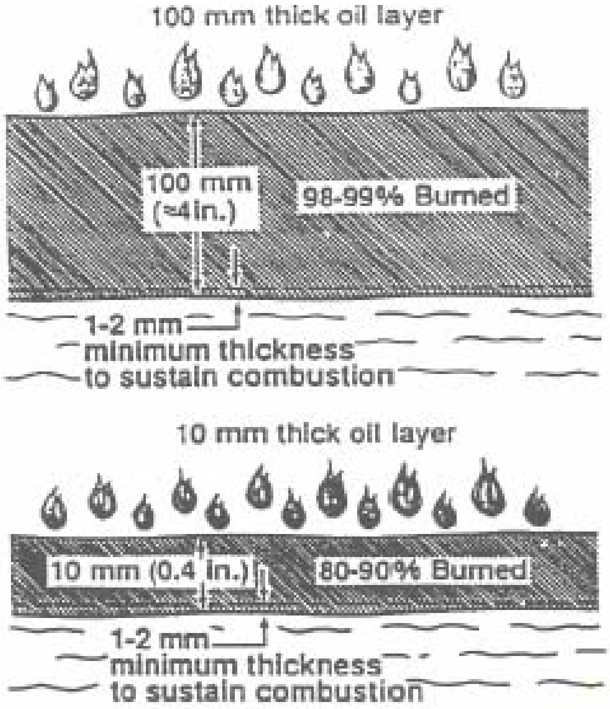
During recent years, numerous controlled burn tests have been conducted in which the burning of contained oil layers has consistently resulted in the elimination of well over 90% of the original oil volume. For example, the controlled burn of 500 gallons (about 1,900 liters) of crude oil off Spitsbergen in 1988 resulted in a 95% elimination of the oil contained within a towed U-configuration of 3M Fire Boom 300 feet (91 meters) long. That burn lasted approximately one-half hour. And, in 1989, a 45-minute burn of from 15,000 to 30,000 gallons of North Slope crude oil from the *Exxon Valdez* resulted in all but 300 gallons being consumed for an estimated 98-99% efficiency of removal. (Allen, 1990).

FIGURE II-2
IN-SITU BURN RATE



Source: Industry Task Group, 1984

FIGURE II-3
EFFICIENCY OF BURN



Source: Allen, 1992

III. ENVIRONMENTAL CONSIDERATIONS

Environmental issues involve both the effects of the environment on the burning process and the effects of burning on the environment. Factors that influence the ignition and sustained combustion of oil on water are covered in Section II.C. In this section the effects of combustion are addressed, along with information that should be helpful in anticipating and minimizing environmental impacts.

A. Products Of Combustion

Particulates & Gasses -- The products of combustion from a petroleum fire include the smoke plume (and particulate matter precipitating from it), combustion gases (e.g., carbon dioxide, carbon monoxide, sulfur dioxide, etc.), unburned hydrocarbons, and the residual oil left as the oil becomes too thin to bum. Of course, the burning of spilled oil also results in the production of heat; however, on a global basis, the amount released is of little ecological consequence since the oil was eventually going to be burned anyway had it not been spilled. The localized effects of heat are also of little concern if a bum is conducted with due consideration of its proximity to other sensitive parts of the environment. These issues of proximity and timing are addressed in Section III.E (regarding safety) and in Section IV.B (regarding environmental impact).

Of all of the products of combustion, (illustration next page), it is the highly visible smoke plume (or soot) that seems to create the greatest amount of concern. This, of course, is because of the plume's dark black appearance and the potential for particulate fallout downwind of the fire. It is important to recognize that the soot produced by in-situ oil fires is typically only a few percent of the original volume of oil burned (Fingas and Laroche, 1990; Alaska Clean Seas, 1991 Ferek, 1991, 1992). With the kinds of fires normally contained within fire containment boom -typically on the order of 100 feet (30.4 meters) in diameter or less-the smoke plume will usually pass from a concentrated dark cloud to a widely dispersed gray cloud within a few miles from its source. The rate of dispersion would be reduced, of course, during calm wind conditions. With even a light wind, however, the smoke from comparably sized fires will normally be diluted to levels that are difficult to detect using standard pollution monitoring equipment within a few hours of travel (Alaska Clean Seas, 1991).

The burning of oil within a boom will in many ways be comparable to the pool fires that resulted during the 1991 war-related oil-well fires in Kuwait. University of Washington researchers who sampled the smoke plumes from these fires found that they contained very low amounts of carbon monoxide (~1 %, as a percentage of fuel burned), nitrogen oxides (~0.1%), volatile organic compounds (~0.5%), organic aerosol (~1 % to 2%), and soot (~2% to 3%). With crude oils consisting of approximately 85% carbon, it was found that about 95% of the carbon burned was converted to carbon dioxide (Ferek, 1991).

It is interesting to note that while the vast majority of a burned oil layer is actually converted to carbon dioxide, there are those who will argue that carbon dioxide is a "greenhouse" gas and that in-situ burning is therefore unacceptable. This position must be re-examined in light of the fact that approximately the same percentage of carbon dioxide would have been created had the oil not been spilled in the first place and was burned as fuel. Even if the greenhouse issue was significant here, one would have to compare the amount of carbon dioxide created during the infrequent burning of an oil spill with the many other continuous sources of carbon dioxide around the world (e.g., auto emissions, stacks, forest fires, volcanoes, etc.).

Depending on the sulfur content of the oil being burned, sulfur dioxide will also be emitted to the atmosphere. With crude oils of approximately 1 % sulfur by weight (e.g., North Slope crude oil), it is .believed that within a mile downwind of a typical contained burn site, the sulfur dioxide concentrations will very likely be on the order of a few hundred parts per billion (ppb). It should be realized that virtually all of the sulfur in the oil is combusted to sulfur dioxide. As with the other gaseous emissions (e.g., carbon monoxide, carbon dioxide, nitrogen oxide, etc.), the concentration of sulfur dioxide will very likely be diluted at least tenfold within a few hours. This dilution would place the gaseous emissions far below the concentrations allowed by the National Ambient Air Quality Standards in the United States (Alaska Clean Seas, 1991).

Another combustion product involves polycyclic aromatic hydrocarbons (PAHs), some of which are believed to be carcinogenic. Most of the original PAHs are consumed in the fire; however, other higher-molecular-weight PAHs can be produced during burning. Laboratory tests (Benner et al., 1990) indicate that an amount of PAH (equivalent to half of what was present in the original oil) ends up in the smoke. However, recent field results indicate that the smoke contains a much smaller amount of PAH (four to five times less) than was shown in the laboratory tests (Fingas and Laroche, 1990). If the field results are representative of burning under realistic at-sea conditions, the likely result is that about 90% of the PAHs could be removed by burning (Ferek, 1992). In addition, the significantly reduced volume of PAHs that is released is quickly diluted (along with other emissions) into the air downwind of the fire and dispersed to concentrations of little, if any, environmental consequence.

There is no question that it would be better to avoid any additional emissions (including carbon dioxide) to the atmosphere; however, one must examine realistically the trade-offs between the burning of a spill and the potential impacts of not burning during a specific spill situation. If a spill is not burned, evaporation will result in the release of a much greater volume of volatile organic compounds (VOCs) and other emissions to the atmosphere. The unburned oil may move into shallow, more sensitive environments; it may impact shorelines; and it may sink through sedimentation to the ocean floor. It is generally felt that in many cases, the net overall adverse effects of a spill will be reduced by burning and that the short-term impacts of combustion (temporary, localized air pollution) will be less damaging than the potentially long-term impacts of an uncontrolled oil spill that could spread out and contaminate larger areas of the environment.

Burn Residue --

As discussed in Section II.C, Basic Combustion Theory, oil will normally burn down to about a millimeter or two (<0.1 inch) in thickness before the fire is extinguished by a rapid reduction in oil temperature and therefore vapor release. If the original oil thickness was several inches, the percentage of oil left after the burn would be quite low (typically 2% to 3% or less). If the starting oil layer was only 0.5 inch thick, then the oil remaining after burning might represent as much as 20% or more of the original volume.

The amount of burn residue after a burn will also depend on the type of containment used and the way in which oil is fed to the fire. If wind and/or currents are available to help move burning oil up against a barrier, the oil may be maintained at an adequate combustion thickness while the area coverage of the burn is reduced. This same type of assistance would be realized while towing the fire containment boom and allowing winds or induced surface currents to keep the burning oil thick enough for combustion.

Regardless of the burn mode employed, the amount of residue after burning will very likely represent a very small portion of the original oil (typically between 2% and 10%). Numerous controlled burns have been conducted with a variety of crude oils under a wide range of environmental conditions. These tests, including two with towed fire containment boom at sea (Allen, 1990), have revealed that the burn residue from a contained fire is initially very fluid and frothy. Within minutes, the residue cools and becomes highly viscous, releasing some of the bubbles that had been entrained within the oil. Through this cooling period, the residue continues to thicken as winds and/or currents pile the oil residue upon itself. In static tank tests, the burn will often result in the accumulation of a taffy- like residue with an average thickness of only a millimeter or two (<0.1 inch). However, during both burns with towed 3M Fire Boom in Prince William Sound and off Spitsbergen (Allen, 1990), the burn residue reached thicknesses of several inches within about 5 to 10 minutes following completion of the burn. The thick, taffy-like residue was still buoyant and easily contained within the boom.

From an environmental standpoint, the bum residue is not very different from the original oil prior to burning, other than the fact that the residue is viscous and has a consistency like weathered oil. Some of the lighter volatiles have obviously been removed, thus lowering its toxicity. The specific gravity of the residue, however, remains sufficiently low to keep it afloat for at least several hours and, in some cases, at least several days. With time, it is believed that the captured bubbles of hydrocarbon vapor will collapse as the vapors are reabsorbed into the oil and/or released through the upper surface of the residue. Bubbles of water vapor are also believed to be entrained in the residue from the thin layer of heated water immediately below the oil during the last minute or two of the bum. As these bubbles collapse and the residue continues to weather and possibly pick up slightly denser particulates from the sea, the residue will gradually become dense enough to be neutrally buoyant and eventually sink.

Because of the limited area extent of the burn residue, typically on the order of 100 square feet or less for a towed burn configuration, there is very little possibility for any long term, major impacts on birds, mammals, fish, or planktonic organisms. The consistency of the residue is such that recovery is very simple with hand tools or nets. Therefore, the time that the residue is in the water need not be very long following completion of the burn.

