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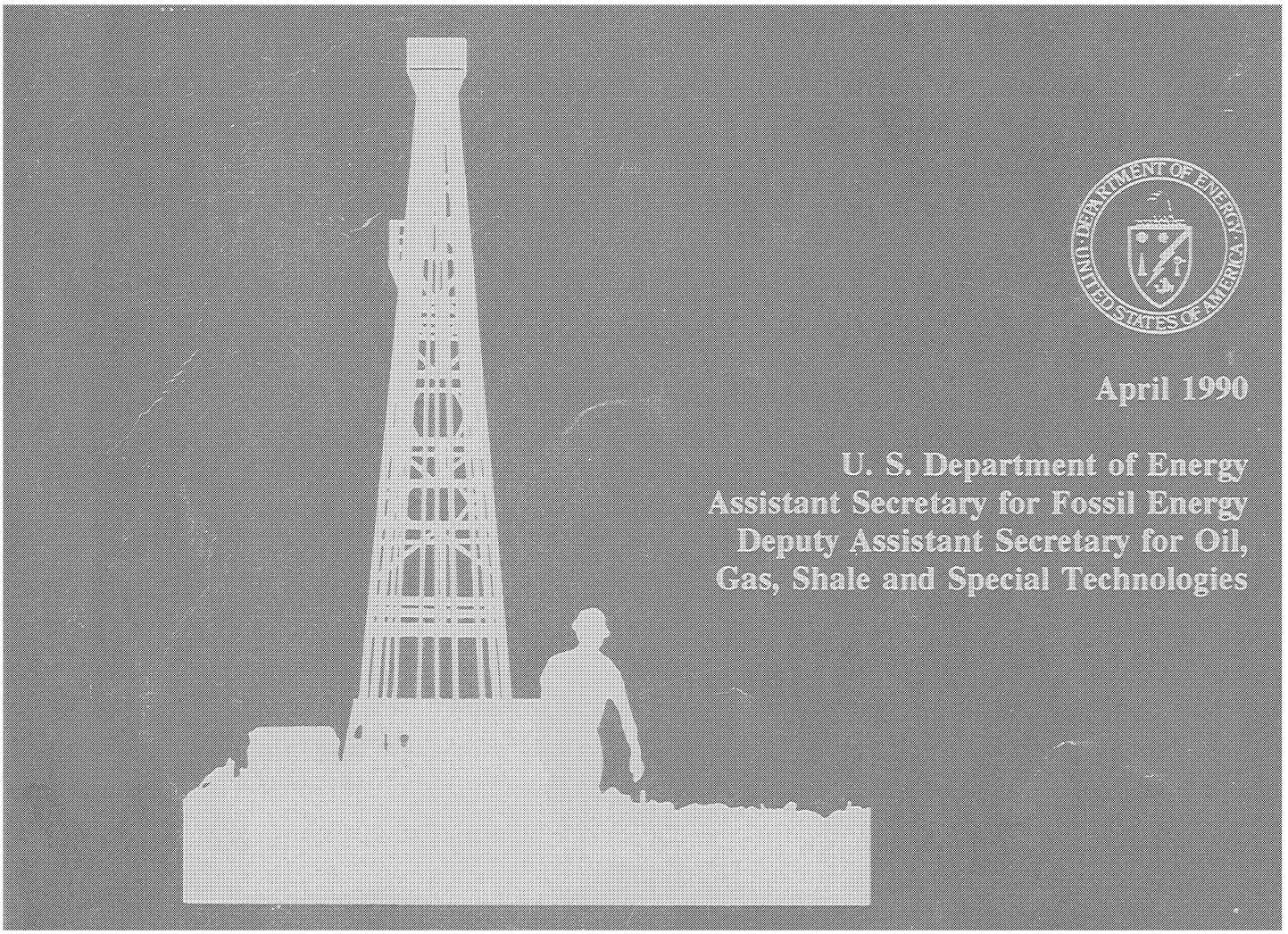
OIL RESEARCH PROGRAM
IMPLEMENTATION PLAN