Once recovered, the residue should be placed in proper containers for transport to shore. Fish totes, drums, and plastic bags make good temporary storage containers until the burn residue can be transferred to a suitable long-term storage container or moved directly to an approved disposal facility: The burn residue should be treated the same way that other mechanically recovered oil or oily debris is treated. .

Heat --

The effects of heat from in-situ burning are insignificant in light of the size, duration, and frequency of such potential burns. The results of several major burns (10's of 1000's of barrels) every day would be dwarfed by the numerous other sources of heat operating every day (e.g., combustion engines, factories/refineries, forest fires, volcanoes, agricultural buns, etc.). As with the production of C02 during in-situ burning, the heat produced must be considered while recognizing that the C02 and the heat would have been produced anyway had the oil <u>not</u> been spilled in the first place. The net global contributions are about the same.

With respect to the ocean waters and their inhabitants, the effects of heat from in-situ burning are again insignificant. Typically 2 to 3 percent of the heat produced during a burn is radiated back toward the surface. With most of this energy being used to volatilize the oil, the amount of heat absorbed by the underlying water is generally negligible. This is particularly true during a controlled burn at sea where currents (natural and/or induced) would continually cause an exchange and mixing of water directly under and adjacent to the burning oil.

B. Proximity Issues

The potential exposure of public, private, and environmental resources to the effects of burning spilled oil will always be given the highest concern prior to an in-situ burn. If properly planned and implemented, the burning of oil should not expose people, equipment, or facilities to harmful levels of heat or the products of combustion. Section I.D addresses the potential for the exposure of on-site workers to the effects of heat and combustion products. Information is also provided on safe operating procedures and how to minimize the risks of exposure. Section I.E addresses the potential for the exposure of populated areas, shoreline facilities, etc. to the effects of burning. In both Sections I.D. and

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I.E safety is stressed as the highest of all concerns.

Every spill situation is different, and therefore, every potential burn situation is also different. Clear guidelines and priorities for the potential use of burning under a broad range of spill scenarios should be established by appropriate regulatory groups and the general public. Pre-authorization for burning is essential so that there is no question about acceptable distances from shorelines, communities, shipping lanes, etc. prior to a burn. Because of the need to mobilize people and equipment quickly, responders and government representatives need to agree in advance about any restrictions on burning because of weather, visibility, sea state, night operations, etc. Every effort should be made to identify in advance those issues that could conceivably delay the decision-making process.

Many of the issues involving worker safety, public safety, etc have already been discussed in this section and in Section I. As these issues are examined, the most common environmental concerns seem to include:

- The depth to which high temperatures will be experienced _in the water column and the effects of such heating on marine life;

- The effects of burning oil on birds, mammals, and fish in close proximity to the bum site;

- The impacts of particulates and/or oil droplets that may precipitate out of the smoke plume onto the water, land, plants and animals, etc.;

- The effects of burn residue on marine life, and if the residue sinks, upon the bottom-dwelling biota;

- The effects of the smoke plume on residents of a community should a sudden wind shift or atmospheric inversion carry combustion products toward a populated area;

- Etc.

Most of these environmental issues have already been addressed. However, one very important factor must be emphasized about all of these issues, regardless of the nature and even the severity of that issue's impact. That factor involves the *scale* of the potential impact under consideration. For example,

- *If the water boiled beneath a burning oil layer, the depth and area extent of that boiling would be extremely small.* Typically 2% to 3% of the heat generated from a burning oil slick is radiated back to the surface. Most of that heat is used in volatilizing the oil for continued combustion. If the oil was being burned on open water in a towed boom, water would also be in constant motion beneath the burning oil, thereby continually replacing any heated water with water at ambient sea temperature. Even if certain biota could not tolerate the very modest temperature increase immediately below the burning oil, the extent and duration of exposure would be very unlikely to result in any significant ecological damage.

During the large-scale experimental burn conducted in August 1993 in Newfoundland, no heating of the water under the burning oil was detected with temperature probes that measure to plus or minus 1/2 a degree. (Personal communication - Merv Fingas, November 18, 1993)

- *If birds, mammals, and fish were abundant near the burn site, the probability that they would fly or swim into the fire or burning oil accidentally or because of forced exposure is very low.* Even if such contact were to occur, the number of contacts that could conceivably happen in a single spill event would normally be of little, if any, environmental consequence, especially when compared to the oil contacts that could result if the oil had not been burned.

- *If soot and/or oil droplets do fall out of the smoke plume downwind, such fallout is normally limited to a very small area and involves only a few percent of the original volume of oil burned.* The burning of spilled oil can be controlled within a fire containment boom and conducted when and where the smoke plume will normally disperse over water. It is therefore highly likely that any fallout from the plume will be deposited onto a water surface where it can be dispersed and degraded naturally and quickly. What little petroleum product is released from the plume will have been reduced in toxicity (i.e., the lighter ends removed), will represent a very low dosage or exposure (i.e., volume per unit area), and will always constitute a very small fraction of the oil that would have otherwise been free to spread as a more toxic medium over much larger areas.

- *If burn residue was not collected and it sank, the burn residue would very likely be deposited as chunks of weathered, tar-like material on the bottom and become entrained with bottom sediments.* These chunks would not have a tendency to spread over large areas or to coat and suffocate large numbers of organisms. Depending on the water depth, temperature, etc., the residence time of these chunks might be very long; however, because of the very small portion of the spill volume left as bum residue, this tar-like material would release very limited amounts of dissolved components. Furthermore, they would contact an insignificant portion of an open-water seabed, and the biota that might come into near or direct contact with them would likely move to avoid prolonged exposure. Any organisms that did not (or could not) avoid direct and prolonged exposure might suffer significant impact; however, the portion of such an impacted resource would very likely be insignificant.

- *If a smoke plume suddenly moved directly toward a populated area or other sensitive resources, immediate response options could be employed including the decision to terminate the burn, to relocate the burn, to alert people to stay indoors until the area was clear again, and/or to implement an evacuation plan.* Populations on earth are exposed to the products of petroleum combustion routinely. Such exposure is obviously not desirable, and should be avoided if at all possible. However, those in control of any decision to initiate and maintain a controlled in-situ burn must be prepared to weigh the relative impacts of a temporary and localized air pollution situation against the impacts of denying a burn request or of terminating an ongoing burn.

Although the results of the large-scale experimental urn off the Newfoundland coast (August 1993) have not yet been published, the following on emissions was gathered:

- Non-respirable particulates larger than PM-10s were unmeasurable at 1 kilometer from the fire.

- PM-10s were undetectable on the ground. Some PM-10s were detected by atmospheric research aircraft in the smoke plume.

- PAHs measured were much less than PAHs measured during test bums.

- Kilograms of PAHs in smoke and residue were 10^{-7} of starting PAHs.

- No gases such as $S0_2$, NOx, and CO were detected.

- Aldehydes and ketones were barely detectable. (Personal communication: Merv Fingas, December 23, 1993)

In nearly all situations, an assessment of the scale of the potential environmental impacts of controlled burning suggests that there are numerous spill situations where in-situ burning can be used safely and with the least overall damage to the environment.

C. Possible Mitigation Efforts

There are several ways to reduce the potential impacts of burning spilled oil. Some involve rather simple operational procedures, while others require the use of special materials or equipment during the burning process. The following summaries address some of the techniques/equipment that have already been used, as well as some promising new ideas for the avoidance or reduction of environmental impact:

- **Planning-**With the specification of acceptable location requirements and plume-transport conditions, burns will be achievable without exposing population centers, natural resources, etc. to potentially harmful emissions from the burning of oil. A well-thought-out burn plan combined with a reliable notification/communications plan, will enable a response team to conduct in-situ burns with minimal risk to on-site workers, vessels, facilities, shorelines, etc.

- **Burn-Time Reduction**--In situations where the duration of a burn is directly related to potential increases in impact, it may be desirable to reduce the bum-time by maximizing the area of the bum. The oil volume burned and the resulting emissions may remain about the same; however, the reduced overall burn-time may allow for the completion of a burn while it is still well away from some

- approaching area of concern. Depending on the location of the burn and the atmospheric conditions, it may be better to create a large, short-lived burn than a small burn of longer duration.

- **Recovery of Burn Residue**-In most situations it should be possible to recover most of the unburned oil residue contained within the boom or other natural barrier. Techniques for recovery of burn residue are discussed in Section V.B.6. If possible, the residue of one burn may be left within the boom while oil is collected for additional burns. Substantial quantities of the residue can be reduced by repeated exposures to subsequent burns.

Exclusion Areas:

Because of concerns about the possibility of sinking residue or atmospheric emissions, certain sensitive areas 'have been set aside for exclusion from the per approved in-situ bum area of 3 miles or farther off the Louisiana and Texas coasts. It is intended that this list be reviewed annually as a part of the total Plan review for adequacy. A list of the Exclusion zones and locations are listed in Appendix F.

D. Resources At Risk

Because biological resources tend to concentrate in critical habitats such as beaches, barrier islands, estuaries, and wetlands; long-lasting environmental damage can often be avoided if spilled oil is prevented from reaching shore. As well as direct impacts on living organisms, spilled oil can cause long lasting damage to certain sensitive coastal habitats. These habitats provide food and shelter for most organisms in the Gulf at one or more stages of their life histories.

Due to subsidence, lack of sediment enrichment, and other natural and man-made influences, Texas and Louisiana are experiencing a dramatic loss of productive, vegetated wetlands. Not only do plants constitute the base of the food web that fuels the biological productivity of the wetlands, but often have a tenuous hold on fragile wetland soils. If the plants are lost, so is the soil and the productivity of the marsh.

Coastal resources at risk for Louisiana and Texas are depicted in two publications: Sensitivity of Coastal Environments and Wildlife to Spilled Oil - Louisiana - An Atlas of Coastal Resources (NOAA, Office of Oceanic and Marine Assessment, Seattle, Washington, 1989 by RPI International INC.) and Coastal Region Spill Response Map Series, June, 1992, LP 9009, Vol. 1, prepared by the Texas Water Commission. Copies of these publications have been presented to the RRT 6 and are thereby incorporated in this application by reference.

Oil spill responders hope to protect the coastal biological resources at risk depicted by these publications on the shorelines of Texas and Louisiana by using in-situ burning and other techniques to prevent spilled oil from reaching shore.

There are thousands of species of plants and animals that inhabit Gulf of Mexico waters three miles or farther offshore. Many of these species could be affected by the in-situ burning of spilled oil but would be at much greater risk if spilled oil were to remain on the surface where spreading and movement increase the area and longevity of impact. Marine mammals, marine turtles, birds and plankton including fish and macro-invertebrate eggs and larvae are groups of organisms most likely to be impacted by oil spills.

1. Marine Mammals

Marine mammals with fur are especially susceptible to oiling since oil destroys the insulating properties of the fur, often resulting in hypothermia and death. In attempts to remove the oil by grooming, oil can be injested and inflammation or hemorraging in the gastro-intestinal tract can occur. Other effects include skin; eye, and respiratory tract irritations.

Marine mammals without fur, such as cetaceans (whales, dolphins, and porpoises) and manatees, depend primarily on fat for insulations so heat loss from oiling is not as severe. However, skin and eye irritations, interference with swimming, and other impacts can occur from contact with spilled oil (Abers, 1990).

In the Gulf of Mexico, there are at least 29 species of Cetaceans (whales, dolphins, and porpoises). Of the 29 species, five are endangered. The continental shelf waters (<180m) have been well studied as compared to deeper waters off the continental shelf (>180m). The bottlenose dolphin is the only species that commonly inhabit most shelf waters. As depths increase off the continental shelf, the cetacean community becomes more diverse (Mullin, et al., 1991).

In aerial surveys conducted in the north-central Gulf from July, 1989, to June, 1990, (Mullin, et al., 1990) 15 species of Cetaceans were sighted. Seven species accounted for 93% of the sightings of identified herds. These species and the number of herds sighted are: Risso's dolphin (61 herds), sperm whale (43), bottlenose dolphin (39), Atlantic spotted dolphin (36), dwarf/pigmy sperm whales (32), striped/spinner/Clyme dolphins (24), and pantrophical spotted dolphin (23).,

In response to the Mega Borg oil spill off the Texas coast on June 9, 1990, The National Oceanic and Atmospheric Administration and Texas A&M, Galveston, conducted aerial surveys to ascertain populations of marine mammals and sea turtles near the spill site. In addition, an analysis of the behavior of marine mammals in confronting spilled oil was made (Scott, 1991).

The surveys documented the presence of bottlenose dolphin (42 herds were sighted), Atlantic spotted dolphin (2 herds sighted), and one Risso's dolphin (individual) in the spill area. Smultea and Wursig (1990) reported the results of the behavior of dolphin when confronted with spilled oil from the Megaborg. In the study, three types of spilled oil were considered: sheen (a light lumnescent oil), slick (a thick iridescent oil), and mousse (a dark-brown, frothy, thicker oil).

Results indicated that bottlenose dolphin did not appear to detect or exhibit behavioral response to sheen oil. They appeared to be able to detect slick oil but their reactions were variable. They detected and in variably avoided contact with mousse. This study indicated that bottlenose dolphin might be at high risk from spilled oil since they do not seem to avoid sheen or slick oil where the volatile components may be the most available, and therefore, most damaging to the exposed animals.

In a recent Draft Environmental Impact Statement prepared by the U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region (Gulf of Mexico Sales 147 and 150: Central and Western Planning Areas - Draft Environmental Impact Statement -Volume 1: Sections I through IV,C. - OCS EIS/EA, MMS93-0012) an excellent species account of the marine mammals in the Gulf of Mexico is included and is quoted as follows:

“Twenty-nine species of cetaceans, one sirenian, and one exotic pinniped (California sea lion) have been sighted in the northern Gulf of Mexico (Table I). Cetaceans are divided into two major suborders: Mysticeti (baleen whales) and Odontoceti (toothed whales and dolphins). The only member of the Order Sirenia found in the northern Gulf is the West Indian Manatee, which is common throughout coastal and inshore waters of Florida. Manatees rarely venture as far west as the Central and Western Gulf Planning Areas, and thus, have been excluded from the analyses of this document. California sea lions exist in the northern Gulf of Mexico as feral individuals that were probably released or escaped from aquaria, animal shows, and marine parks.

Seven species of baleen whales have been reported in the Gulf of Mexico. These include the northern right whale and six species of balaenopterid whales (blue, fin, sei, Bryde's, minke, and humpback). Though sightings and strandings of these species are uncommon in the Gulf, historical sightings and stranding census data suggest that they more often frequent the north-central Gulf region.

Twenty-two species of toothed whales and dolphins have been reported in the Gulf of Mexico. These include the great sperm whale; pygmy and dwarf sperm whales; four species of beaked whales (Cuvier's, Gerais', Blainville's, and Sowerby's); killer whale; false and pygmy killer whale; short-finned pilot whale; grampus (Risso's dolphin); melon-headed whale; and nine other species of delphinid dolphins (bottlenose, Atlantic spotted, pantropical spotted, spinner, clymene, striped, common, Fraser's, and rough-toothed). Many of these species are distributed in warm temperate to tropical waters throughout the world (Mullin et al., 1991).

Nonendangered and Nonthreatened Species

Baleen whales from the Gulf of Mexico that are not listed as endangered include the Bryde's whale and the minke whale. The Bryde's whale is the second smallest of the balaenopterid whales commonly called rorquals, a Norse term meaning "red whale," referring to the pinkish tint of their characteristic throat pleats that expand during feeding. Bryde's whales are not noted for lengthy migrations and tend to.

remain within tropical to temperate waters. This species feeds on small pelagic fishes (such as herring, mackerel, and pilchard) and cephalopods (Cummings, 1985). It is believed that a small, resident population of Bryde's whales may inhabit the Caribbean Sea or Gulf of Mexico (Schmidly, 1981). The-minke whale is the smallest of the rorquals and is cosmopolitan in distribution. It is widespread and seasonally abundant in the North Atlantic Ocean, migrating southward during winter months to the Florida Keys, the Gulf of Mexico, and the Caribbean Sea. Minke whales feed on zooplankton and fish (Stewart and Leatherwood, 1985). With the exception of sperm whales, none of the toothed whales and dolphins from the Gulf of Mexico are listed as endangered or threatened. Dwarf and pygmy sperm whales are typically found in deeper waters (the continental shelf edge and beyond) and congregate in small herd sizes (2-10 individuals). Temporal distribution within the Gulf has been variable (Mullin et al., 1991). Their diet includes squid, benthic fish, and crabs (Caldwell and Caldwell, 1989). Beaked whales (family Ziphiidae) from the Gulf include Cuvier's beaked whale and three members of the genus *Mesoplodon* (North Sea beaked whale, Blainville's beaked whale, and antillian beaked whale). Taxonomy and life history data on these species are extremely limited. Observed herd sizes of beaked whales are in most cases small (1-2 individuals), and the typical behavioral response to survey aircraft and ships is for them to be evasive (Mullin et al., 1991). An analysis of stomach contents from captured and stranded individuals suggest that they are deep-diving animals, feeding predominantly on mesopelagic fish and squid or deep-water benthic invertebrates (Heyning, 1989; Mead, 1989).

The family Delphinidae is taxonomically broad and includes all remaining species of nonendangered whales and dolphins found in the Gulf. Most of the constituents inhabit deeper waters of the Gulf, save the bottlenose dolphins, and their specific distributions appear to be a function of preferred depth range. Bottlenose dolphins are the most common delphinid on the continental shelf and nearshore waters of the Gulf. Many regional studies have demonstrated the presence of morphologically discrete offshore and coastal adult forms (Mead and Potter, 1990). Atlantic spotted dolphins frequent mid-shelf to outer-shelf waters with some degree of overlap with bottlenose dolphins, especially the offshore forms. Grampus are also frequently sighted along the shelf edge. All other delphinids appear to prefer deeper slope waters and feed on fish and/or squid, depending upon the species (Mullin et al., 1991). Knowledge of the spatial and temporal abundance of most deep-water cetaceans in the Gulf has been, until this time, sparse and limited to a few survey areas. At present, MMS is funding a study (GULFCET) using broad based aerial and shipboard surveys to determine the seasonal and geographic distribution of cetaceans along the continental slope in the north-central and western Gulf. Recent surveys have led to the Sightings and acoustic recordings of shelf edge and deep-water species have been made using systematic transects (Texas A&M University, Texas Institute of Oceanography, 1992).

Endangered and Threatened Species

Five species of baleen whales (northern right, blue, fin, set, and humpback) and one species of toothed whale (sperm whale) found within the Gulf of Mexico are .

currently listed as endangered under the provisions of the Endangered Species Act of 1973. All are uncommon to rare in the Gulf except for the sperm whale.

TABLE 1

MARINE MAMMALS OF THE GULF OF MEXICO

Order Cetacea

Suborder Mysticeti (baleen whales)

Family Balaenidae		
Eubalaena glacialis	northern right whale	R*
Family Balaenopteridae		
Balaenoptera musculus	blue whale	R*
Balaenoptera physalus	finwhale	R*
Balaenoptera borealis-	sei whale	R*
Balaenoptera edeni	Byrde's whale	R
Balaenoptera acutorostrata	minke whale	R
Megaptera novaeangliae	humpback whale	R*

Suborder Odontoceti (toothed whales)

Family Physeteridae		
Physeter macrocephalus	great sperm whale	C*
Kogia breviceps	pygmy sperm whale	C
Kogia simus	dwarf sperm whale	U
Family Ziphiidae		
Mesoplodon bidens	North Sea beaked whale	E
Mesoplodon densirostris	Blainville's beaked whale	R
Mesoplodon europaeus	Antillian beaked whale	U
Ziphius cavirostris	goosebeaked whale	U

C=common, U=uncommon, R=rare, E=extralimital record, I=introduced, Ex=extinct, *=endangered

Table 1. **Marine Mammals of the Gulf of Mexico** (continued)

Order Cetacea (continued)		
Family Delphinidae		
Orcinus orca	killer whale	R
Pseudorca crassidens	false killer whale	U
Feresa attenuata	pygmy killer whale	U
Globicephala macrorhynchus	short-finned pilot whale	C
Grampus griseus	grampus/Risso's dolphin	U
Peponocephala electra	melon-headed whale	R
Tursiops truncatus	Atlantic bottlenose dolphin	C
Delphinus delphis	saddleback dolphin	R
Steno bredanensis	rough toothed dolphin	R
Stenella coeruleoalba	striped dolphin	C
Stenella attenuata	pantropical spotted dolphin	R
Stenella clymene	short-snouted spinner dolphin	U
Stenella frontalis	Atlantic spotted dolphin	C
Stenella longirostris	long-snouted spinner dolphin	U
Lagenodelphis hosei	Fraser's dolphin	R
Order Carnivora		
Suborder Pinnipedia (seals, sea lions)		
Family Otariidae		
Zalophus californianus	California sea lion	I,R
Family Phocidae		
Monachus tropicalis	Caribbean (West Indian) monk seal	Ex
Order Sirenia		
Family Trichechidae		
Trichechus manatus	West Indian manatee	C*

Source: Schmidly and Scarborough, 1990.