April 1990

U. S. Department of Energy
Assistant Secretary for Fossil Energy
Deputy Assistant Secretary for Oil,
Gas, Shale and Special Technologies

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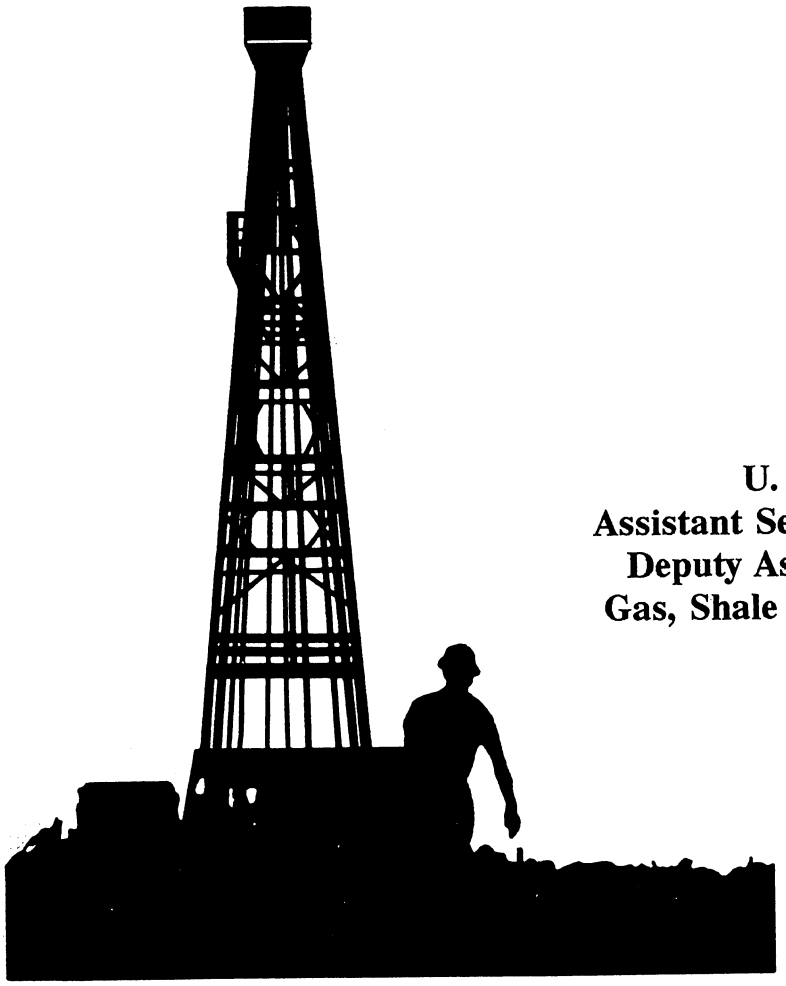

April 1990

U. S. Department of Energy
Assistant Secretary for Fossil Energy
Deputy Assistant Secretary for Oil, Gas, Shale and Special Technologies

Washington, D.C. 20545

PREFACE

The program described in the Oil Research Program Implementation Plan is a self-contained core research program whose goal is to maximize the economic producibility of the domestic oil resource. This plan was developed in support of the Hydrocarbon Geoscience Research Strategy, and in parallel with the Natural Gas Program Implementation Plan.

There are several areas in which the oil plan and the gas plan are mutually supportive: the intensive reservoir data base orientation of the oil plan has been adopted in the gas plan; both plans contain supporting environmental research; much of the research on horizontal drilling sponsored in the gas program should be of interest to the oil program.

This plan has been extensively reviewed. A draft was released to the public in December 1989, and was the subject of a public meeting in Washington in January 1990. Follow up comments from the public were useful in revising the draft.

Because the oil plan was developed before the completion of the National Energy Strategy (NES), it may have to be modified to mesh with other NES related Fossil Energy initiatives. We would expect, however, that this implementation plan would become a key part of the Fossil Energy research program developed under the NES and would be subject to revisions in the ongoing NES process.