C = common, U = uncommon, R = rare, E = extralimital record, I = introduced, Ex = extinct, * = endangered

The northern right whale is a robust, medium-sized baleen whale. As a result of extensive hunting pressure, it remains the rarest of the world's large whales. Current populations within the North Atlantic seasonally migrate around five discrete areas along the eastern seaboard of the U.S. (USDOC, NMFS, 1991 a). Historical records of northern right whales in the Gulf of Mexico consist of a single stranding record in Texas in 1974 and a sighting of two individuals off the western coast of Florida (1963) (Moore and Clark, 1963; Schmidly, 1981). Right whales feed by systematically skimming through surface and subsurface concentrations of zooplankton with their enormous mouth held agape (Watkins and Schevill, 1976).

The blue whale is the largest of the whales and is cosmopolitan in distribution, migrating poleward to feeding grounds in spring and summer after wintering in subtropical waters (Yochem and Leatherwood, 1985). Records of the blue whale in the Gulf consist of two strandings on the Texas coast (1924 and 1940), and it is believed that the entire surviving population in the North Atlantic consists of only a few hundred individuals (Leatherwood and Reeves, 1983). It is the largest rorqual, and feeds almost exclusively on zooplankton via a combination of gulping and lunge-feeding in areas of heavy prey concentration (Yochem and Leatherwood, 1985).

The fin whale is the second largest rorqual in size and is also cosmopolitan in distribution. It is thought that fin whales segregate into independent stocks in each hemisphere and that there may be a small population which inhabits the Gulf of Mexico or Caribbean Sea (Schmidly, 1981). Fin whales feed on zooplankton, cephalopods, and fish, generally via surface and subsurface lunge-feeding (Gambell, 1985a). Sightings in the Gulf have typically been in deeper waters, more commonly in the north-central area (Mullin et al., 1991).

The sei whale is a medium-sized rorqual that is widely distributed in all oceans. They migrate between temperate waters and higher latitudes, though they do not go so far towards polar waters as do some other rorquals. Sei whales feed primarily on plankton via skimming, though they do consume small schooling fish in some areas via lunge-feeding (Gambell, 1985b). Two sei whales were sighted off the Mississippi River Delta in 1956 and off Gulfport, Mississippi, in 1973 (Mullin et al., 1991). Valid sighting and stranding records from the Guff of Mexico, Caribbean Sea, and off eastern Florida suggest that there may be a resident population in the Gulf (Mead, 1977).

The humpback whale, though a member of the family Balaenopteddae, is distinctively different in appearance from the true rorquals. They occur in all oceans, and seasonally migrate from summer feeding grounds in higher latitudes to a winter range over shallow tropical banks where they calve and do not feed. Humpbacks feed on fish and zooplankton, which typically aggregate into dense or large patches. They capture prey using a diverse and oftentimes elaborate array of feeding techniques, either singly or within groups (Winn and Reichley, 1985). Sightings in the Gulf of Mexico have been sporadic and include the Central discovery of at least one rather large herd (approximately 200 individuals) of Fraser's dolphins (hitherto known to the Gulf only via a single stranding in the

Florida Keys). Gulf, in the Eastern Gulf off Florida, and most recently (1992) off Galveston Bay, Texas (Schmidly, 1981; Gainesville Sun, 1983).

The sperm whale is the only toothed whale listed as an endangered species. They have a cosmopolitan distribution within deep-sea areas and form social aggregations consisting of mature females, juveniles, and calves. Male sperm whales form separate bachelor herds of varying size or, in the case of large males, remain solitary. As a group they seem to prefer certain areas within each major ocean basin, which historically have been termed "grounds" (Rice, 1989). Large mesopelagic squid are the primary diet of sperm whales, though other cephalopods, demersal fishes, and occasionally benthic invertebrates are eaten (Rice, 1989). It is the most abundant large whale in the Gulf of Mexico and has been sighted on most surveys conducted in deeper waters (Fritts et al., 1983; USDOC, NMFS, 1988; Mullin et al., 1991). Congregations of sperm whales are commonly seen off the shelf edge: in. the vicinity of the Mississippi River Delta (Mullin et al., 1991). There is, as yet, no data available that suggests seasonal movements of sperm whales in the Gulf of Mexico (Schmidly, 1981). A component of the ongoing GULFCET study will include an attempt to tag and track a limited number of sperm whales within the continental slope area of the north-central and northwestern Gulf using satellite telemetry to determine seasonal movements, diving behavior, and preferred habitat (Texas A&M University, Texas Institute of Oceanography, 1992)."

2. Marine Turtles

All five of the marine turtles (greens, leatherbacks, hawksbills, loggerheads, and Kemps ridleys) in the Gulf of Mexico are threatened or endangered species. Lutcavage et al. (1993) reported on physiological effects of weathered south Louisiana crude on juvenile loggerhead and green sea turtles. Among the impacts were low blood serum glucose, increased white blood counts, interruption of salt gland function, and skin chemistry were significantly affected by exposure to oil.

Lutz et al. (1993) reported that since sea turtles breath air, their repeated surfacing would cause them to have maximum contact with the floating oil. Their rapid, high volume exchange mode of respiration could introduce volatile compounds into the lungs. Juvenile and adult turtles alike apparently indiscriminately swallow any material of appropriate size, including tar balls which the turtles cannot easily eject.

Oiling of nesting beaches could interfere with embryo development and threaten hatchling survival (Fitts and McGehee). The recent Tampa Bay fuel and crude oil spill in August, 1993, impacted adjacent turtle nesting beaches, and dead hatchlings and at least one subadult green turtle were found covered with viscous oil (M. Lutcavage, personal communication, 1993). In a recent Draft Environmental Impact Statement prepared by the U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region (Gulf of Mexico Sales 147 and 150: Central and Western Planning Areas - Draft Environmental Impact Statement - Volume 1: sections I through IV.C. -OCS ..

EIS/EA, MMS93-0012) an excellent species account of the marine turtles in the Gulf of Mexico was prepared and is quoted as follows:

`This section contains a brief, species account of the sea turtles of the Gulf of Mexico.

The green turtle *(Chelonia mydas)* population in the Gulf once supported a commercial harvest in Texas and Florida, but the population has not completely recovered since the collapse of the fishery around the turn of the century (Hildebrand, 1982). Reports of nesting in the northern *Guff* are isolated and infrequent, except on Santa Rosa Island, Walton County, Florida. The closest significant nesting aggregations are on the Florida east coast and the Yucatan Peninsula. In feeding habitats green turtles prefer depths of less than 20 m, where seagrasses and algae are plentiful (Carr and Caldwell, 1956; Hendrickson, 1980). In coastal Texas, green turtles demonstrated site fidelity, remaining in one location for several months (NMFS Newsbreaker, 1993).

Leatherbacks *(Dermochelys coriacea),* the largest and most oceanic of marine turtles, seasonally enter coastal. and estuarine habitats where jellyfish are plentiful (Lazell, 1980). Their nesting is concentrated on coarse-grain beaches in the tropical latitudes (Pritchard, 1971), but there are rare occurrences on the Panhandle and Flagler County coasts in Florida (Ogren, 1990). Leatherbacks have unique deep diving abilities (Eckert et al., 1986), a specialized jellyfish diet (Brongersma, 1972), and unique physiological properties that distinguish them from other sea turtles (Lutcavage et al., 1990; Paladino et al., 1990).

The hawksbill *(Eretmochelys imbricata) is* the least commonly reported marine turtle in the Gulf (Hildebrand, 1982). Stranded turtles are regularly reported in Texas (Hildebrand, 1982; Ogren et al., 1989), and recently, in Louisiana (Choromanski, personal communication, 1992) these tend to be either hatchlings or yearlings. Northerly currents may carry them away from their natal beaches in Mexico northward into Texas (Amos, 1989; Collard and Ogren, 1989). They are more common in tropical areas of the Atlantic, *Guff* of Mexico, and Caribbean. Hawksbill turtles prefer reefs and shallow coastal waters where marine invertebrates are abundant (Carr and Stancyk, 1975; Witzell, 1983).

The Kemp's ridley sea turtle *(Lepidochelys kempi) is* the most imperiled of the . world's marine turtles. The population of nesting females has dwindled from an estimated 47,000 in 1947(Hildebrand, 1963) to less than 1,000 today (Pritchard, 1990). An estimated 700-1,000 nests are laid annually, primarily on a 17-km stretch of beach in Rancho Nuevo, Vera Cruz, Mexico (Marquez et al., 1989; Burchfield et al., 1992). Nesting in the United States occurs infrequently on Padre and Mustang Islands in south Texas from May to August (Thompson, 1988). Natural nesting is supplemented by a NMFS hatchling and rearing program on. Padre Island National Seashore (Klima and McVey, 1982). Hatchlings appear to disperse offshore, and are sometimes found in sargassum mats (Carr and Meylan, 1980; Collard and Ogren, 1990). The Kemp's ridley's distribution is associated with the abundance of portunid and other crabs (Ogren, 1989; Shaver, 1991) and seagrass ecosystems (Carr and Caldwell, 1956; Lutcavage and Musick, 1985). In the Gulf, Kemp's ridleys inhabit nearshore areas, and have also been recorded off the mouth of the Mississippi River (Fuller and Tappan, 1986; Byles, 1989). Although adult Kemp's ridleys primarily inhabit the Gulf of Mexico, subadults range on the Atlantic coast to Massachusetts (Lazell, 1980; Lutcavage and Musick, 1985; Standora et al., 1989). Carr (1980) and Hendrickson (1980) believed that young ridleys found beyond the Gulf of Mexico are lost to the breeding population, but some researchers dispute this view (Lutcavage and Musick, 1985; Henwood and Ogren, 1987; Standora et al., 1989). Juvenile ridleys recently tagged and released in Atlantic coastal habitats demonstrated movements southward along the coast of Florida (NMFS Newsbreaker, 1992), but to date their remigration to the Gulf is unverified.

The loggerhead sea turtle (*Caretta caretta*) occurs worldwide in habitats ranging from estuaries to the continental shelf (reviewed in Dodd, 1988). It is found in the Atlantic from Newfoundland to Argentina, and nesting occurs worldwide. Aerial surveys indicate that loggerheads are common in less than 50 m depth, but they are also found in deep water (Shoop et al., 1981; Fritts et al., 1983). The largest nesting concentration in the United States is on the Southeast Florida coast from Volusia to Broward Counties (Hopkins and Richardson, 1984). In the Gulf of Mexico, recent surveys indicate that the Florida Panhandle accounts for approximately one-third of the nesting on the Florida Gulf Coast. In the Central Gulf, loggerhead nesting has been reported on Gulf Shores and Dauphin Island, Alabama, Ship Island, Mississippi, and the Chandeleur Islands, Louisiana (Fuller et al., 1987). Nesting in Texas occurs primarily on North and South Padre Islands, although occurrences are recorded throughout coastal Texas (Hildebrand, 1982). The banks off of the central Louisiana coast and near the Mississippi Delta are also important marine turtle feeding areas (Hildebrand, 1982). Hatchlings have a pelagic phase followed by movement inshore. Loggerheads engage in omnivorous benthic (Hendrickson, 1980 and surface feeding (Plotkin, 1989). Adults and juveniles are frequently found in association with concentrations of portunid and horseshoe crabs, but the loggerhead's prey includes invertebrates from eight phyla (reviewed in Dodd, 1988).

The recently designated Archie Carr National Wildlife Refuge in Brevard and Indian River Counties, Florida, hosts the largest concentration of nesting loggerhead and green sea turtles in the United States (Ehrhart and Witherington, 1987). It is believed to be the second largest nesting beach for loggerheads in the world (Ross, 1982)."

3. Marine Birds

Birds are possibly the animals most susceptible to spilled oil. Birds depend on their feathers for insulation, buoyancy, water, repellency, and flight. When birds come in contact with spilled oil, feathers absorb oil and become matted, the internal structure of the feather is compromised, and birds die from hypothermia, starvation, and drowning. (Leighton, 1993).

The internal effects of oiling are equally life threatening. Toxic compounds of oil can enter the body through inhalation, ingestion, and/or adsorption through the skin. Birds may attempt to rid themselves of oil by preening which can lead to injestion. Injestion can lead to enteritis and ulceration of the gastro-intestinal tract. Other internal effects can be disfunction of the kidneys, liver, and respiration system (Stout, 1993).

Avian embrys are extremely sensitive to oil applied to the egg shell. A few microlitres of oil on an egg shell can be lethal to the embryo. Adult birds contaminated with oil can deliver enough oil to the eggs to kill them (Leighton, 1993). _

In the Gulf of Mexico, there are many species of sea birds, wading birds, waterfowl, shorebirds, rapors, and diving birds that could be at risk from a nearshore or offshore oil spill. Martin and Lester, 1990, prepared an atlas and census of wading bird and seabird nesting colonies in Louisiana. This information is indicative of the species of birds likely be impacted by oil spills in the Gulf of Mexico as well as the seasonal nesting activity for each species (Table 2).

Species of plagic birds likely to be encountered offshore include: yaegers, boobies, gannets frigate birds, petrols, black tems herring gulls, migratory waterfowl, especially lesser scaup (personal communication: Bill Vermillion, Gary Lester - La. Department of Wildlife and Fisheries, Natural Heritage Program).

Also of concern in the offshore environment are the many species of birds, including species of waterfowl as well as songbirds, that cross the Gulf of Mexico to Yucatan, Central and South America in the fall and return to North American breeding grounds in the spring. Gusey,1974, reported on the findings of researchers who have documented large-scale trans-Gulf .bird migrations.

In a recent Draft Environmental Impact Statement prepared by the U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region (Guff of Mexico Sales 147 and 150: Central and Western Planning Areas - Draft Environmental Impact Statement - Volume 1: Sections 1 through IV.C. - OCS EIS/EA, MMS93-0012) an excellent species account for the coastal and marine birds of the Gulf of Mexico was prepared and is quoted:

TABLE 2

Nesting chronology for colonial-nesting waterbirds in Louisiana with suggested activity windows.[a]

Species	Incubation Season	Incubation Period (Days)	Days to Fledging	Activity[b] Window
Brown Pelican	1 Nov-15 Jun	28-30	74-76	1 Aug-31 Oct
Olivaceous Carmorant	15 Mar-15Apr	23-26	35-42	1 Jul-1 Mar
American Anhinga	15 Mar-15 Apr	25-28	?	1 Jul-1 Mar
Great Blue Heron	1 Mar-30 Apr	25-29	58-62	1 Aug-15 Feb
Great Egret	1 Mar-31 May	23-24	40-44	1 Aug-15 Feb
Snowy Egret	16 Mar-15 Jun	17-19	20-25	1 Aug-1 Mar
Little Blue Heron	16 Mar-15 Jun	22-24	28-32	1 Aug-1 Mar
Tricolored Heron	16 Mar-15 Jun	20-22	?	1 Aug-1 Mar
Reddish Egret	16 Mar-15 Jun	23-26	?	1 Aug-1 Mar
Cattle Egret	16 Apr - 30 Jun	21-24	35-40	1 Sep- 1 Apr
Green-backed Heron	1 Apr-30 Jun	19-21	16-17	1 Sep-15 Mar
Black-crowned Night-Heron	16 Mar-15 Jun	24-26	40-42	1 Sep- 1 Mar
Yellow-crowned Night-Heron	1 Apr-15 Jun	?	?	1 Sep-15 Mar
White Ibis	16 Apr-30 Jun	21-23	35-42	1 Sep-1 Apr
Glossy/White-faced Ibis	16 Apr-30 Jun	21-23	42-49	1 Sep-1 Apr
Roseate Spoonbill	16 Apr-15 Jun	23-24	49-56	1 Aug-1 Apr
Laughing Gull	16 Apr-15 Jun	23-25	35-45	1 Aug _1 Apr
Gull-billed Tern	16 May-15 Jul	22-23	28-35	16 Sep-1 May
Caspian Tern	1 May-15 Jul	26-28	36-4.8	16 Sep-15 Apr
Royal Tern	1 May-15 Jul	28-31	36-48	16 Sep-15 Apr
Sandwich Tern	1 May-15 Jul	23-25	22-33	16 Sep-15 Apr
Commom Tern	1 May-15 Jul	21-25	23-27	16 Sep-15 Apr
Forster's Tern	1 Apr-31 May	25-29	23-27	1 Aug-15 Mar
Least Tern	1 May-15 Jul	20-25	19-23	16 Sep-15 Apr
Sooty Tern	16 May-15 Jul	22-23	30-35	16 Sep-15 Apr
Black Skimmer	16 May-15 Jul	22-23	30-35	16 Sep-1 May

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[a] Data are compiled from Bent (1921), Bent (1926), Palmer (1962), Harrison (1975), Portnoy (1977), Terres (1980).

[b] Suggested project initiation and completion dates to minimize disturbance to nesting birds.

Nonendangered and Nonthreatened Species

“The offshore waters, coastal beaches, and contiguous wetlands of the northern Gulf of Mexico are populated by both resident and migratory species of coastal and marine birds. They are herein separated into five major groups: seabirds, shorebirds, wading birds, marsh birds, and waterfowl. Many species are strongly pelagic, and therefore rarely seen from shore. The remaining species, which are most susceptible to potential deleterious effects resulting form OCS-related activities, are found within coastal and inshore habitats (Clapp et al., 1982). Recent surveys indicate that Louisiana and Texas are among the most important states in the south and southeastern U.S. in terms of nesting colony sites and total number of nesting coastal and marine birds (Martin and Lester, 1991; Martin, 1991). Fidelity to these nesting sites varies from year to year along the Gulf Coast, with site abandonment along the northern Gulf Coast often attributed to habitat alteration and excessive human disturbance (Martin and Lester, 1991).

Seabirds are defined as those species which spend extended periods away from land and obtain all or most of their food from the sea while, swimming, or diving (Nettleship, 1977). Some are coastal feeders and residents, whereas others remain offshore, foraging over deep water in pelagic regions (Nettleship, 1991). Within the Gulf of Mexico, the group comprises four taxonomic orders—Gaviiformes (loons), Podicipediformes (gerbes), Procellariiformes (albatrosses, fulmars, petrels, shearwaters, and storm-petrels), Pelicaniformes (pelicans, tropicbirds, boobies and gannets, cormorants, and frigatebirds), and Charaddiformes (phalaropes, gulls, terns, noddies, skimmers) (Clapp et al., 1982; Harrison, 1983). Evolutionary histories of all these species have been principally marine (Fisher and Lockley, 1954; Lack, 1968; Nelson, 1979). Many species migrate and are found within the Gulf region only seasonally. Others display more localized dispersal and nomadic types of geographic movement in order to exploit food resources, which are patchy in distribution (Nelson, 1979). Seabirds, which nest along the Gulf Coast, typically aggregate into social assemblies, or colonies, with the degree of coloniality varying between species (Parnell et al., 1988). The laughing gull is the only regularly nesting species of gull along the northwestern Gulf Coast. Populations have apparently been increasing as of late, presumably as a result of their acceptance of omni-present. and increasing anthropogenic food resources, e.g., garbage and discarded commercial fishing bycatch (Pashley, 1991). A total of eight species of terns nest along the northwestern Guff, along with black skimmers. This region also supports the majority of several nesting tern species within the U.S. in terms of numbers of individuals, though some of these species appear to be in decline (Pashley, 1991). Recent surveys along the Gulf coastal areas suggest that the nesting colony on South Grand Gossier Island (Louisiana) may be the largest gull and tern colony in North America, numbering 40,000-60,000 pairs annually (Martin and Lester, 1991). Other nesting seabird species include pelicans and cormorants.

Shorebirds are a heterogeneous group belonging to the taxonomic order Charadriiformes. They rank among the world's greatest long-distance migrants, with species that seasonally traverse from the high Arctic to South America, to those which actually spill over into both Asia and the Old World (Pitelka, 1979). Within the Gulf of Mexico, shorebirds comprise five taxonomic families--Jacanidae (jacanas), Haematopodidae (Oystercatchers), Recurvirostridae (stilts and avocets), Charadriidae (plovers), and Scolopacidae (sandpipers, snipes, and allies) (Hayman et al., 1986). Few of the species nest in the Gulf area. The remaining numbers of species are either only wintering residents and/or "staging" transients. Many coastal habitats along the Gulf of Mexico are critical for the survival of these birds, providing essential wintering grounds and staging areas where migrating shorebirds ready themselves physiologically (increasing body mass up to 100%) for migrational leaps and possibly to gain energy reserves for reproduction (Terborgh, 1989, Pitelka, 1979; Helmers and Castro, 1991). Suitability of habitat is coupled with the fact that shorebirds exhibit a high degree of site-fidelity, returning to their wintering and/or nesting sites year after year (Hayman, et al., 1986). Along the central Gulf Coast, 44 species of shorebirds have been recorded; though only 6 nest in the area (Pashley, 1991).