The funding options were developed in response to Congressional direction contained in the Conference Report on Act (Public Law 101-121), the FY 1990 Department of the Interior and Related Agencies Appropriations. The options present alternative implementation schedules for the plan, and cover funding for this core research program only. The program described in this plan addresses the objective of improving the economic producibility of the Nation's remaining oil resource. The complete oil program may also address other objectives, including those developed in the National Energy Strategy.

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OIL RESEARCH PROGRAM
IMPLEMENTATION PLAN
APRIL 1990

SUMMARY

The United States has produced more oil than any other nation in history but, unless new technologies are rapidly developed and installed, the *U.S. will leave behind twice as much oil in known reservoirs as it has ever produced from them.* Of this massive, 340-billion-barrel resource, as much as 76 billion barrels could be made economically producible using technologies that could be developed within the next decade. Economic recovery of this oil presupposes use of existing wells, but the accelerating rate of well plugging could eliminate economic access to as much as two-thirds of the remaining oil by 1995.

Realizing this significant but time-sensitive potential, especially in light of escalating oil imports, is the subject of this Implementation Plan. The new Oil Research Program, based on current policies and recent assessments of the oil industry and national research needs, builds upon the predecessor program but envisions a more comprehensive and timely approach. Its goal is to *maximize the economic producibility of the domestic oil resource.* The program will implement a highly targeted research, development, and demonstration (RD&D) plan in collaboration with the states, industry, and the academic community, focusing on the reduction of technical and economic constraints on producibility to realize the enormous potential of the resource remaining in known domestic reservoirs. Three time-specific, strategic objectives address this goal and the constraints on attaining it:

- *In the near term (within five years), preserve access to reservoirs with high potential which are rapidly approaching their economic limits.* This objective poses three requirements: (1) identification and selection, on a national basis, of the highest priority classes of reservoirs, i.e., those with greatest ultimate potential for recovery and greatest urgency due to well and field abandonments; (2) identification of *currently available, economic* technologies that have proven effective in extending well life and mediation toward their broader application to sustain production where possible in cooperation with the states and industry; and (3) development of a sound, credible environmental program that addresses oil field operational problems in such areas as waste disposal, injection practices, air quality, and other issues that may affect future productivity. The environmental program will also include an evaluation of the potential of environmentally sound, economically reversible well plugging techniques for situations where current recovery technology is not feasible but where the well may be an important access point for future production.

- *In the mid term (within ten years), develop, test, and transfer the best, currently defined, advanced technologies* to operators of the reservoirs with the greatest potential for incremental recovery. This will require an integrated, interdisciplinary approach to field work, research, and technology transfer.

- *In the long term, develop sufficient fundamental understanding to define new recovery techniques* for the oil left after the most advanced, currently defined mid-term

processes, and for major classes of reservoirs for which no advanced technologies are anticipated to be available in the mid term. The program will continue to support universities in the performance of this research to sustain the Federal Government's ongoing commitment to education.

Pursuit of these strategic objectives entails a tightly integrated, focused RD&D approach that is guided by five basic tenets:

- *Be Selective.* A reservoir classification scheme based on geological history (depositional, diagenetic, tectonic) has been proposed and is under review for national application, to be used to focus RD&D efforts by identifying reservoir classes that have the greatest recovery potential, taking the most urgent first, based on the projected loss of economic access caused by well abandonments. RD&D will focus on the highest priority reservoir classes, which the plan will identify based on analysis of the entire U.S. resource. These classes collectively are estimated to represent 80 to 90% of the oil remaining in known U.S. reservoirs. DOE will work with industry and the states to identify the *specific* problems and opportunities associated with *each* high priority reservoir class, thus detailing the basis for RD&D planning.

- *Conduct Field RD&D on the Selected Classes.* An interdisciplinary, problem-solving approach to maximize the producibility of the respective reservoir classes will include: advanced description of reservoir heterogeneities, architecture and flow paths; reservoir simulation and process design; and testing and evaluation of advanced production technologies. Several sites in each high priority class will be used to support comparative analysis and extrapolation to other reservoirs of the same class. DOE will rely on industry to participate in the selection of reservoir sites for RD&D projects. Effective technology transfer of the results to operators across the full geographical area covered by each class is a major goal of this work. Where appropriate, the work would be performed by consortia of companies, industry organizations, state and federal organizations, universities, and consultants. This would provide immediate technology transfer to the participants, and establish a viable experience base for further transfer.