Wading birds are conspicuous coastal and inshore species belonging to the taxonomic order Giconiiformes, which contains the families Ardeidae (herons and egrets), Ciconiidae (storks), and Threskiornithidae (ibises and spoonbills) (Parkes, 1978). As a group they exhibit diverse foraging adaptations and strategies, and they are well distributed throughout the warmer regions of the globe. Most species nest in discrete colonies and many are virtually solitary outside of the nesting season (Mock, 1978). Seventeen species are currently known to nest in the U.S., with all but the wood stork nesting within the northern Guff coastal region (Martin, 1991). Within the central Gulf Coast region, approximately 160 wader colonies were determined active during the 1990-1991 nesting seasons, with 110,000 of the 113,500 total nesting pairs in the region. Great egrets were the most widespread nesting species in the central region (Martin, 1991). Within the western Gulf Coast region, little blue herons, snowy egrets, and tricolored herons constituted the greatest number of coastal nesting pairs (Texas Parks and Wildlife Department, 1987, 1988, 1989, and 1990).

Marsh birds are omnivorous coastal and inshore species belonging to the taxonomic order Gruiforrmes, containing the families Gruidae (cranes) and Rallidae (rails, moorhens, gallinules, and coots). Cranes are long-legged and long-necked birds that resemble large herons. The two North American species are the whooping crane (refer to description under endangered species) and sandhill crane. They inhabit prairies, fields, and marshes. Members of the Rallidae family are compact birds of cryptical habits. Gallinules, moorhens, and coots swim and are commonly found within ponds, lakes, marshes, and bays. True rails are highly elusive and rarely seen within the low vegetation of fresh and salt marshes, swamps, and ricefields (Bent, 1926a; National Geographic Society, 1983; Ripley and Beehler, 1985).

Waterfowl belong to the taxonomic order Anseriformes and include swans, geese, and ducks and their allies. A total of 36 species are regularly reported along the north-central and western Gulf coast, consisting of 1 swan, 5 geese, 11 surface feeding (dabbling) ducks and teal, 5 diving ducks (pochards), and 14 others (including the wood duck, whistling ducks, sea ducks, the ruddy duck, and mergansers) (Clapp et al., 1982; National Geographic Society, 1983; Madge and Bum, 1988). A diverse array of adaptations associated with foraging and food getting between species is in parallel with the complement of habitats utilized (Johnsgard, 1975). Many species annually migrate from wintering grounds along the Gulf Coast to summer nesting grounds to the north. These summer nesting grounds vary among species, ranging from low tundra in the Arctic to the broad belt across the northern plains of the U.S., which is known as the prairie pothole region (Terborgh, 1989). Waterfowl migration pathways have traditionally been divided into four parallel north-south paths, or "flyways", across the North American continent. These flyways actually consist of a complex series of crisscrossing routes of individual species (Lincoln, 1979). The Guff of Mexico coast serves as the southern terminus of both Central (Texas) and Mississippi (Louisiana, Mississippi, and Alabama) flyways. Many waterfowl species are to be found either offshore and on large embayments during winter months, or while passing through during spring and autumn migrations. Other species prefer inshore areas, primarily the coastal marshes (Clapp et al., 1982). Except for certain pochards such as redheads, most wintering waterfowl along the Gulf Coast are neither static nor confined to any specific area on the coast. Ongoing modification of wetland habitats throughout the coastal region is thought to be partly responsible for declines in the populations of wintering waterfowl (Wolington, 1988).

Endangered and Threatened Species

Following coastal and marine bird species, which inhabit or frequent the north-central and western Gulf of Mexico coastal areas, are recognized by the FWS as either endangered or threatened; piping plover; whooping crane; Eskimo curlew; bald eagle; peregrine falcon; eastern brown pelican; and interior least tern.

The piping plover *(Charadrius melodus) is* a distinctive ringed plover of central and eastern North America and is currently declining in numbers. It nests on sandy beaches along coasts or inland lakeshores, preferring areas with scant vegetation and cover. Uncontrolled hunting in the early 1900's brought the species close to extinction, and today expending recreational use of its specific nesting and wintering habitat requirements have brought about the present decline in population numbers (Hayman et al., 1986; Collar and Andrew, 1988). Nesting areas include the Central and North Atlantic seaboard of the U.S., Atlantic Canada, the Great Lakes area, and a large swath of the Northern Great Plains (Goosen, 1990). Although piping plovers spend most of their annual cycle associated with wintering areas, information on the wintering ecology of this species is sparse. It has been hypothesized that specific wintering habitat, which includes coastal sandflats and mudflats in close proximity to large inlets or passes, may attract the largest concentrations of piping plovers because of a preferred prey base and/or because the substrate coloration provides protection from aerial predators due to chromatic matching, or camouflage (Nicholls and Baldassarre, 1990). In Louisiana, barrier islands appear to provide the most favorable habitat for this species. Unfortunately, some of these sites are experiencing dramatic rates of land : loss via erosion (Martin, written communication, 1992). The piping plover was

Placed on the endangered specie's list on January 10, 1986, as a result of the marked decline in total numbers.

The whooping crane *(Grus americana)* is the tallest bird in North America. It formerly ranged from summer breeding grounds within the central Canadian provinces and northern prairie states to southern coastal wintering grounds form central Mexico to the Carolinas (Bent, 1926a). It is believed that depletion and modification of summer and winter habitats led to the decline in the population (USDOI, FWS, 1980; Collar and Andrew, 1988). Wild whooping cranes presently occur in two migratory populations. The first nests in northeastern Alberta and south-central Northwest Territories, Canada, and migrates in a nearly straight-line path to wintering grounds along the Texas coast on salt flats and islands in and around Arkansas National Wildlife Refuge (ANWR). - The second population was established in southeastern Idaho using greater sandhill cranes (Grus *canadensis* tabida) as foster parents for eggs taken from the Canada-Texas population (Armbruster, 1990). Results from the 1991 winter census indicated only 132 whooping cranes, including 8 juveniles, in the peak ANWR population. This represents a drop in the previous year's census of 146 birds (USDOI, FWS, 1992). Cranes are omnivorous and feed during the winter months on a wide variety *off* foods gathered from the coastal environment (USDOI, FWS, 1980). Human contact with cranes on ANWR largely involves vessel traffic along public waterways (Mabie et al., 1989).

The eskimo curlew *(Numenius-borealis)* is a small American curlew that nests on Arctic tundra and migrates to wintering habitat in the pampas grasslands of southern South America.. On migration, it formerly occurred in large flocks on the prairies and on coastal grasslands. It was greatly reduced by hunting pressure between 1850 and 1890, and perhaps also by habitat alteration. By 1929 it was thought to be extinct, but has occasionally been seen in very small numbers (Hayman et al., 1986; Gollop et al., 1986). The last confirmed sightings of the eskimo curlew were in Texas during 1981, Alaska in 1983, and Canada (Northwest Territories) in 1985 (Collar and Andrew, 1988). Census efforts are underway to ascertain whether the species is extinct (Ambrose, personal communication, 1992). Because of the uncertainty of the existence of the eskimo curlew, it has been omitted from the analyses of this EIS.

The bald eagle is the only species of sea eagle regularly occurring on the North American continent (Murphy, 1984). There are two subspecies of bald eagles: the smaller, southern race, *Haliaeetus leucocephalus leucocephalus,* and the northern race, H.I. *alascanus.* The two subspecies are separated by an arbitrary geographic line across the southern U.S., although migration and interbreeding creates uncertainty in racial distinction within some areas (Stalmaster, 1987). The bulk of the bald eagle's diet is fish, combined with opportunistic capture of a variety of vertebrate species. The bald eagle requires a large area for hunting and is sensitive to chemical contaminants in the food chain (Murphy, 1984). A precipitous decline in the population occurred subsequent to widespread application of the organochloride insecticide dichloro diphenyl trichloroethane (DDT) from the 1940's through 1972; the bald eagle was listed as endangered in 1967. Other factors that contributed to the species; decline included habitat loss and alteration, shooting, poisoning, and electrocution (Federal Register, 1990). The historical nesting range of the bald eagle within the Southeast U.S. included the entire coastal plain and along major rivers and lakes.

The peregrine falcon of North America has been separated into three subspecies: the arctic peregrine (Falco *peregrinus tundrius),* American peregrine (F. p. *anatum),* and Peale's peregrine (F.p. *peali.* The Arctic peregrine nests in tundra areas of North America and Greenland, and migrates south to the Guff Coast, West Indies, and Central and South America (USDOI, FWS, 1980). Coastal areas along the Gulf Coast are well known as foci for migrant peregrines, where beaches, flats, and wetlands are used for hunting and resting (Enderson, 1969). Peregrines feed almost exclusively on various bird species, and, similar to the brown pelican and bald eagle, experienced drastic declines as a result of the effects of DDT and its metabolite, dichloro diphenyl dichloroethane (DDE) (Federal Register, 1983). Recent surveys indicate that many local and regional populations of peregrines are reproducing well and are either stable or increasing (Nisbet, 1988; Maechtle, 1992).

The eastern brown pelican *(Pelicanus occidentalis carolinensis)* is one of two species of pelicans in North America. It is a colonial nesting species that feeds entirely upon fishes captured by plunge diving in coastal waters. It rarely ventures beyond 20 mi from the coast (Bent, 1926b). A severe reduction in the population during the late 1950's has been attributed to the toxic effects of the organochlorine pesticides (DDT and DDE). Subsequent to the 1972 U.S. ban on the use of DDT, there has been a marked increase in populations of the brown pelican along its entire former range. It remains classified as endangered within the states of Texas, Louisiana, and Mississippi (Federal Register, 1985). Surveys conducted from 1990 to 1992 showed one large nesting colony in Alabama (containing approximately 2,000 individuals), no colonies in Mississippi, six colonies in Louisiana (2,196 individuals), and three colonies in Texas (1,238 individuals) (Clay, personal communication, 1992; Eakes, personal communication, 1992; Martin and Lester, 1991; Texas Parks and Wildlife Department, 1990). Results from the Annual Christmas Bird Count for 1990 showed quantities of individual brown pelican sightings on the coasts of Alabama (925), Louisiana (212), and Texas (553), but only 23 sightings in Mississippi (National Audubon Society, 1991).

The least tern (Sterna *antillarum) is* the smallest North American tem. Populations occurring within the Mississippi basin have been eliminated as a result of destruction and alteration of nesting habitat along the Mississippi River and its tributaries. In Alabama, the least tem nests sporadically along the coast in colonies of less than 25 individuals (Clay, personal communication, 1992). Surveys from 1990 to 1992 showed 10 tern colonies in Mississippi, 14 colonies in Louisiana (with 4,460 breeding pairs). and 35 colonies in Texas (with 3,028 breeding pairs). Least terns are the only nesting tern species in Louisiana to use mainland beaches, and they will use human-made and managed spoil sites as well. Banded coastal individuals have been reported at inland nesting sites, which might suggest a source of recruitment from the coastal population (Pashley, 1991)."

4. Planktonic Fish And Macro-Invertebrate Eggs And Larvae

Experience with major oil spills worldwide indicates that adult, free-swimming fish are rarely at risk from spilled oil (Anon, 1991). Large numbers of fish eggs and larvae as well as the eggs and larvae of shrimp, crabs and oysters have been killed by spilled oil. Fish over produce eggs on an enormous scale and the overwhelming majority die at an early age, mostly as food for predators. In both the Torry Canyon and the Argo Merchant spills, a 90% mortality of fish eggs and larvae was observed in the-affected areas but apparently had no impact on the regional commercial fishery (Baker et al., 1991).

It is difficult to characterize the distribution of icthyoplankton and the planktonic forms of commercially important macro-invertebrates. As plankton they are at the mercy of currents, winds, and other forces that make their distribution patchy and unpredictable.

There is evidence that nearshore icthyoplankton can be concentrated in frontal waters (a mixture of Mississippi plume water and northern Gulf of Mexico shelf water) off the mouth of the Mississippi River. Individual plankton net catches in frontal water were ten times greater than in adjacent plume or shelf water (Grimes and Finucane - Draft). Loop currents or other factors may create covergence areas similar to frontal waters where icthyoplankton could be concentrated.

In a recent Draft Environmental Impact Statement prepared by the U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region (Gulf of Mexico Sales 147 and 150: Central and Western Planning Areas - Draft Environmental Impact Statement - Volume 1: Sections I through IV.C. - OCS EIS/EA, MMS93-0012) is an excellent discussion on fisheries resources is presented and is reproduced in its entirety as follows:

Nonendangered and Nonthreatened Species

"The Gulf of Mexico supports a great diversity of fish resources that are related to variable ecological factors, such as salinity, primary productivity, bottom type, etc. These factors differ widely across the Gulf of Mexico and between the inshore and offshore waters. Characteristic fish resources are associated with the various environments and are not randomly distributed.

High densities of fish resources are associated with particular habitat types (e.g., east Mississippi Delta area, Florida Beg End seagrass beds, Florida Middle Ground, mid-outer shelf, and the DeSoto Canyon area). Approximately 46 percent of the southeastern United States wetlands and estuaries important to fish resources are located within the Gulf of Mexico (Mager and Ruebsamen, 1988). Consequently, both finfish and shellfish resources that are estuary-dependent species dominate the fisheries.

The life history of estuary-dependent species involves spawning on the continental shelf; transporting eggs, larvae, or juveniles to the estuarine nursery grounds; growing and maturing in the estuary; and migrating of the young adults back to the shelf for spawning. After spawning, the-adult individuals generally remain on the continental shelf. Movement of adult estuary-dependent species is essentially onshore-offshore with no extensive east-west or west-east migration.

Estuary-related species of importance include menhaden, shrimp, oysters, crabs, and sciaenids. Estuary communities are found from east Texas through Louisiana, Mississippi, Alabama, and northwestern Florida. Darnell et al. (1983) and Darnell and Kleypas (1987) found that the density distribution of fish resources in the Gulf was highest nearshore off the central coast. For all seasons the greatest abundance occurred between Galveston Bay and the Mississippi River. The abundance of fish resources in the far western and eastern Gulf of Mexico is patchy. The high salinity bays of-the Western Gulf contain no distinctive species, only a greatly reduced component of the general estuary community found in lower salinities (Darnell et al., 1983). High salinity bays and sounds in the Eastern Gulf contain species amenable to shell, coral sand, and coral sift bottoms. These include pink shrimp, rock shrimp, and stone crab (Darnell and Kleypas, 1987).

Estuaries of the Gulf of Mexico export considerable quantities of organic material, thereby enriching the adjacent continental shelf areas (Darnell and Soniat, 1979). Populations from the inshore shelf zone (7-14 m) are dominated seasonally by Atlantic croaker, spot, drum, silver seatrout, southern kingfish, and Atlantic threadfin. Populations from the middle shelf zone (27-46 m) include sciaenids, but are dominated by longspine porgies. The blackfin searobin, Mexican searobin, and shoal flounder are dominant on the outer shelf zone (64-110 m).

Natural reefs and banks, located mainly between the middle and outer shelf zones support large numbers of grouper, snapper, gag, scamp, and seabass. Reef fish occur on the continental shelf wherever hard/live bottoms with rocks, holes, or crevices are available (USDOC, NOAH, 1986). In the Western and Central Gulf, natural reefs are scattered along the 200-m isobath. Numerous offshore petroleum platforms, believed to act as artificial reefs, augment the hard substrate of natural reefs in this area (Linton, 1988). In the Eastern Gulf, prominent reef complexes such as the Florida Middle Ground provide reef fish habitat (USDOC, NOAH, 1986).

Hard substrates with some vertical relief act as important landmarks for pelagic species. Coastal pelagics such as mackerels, cobia, bluefish, amberjack, and dolphin move seasonally within the Gulf of Mexico. In spring, king and Spanish mackerels leave their wintering grounds in the southeastern Guff and move northward along the continental shelf to their spawning and summering areas in the northwestern Gulf (USDOC, NOAH, 1986). Their nursery area is probably the shallow portion of the. shelf at high nutrient areas near river plumes (Grimes, 1988).

Oceanic species such as yellowfin and bluefin tuna are mainly found beyond the continental shelf during winter and spring, but after spawning they move through.

the Florida Straits into the Atlantic Ocean. Billfishes (black marlin, white marlin, sailfish, and swordfish) spawn in the northeastern Gulf, mostly in areas beyond the continental shelf (State of Florida Marine Fisheries, written communications, 1988).

Competition between large numbers of fishermen, between fishing operations employing different methods, and between commercial and recreational fishermen for a given resource, as well as natural phenomena such as weather, hypoxia, and red tides, may reduce standing populations. Fishing techniques such as trawling , gill netting, or purse seining, when practiced nonselectively, may reduce the standing stocks of the desired target species as well as substantially affect fish resources other than the target. Finally, hurricanes may affect fish resources by destroying oyster reefs, damaging gear and shore facilities, and changing physical characteristics of inshore and offshore ecosystems (Horst, 1992a).

Recruitment is by far the most important, yet the least understood, factor contributing to the ups and downs in the numbers of harvestable Gulf fish (Sports Fishing Institute, 1992).

The degradation of inshore water quality and loss of Gulf wetlands as nursery areas are considered significant threats to fish resources in the Gulf of Mexico (Christmas et al., 1988; Horst, 1992a). Loss of wetland nursery areas in the north central Gulf is believed to be the result of channelization, river control, and subsidence of wetlands (Turner and Cahoon, 1987). Loss of wetland nursery areas in the far Western and Eastern Gulf is believed to be the result of urbanization and poor water management practices (Texas Parks and Wildlife Department, written communication, 1989; USEPA, 1989).

Many of the commercially important fish species in the Gulf of Mexico are believed to be in decline due to overfishing (USDOC, NMFS, 1992a). Continued fishing at the present levels are likely to result in eventual failure of certain fisheries. Standing stocks of traditional fisheries, such as shrimp and red snapper, and of recent fisheries, such as black drum, shark, and tuna, have declined and are thought to be in danger of collapse (Angelovic, written communication, 1989;Goodyear and Phares, 1990; USDOC, NOAA, 1986).

5. Finfish

Finfish resources are linked both directly and indirectly to the vast estuaries that ring the Gulf of Mexico. Finfish are directly dependent when the population relies on low salinity brackish wetlands for most of their life history, such as during the maturation and development of larvae and juveniles. Even the offshore demersal species are indirectly related to the estuaries because they influence the productivity and food availability on the continental shelf (Darnell and Soniat, 1979; Darnell, 1988).

Gulf menhaden spawn near the water surface in a localized area of the middle continental shelf proximate to the Mississippi River Delta from fall to spring (mid-October through March). Planktonic larvae are transported via currents to estuary nursery areas. Larvae enter estuaries when 3-5 weeks old. After the larvae grow and transform into juveniles in the shallow portions of the estuary, they move to open and deeper estuarine waters. Juvenile and adult Gulf menhaden inhabit estuaries throughout the year (Christmas et al., 1982). Some first-year juveniles may overwinter in estuaries. However, most Gulf menhaden move form estuaries into offshore marine waters in late fall and winter. There is evidence that older fish move toward the Mississippi River Delta (Shaw et al.,1985; Vaughen et al., 1988). Sexual maturation is completed after two growing seasons. Immature and spent adult menhaden migrate to estuarine waters from spring to fall (April-to October). Mature menhaden are sexually inactive in the estuary, but gonads mature for spawning in marine waters (Christmas and Waller, 1975).

Schooling is apparently an inborn behavioral characteristic beginning at the late larval stage and continuing throughout the remainder of life. Their occurrence in dense schools, generally by species of fairly uniform size, is an outstanding characteristic that facilitates mass production methods of harvesting menhaden. The seasonal appearance of large schools of menhaden in the inshore Gulf waters from April to November dictates the menhaden fishery (Nelson and Ahrenholz, 1986).

Larval menhaden feed on pelagic zooplankton in marine and estuarine waters. Within the estuary, the mouthparts of the larvae transform, and juvenile and adult Gulf menhaden become filter-feeding omnivores that primarily consume phytoplankton, but also ingest zooplankton, detritus, and bacteria. As filter-feeders, menhaden form a basal link in estuarine and marine food webs and, in turn, are prey for many species of larger fish (Vaughan et al., 1988).