- *Support Field RD&D With Targeted and Discipline-Oriented R&D.* Technical constraints, identified in the course of the field work, will define requirements for technology support (supporting development and engineering) and for solution by more disciplinary research in the following areas: geoscientific methods of reservoir measurement, description, and modeling; advanced simulation and process performance prediction; techniques of oil production, including drilling methods and siting, and advanced secondary and tertiary recovery processes; and environmental research to identify, quantify, and mitigate the impacts of oil recovery operations, including the sound management of drilling and production wastes, improvements in the cost effectiveness of environmental protection in the oil field, and alternatives to cement plugging and abandonment of wells that provide access to significant future oil production.

- *Exploit the Available Interdependencies and Synergies.* These include the dependence of success in the mid term on successful preservation of reservoir access in the near term, the dependence of long-term R&D on findings in mid-term field work and supporting research, synergies available through solving technical constraints that are common to multiple reservoir classes, synergies attributable to integrated

application of multiple techniques to specific reservoirs, and interdependencies between program activities and distinct state initiatives such as regulatory reform.

- *Focus Technology Transfer Activities.* Effective technology transfer approaches, responsive to input from the states and industry, will be developed to target operators, service companies, consultants, state agencies, and others to achieve routine and widespread application of effective reservoir description and recovery technologies. Interaction with the targeted groups in the high priority reservoir classes, integral to the problem definition for each class, will begin immediately after the selection of the classes and will continue until the objectives for that class have been met.

While the objective, strategy, and management tactics of the program are described in some detail herein, this Implementation Plan is *not* complete. It is based on the best analysis that is now available and will be revised as new analysis directs. Certain aspects of the plan are recognized to be preliminary in nature, such as the work in heavy oil, where the basic analysis required to identify the urgent issues affecting this resource is just now being initiated. Only a portion (about 40%) of the known U.S. resource has undergone the detailed assessment, classification, and analysis which is required for program planning. Classification and analysis of the full U.S. oil resource is expected to be complete by October 1992. Because of the abandonment urgency, work may be proposed in at least some of the priority classes as soon as they are identified, but before all of the classification work has been completed. Finally, the field RD&D activities and supporting R&D projects are purposely non-specific in this plan, because they must be detailed in response to the problems that will be identified as work begins with the states and industry *on specific reservoir classes*. The FY 1991 budget requests funds to begin work on the first two high priority reservoir classes to be identified as a result of the current National reservoir classification effort. This Implementation Plan will be revised annually, and the currently underspecified elements will become substantially more explicit as the work takes shape.

Budgetary and benefit analyses suggest that this program can return its costs in benefits many times over. This Implementation Plan describes an integrated, focused RD&D program working within the requirements of the Federal budget cycle, that seeks to make *76 billion barrels of oil* in known reservoirs *economically producible*, using currently defined technologies that require R&D and transfer to industry. The program cost to address 80 to 90% of this target is an average of about $35 million per year, with annual requirements dependent upon how many reservoir classes are addressed simultaneously. A firm recommendation on this point will follow the problem definition phase of the work. Based on reasonable assumptions regarding program content and time to achieve project results, the basic effort is expected to cost around $600 million over a period of 15 years; this estimate will be revised as problem definition and research results are achieved. If successful, the RD&D cost of the incremental production is estimated to be less than a penny per barrel. In addition, production of this resource would create over 300,000 jobs and would improve the balance of payments, eliminating over $2 trillion that would otherwise be paid for oil imports. Even if the estimates of benefits prove to be high by an order of magnitude, this program remains highly cost-effective for the nation.