Members of the Sciaenidae family such as croaker, red and black drum, and - . spotted seatrout have similar life histories. Throughout the Gulf, sciaenids have a protracted spawning season over the spring and summer or fall and winter. The inception of spawning is variable and dependent on raising or falling water temperatures. There is no consensus on the preferred spawning habitat. Large schools of spawning red drum congregate around major passes in relatively shallow water during late summer and fall. Croaker prefer deeper, high salinity waters for spawning. Planktonic larvae develop in nearshore areas and with the help of prevailing currents actively seek protected areas of estuaries and inshore bays with slightly middy bottoms. Sciaenids move to deeper waters of bays during their first year. After the first year there is gradual movement of sciaenids into the Gulf during cold weather and a pronounced movement back into bays and estuaries in early spring. When mature, older fish move offshore to assemble and spawn. Sexual maturation in seatrout occurs after 5 years and continues until 5 or 6 years of age. Sexual maturation in croaker occurs after 5 years and continue for up to 15 years. Sciaenids are opportunistic carnivores whose food habits change with size. Larval sciaenids feed selectively on pelagic zooplankton, especially copepods. Juveniles feed upon invertebrates, changing to a more piscivorous diet as they mature (Perret et al., 1980; Sutter and McIllwain, 1987; USDOC, NOAH, 1986).

About 10 percent of finfish in the Gulf of Mexico are not directly dependent on estuaries during their life history. 'This group can be divided into demersal and pelagic species. Demersal species are associated with live bottoms, reef complexes, hard-bottom banks, and patch reefs. Pelagic species are associated with high-salinity open water beyond the direct influence of coastal systems.

Snappers are nonestuary-dependentdemersal fish associated with natural reefs, hard bottom, and artificial reefs of the mid-outer continental shelf. Called reef fish, snappers remain close to underwater structures and exhibit little or no movement. Snappers spawn offshore in groups over unobstructed bottoms adjacent to reef areas. Juvenile snapper form loose aggregates, while adults form schools during the day and disperse at night. Snappers do not migrate or travel away from their reef environment and the surrounding areas. There is a tendency for larger, older snappers to occur in deeper water than juveniles. Seasonal spawning patterns vary among snapper species, but generally, once they attain sexual maturity, they have a protracted spawning period with seasonal peaks. There is a decline in spawning activity among snappers during the winter. Juveniles inhabit shallow nearshore and estuarine waters and are most abundant over sand or mud bottoms. Snappers feed along the bottom on fishes and benthic organisms such as tunicates, crustaceans, and mollusks. Juveniles feed on zooplankton, small fish, crustaceans, and mollusks (Bortone and Williams, 1986; USDOC, NOAH, 1986).

Coastal pelagics are open-water fish widely distributed throughout the Gulf of Mexico. Pelagic species such as king and Spanish mackerel move seasonally in response to water temperature-and oceanographic conditions. Mackerels are found from the shore to a 200-m depths. Spanish mackerel frequent the coastal areas while king mackerel stay farther offshore. King mackerel move from the eastern to the north-central and western Gulf in the spring. During cooler fall seasons, they move back into the warmer waters of the southeastern Gulf. R contingent of large solitary adult king mackerel can be found in a localized area of the north-central Gulf during part of the winter. Spanish mackerel spread over the northern Gulf during the summer and are mainly during the spring and summer. Spawning may occur more than once per season. Juvenile mackerel utilize nearshore areas of high salinity as nurseries. Mackerel feed throughout the water column on other fishes, especially herrings, and on shrimp and squid. Mainly a schooling fish, larger king mackerel occur in small groups or singly (Godcharles and Murphy, 1986; USDOC, NOAA, 1986).

6. Shellfish

To a greater degree, estuaries determine the shellfish resources of the Gulf of Mexico. Life history strategies are influenced by tides, lunar cycles, maturation state, and estuarine temperature changes. Very few individuals live more than a year, and the majority are less than six months old when they enter the extensive inshore and nearshore fishery. Year-to-year variations in shellfish populations are. frequently as high as 100 percent and are most often a result of extremes in salinity and temperature during the period of larval development. Shellfish resources in the Gulf range from those located only in brackish wetlands to those found mainly , in saltmarsh and inshore coastal areas. Life history strategies reflect estuary relationships, ranging from total dependence on primary productivity to opportunistic dependence on benthic organisms. Gulf shellfish resources are an important link in the estuary food chain between benthic and pelagic organisms (Darnell et al., 1983; Darnell and Kleypas, 1985; Turner and Brody, 1983).

Up to 15 species of penaeid shrimp can be expected to utilize the coastal and estuarine areas in the Guff of Mexico. Brown, white, and pink shrimp are the most numerous. Pink shrimp have an almost continuous distribution throughout the Gulf but are most numerous on the shell, coral sand, and coral silt bottoms off southern Florida. Brown and white shrimp spawn offshore in high salinity waters; the fertilized eggs become free-swimming larvae. After several molts they enter estuarine waters as postlarvae. Wetlands within the estuary offer both a concentrated food source and a refuge from predators. After growing into juveniles the shrimp larvae leave the saltmarsh to move offshore where they become adults. The timing of immigration and emigration, spatial use of a food-rich habitat, and physiological and evolutionary adaptations to tides, temperature, and salinity differ between the two species (Muncy, 1984; Turner and Brody, 1983; USDOC, NOAA, 1986).

Brown shrimp spawn in shallow offshore marine water in spring and early summer. Postlarval brown shrimp move into estuaries from January through June with peaks in early spring. Four to six weeks after entering the estuarine nurseries, brown shrimp postlarvae transform into juveniles. Juveniles remain in shallow estuarine areas near the marsh-water interface, which provides both feeding habitat and protection from predators. With maturation they move into deeper saltmarsh bays and finally to the outer continental shelf (Turner and Brody, 1983).

White shrimp spawn in shallow nearshore waters from spring to fall. Spawning activity is probably correlated with a rapid change in bottom temperature. Recruitment of postlarval white shrimp occurs from early summer to fall. Some young white shrimp move from estuaries to nearshore marine waters during late fall to overwinter and move back to estuaries in early spring when the water temperatures rise. In nursery grounds, juvenile white shrimp move further up waters courses than brown shrimp. White shrimp leave Gulf embayments as waters cool from fall through early winter (Muncy, 1984).

Active feeding stages of both brown and white shrimp are omnivorous. Larvae feed in the water column on both phyto- and zooplankton. After moving into estuarine nursery areas, postlarvae become demersal and feed at the vegetation-water interface. Developing larvae ingest the top layer of sediment, which contains primarily marsh plant detritus, algae, and microorganisms. When shrimp move to deeper embayments they become more predaceous (USDOC, NOAH, 1986).

About eight species of portunid (swimming) crabs utilize the coastal and estuarine areas in the Gulf of Mexico. There is only one species, however, that is located throughout the Gulf and comprises a substantial fishery. Blue crabs *(Callinectes* sapidus) occur on a variety of bottom types in fresh, estuarine and shallow offshore -waters. Spawning grounds are areas of high salinity such as saltmarshes and nearshore waters. Spawning occurs from March to November in the northern Gulf and year-round in the warmer waters of the southern Gulf. Larval blue crabs occur throughout the water column. Movement during the larval stages is governed by tidal action and coastal currents. Female blue crabs move into areas of lower salinity to mate, then to higher salinities to spawn. Mature crabs usually remain in the same estuary until, after mating, males move into lower salinities as females head for the Gulf. During cold periods, blue crabs move into deeper water or burrow into the mud. A benthic omnivore with a high degree of variability in food habits, the blue crab feeds on annelids, mollusks, crustaceans, and other benthic invertebrates, fishes, carrion, and some detritus (Steele and Perry, 1990).

Vast intertidal reefs constructed by sedentary oysters are prominent biologically and physically in estuaries of the Gulf of Mexico. Finfishes, crabs, and shrimp are among the animals using the intertidal reefs while they are submerged for refuge and also as a source of food, foraging on the many reef-dwelling species. Reefs, as they become established, modify tidal currents and this, in turn, affects sedimentary patterns. Further, the reefs contribute to the stability of bordering marsh (Kilgen and Dugas, 1989).

Oysters spawn from late spring through summer and fall in the Gulf of Mexico. A rapid change in water temperature triggers mass spawning over localized areas of reefs. Oysters may spawn several times during a season. Oyster larvae are transported throughout estuarine systems by tidal action. After several weeks, free-swimming larvae attach in clusters to shell reefs, firm mud/shell bottoms, and other hard substrates. Oysters filter-feed principally on small unicellular algae and incidentally on suspended detrital particles (Burrell, 1986)."

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IV. SUMMARY - ADVANTAGES & DISADVANTAGES OF BURNING

Tables IV-1 and IV-2 present a summary of the primary advantages and disadvantages of in situ burning. For many offshore oil spill scenarios the advantages of controlled burning appear to outweigh the. disadvantages. Burning offers a logistically simple and highly efficient means of eliminating large quantities of oil quickly and economically. In situ burns can be conducted on oil within a fire containment boom on oil that is wind or current herded against other barriers such as ice or shorelines, or on large uncontained layers of oil that are still thick enough to support combustion. The versatility of burning, together with its potential for operations at night or during periods of reduced visibility, provides spill response personnel with a control technique that has a broad range of applicability with minimal backup support. A major advantage is the lack of dependence on skimming, transfer, and storage equipment for recovered oil and water. During a major spill, burning can proceed as efforts are made to secure additional equipment for the recovery of what little floating residue remains on the surface.

Personnel can conduct in-situ burning safely because burning requires simple and easily taught concepts involving the towing of boom, as well as the ignition of oil while all personnel and equipment are kept at a safe distance from the fire. Burns can be conducted when and where other techniques are less effective (or unavailable), or they can be used simultaneously with other techniques by confining each type of response to a properly designated segment of the spill or geographic region.

In situ burning is limited by the same wind and sea constraints as most conventional containment systems, it is dependent on a proper oil thickness, and the oil must not be heavily emulsified. As a result, burning often has a window of opportunity involving only a few hours to a day or two of oil exposure, and seas where the short period wind waves are around three feet (about a meter) or less in height. The use of in-situ burning must also include a continuous monitoring of the proximity of the burn to all facilities and population centers toward which the controlled burn or its smoke plume could move. Planners and responders should consider these constraints carefully so that specific guidelines and procedures are established in advance for the timely use of in-situ burning techniques.

What often appears to be the most significant adverse impact of burning is the black smoke released to the atmosphere. These emissions (both particulates and gaseous), however; would represent insignificant contributions to the atmosphere even if a major bum were conducted every day. Compared to the ongoing emissions from wild-fires and slash burns alone, the products of combustion from an in-situ burn would be many orders of magnitude less. The issue really comes down to a balance of priorities among the people of a given region of potential oil spill impact. Issues need to be examined before a spill event on whether a community prefers a short-term, minor impact to the air or a relatively long-term, potentially major impact to the shoreline. Burning, along with mechanical recovery and chemical dispersants, must be planned for in advance so that the best mix of personnel and equipment can be activated without delay during the critical first few hours of a major spill event.

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