The presentation of the Implementation Plan is structured to provide a comprehensive overview in the first section, followed by four sections containing details on each major program component nd funding options. The overview is comprised of a separate section describing the Background to the development of the plan, an analysis section covering the Potential and Urgency of the Remaining Oil Resource, followed by sections addressing the Program Goal and Objectives, Program Strategy, the Program Logic dealing with the flow of activities, Tactics developed to implement the strategy and logic, and the Program Budget and Schedule.

OIL RESEARCH PROGRAM
IMPLEMENTATION PLAN
APRIL 1990

BACKGROUND

The United States has produced more oil than any other nation in history, but *twice as much oil as it has produced still remains unrecovered in its known reservoirs.* U.S. proved reserves and production have declined more or less steadily since 1970 while imports are once again rising dramatically. These apparent anomalies are attributable to the lack of predictable, cost-effective technologies to produce the remaining, known oil under present economic conditions.

Technological advances now offer significant opportunities to produce more oil from our nation's oil reservoirs, provided that the Oil Research Program, the producing states, and industry collaborate to implement a targeted strategy for developing sophisticated reservoir description and oil recovery techniques and make them accessible to all aspects of industry.

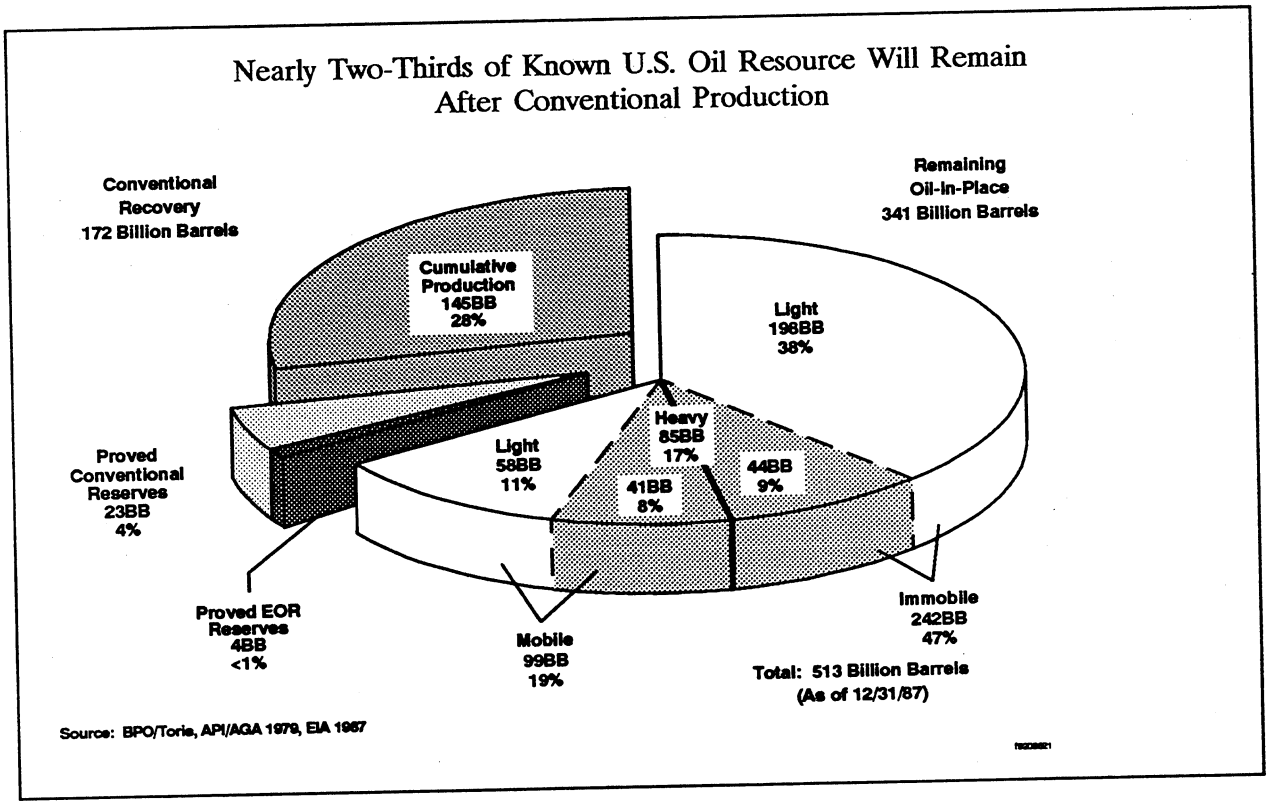
The U.S. economy's heavy dependence on oil is likely to persist for decades. The transportation sector of the economy alone uses more oil than we produce domestically and relies on oil for 97% of its energy needs. While economical, environmentally sound substitutes for oil products are under development, their widespread use will be delayed by at least two constraints: (1) cost — as global competition intensifies, the U.S. cannot afford to inflate product costs by choosing high price fuel options, and (2) infrastructure — time and substantial capital will be required to replace the existing oil-based infrastructure. Thus, even to prepare for the fuels that will succeed oil, we need a secure source of oil supply for at least several decades.

New U.S. discoveries will provide only a fraction of our petroleum needs. The U.S. is a highly explored, mature producing region. For several decades, exploration has been yielding smaller and smaller discoveries despite increasing drilling efforts. While the most promising areas of new discovery — Alaska and offshore — are important, they do not have the potential to halt the decline in production, nor to replace the reserves that are now being produced.

Imports fill the growing gap between domestic consumption and production. Already at more than 40% of domestic consumption, EIA projects that net imports will exceed 50% by 1994. Projections by others foresee the 50% level even earlier. The scale of rising oil imports is costly, at over $40 billion per year, with disturbing implications for national security, international competitiveness, the balance of payments, employment, and the standard of living.

The remaining alternative is to develop the oil that remains in the ground after conventional recovery methods. This is a massive resource, estimated at 341 billion barrels. Conventional recovery generally extracts only about one third of the oil known to be in a reservoir (Figure 1). The remaining oil can be considered as either "mobile" to waterflooding or steam injection or "immobile" to such processes. This resource may be further differentiated into light oil (API gravity 20° to 45°+) and heavy oil (API gravity 10° to 20°), which entail different constraints on the recovery process.

Figure 1



Conventional methods fail to produce all the mobile oil because heterogeneities in reservoir rock formations restrict or seal off flow paths, and because variations in density, viscosity, and mobility of oil relative to injected fluids cause the injectants to "finger through," override, underride, and bypass mobile oil.[1] Advanced secondary recovery techniques have been developed, and continue to be improved through R&D, to recover some of the 99 billion barrels of mobile oil that remain after conventional methods have been applied — waterflooding for light oil and steam injection for heavy oil. Geologically targeted infill drilling reaches oil trapped in compartments isolated from the flow paths established in conventional recovery efforts. To reduce vertical bypassing due to high permeability contrast, gelled polymers or foams may be injected to reduce the contrast between strata or to selectively complete zones in the reservoir. Areal bypassing may be reduced by adding polymers or foams designed to increase the viscosity of the injectant, thus lowering mobility differences between oil and the injected fluids. Areal and vertical bypassing are problems common to the recovery of both light oil and heavy oil resources. Much of the R&D effort over the past two decades has focused on the development of injectant fluids that remains stable under reservoir conditions to control the flow of oil — using polymers in light oil formations and foams in both light and heavy oil formations.

Another 242 billion barrels of immobile oil is held in the rock pores by surface tension and capillary forces after injected fluids have produced the mobile oil. Advanced tertiary, or enhanced oil recovery (EOR), processes are required to overcome these forces.

Chemical and miscible processes are the principal EOR methods for producing immobile light oil. In a chemical flood, an agent that reduces surface tension (surfactant) is injected to overcome capillary forces. Miscible flooding consists of the injection of solvents — carbon dioxide, nitrogen, propane, etc. — to reduce surface tension, reduce oil viscosity, and swell the oil to re-form droplets into a more continuous oil phase that is amenable to recovery. EOR may also require the application of advanced secondary recovery techniques to minimize bypassing of immobile oil by the injected fluids. Thermal EOR techniques are applied mainly in heavy oil reservoirs. Application of thermal processes immediately follows primary recovery, because shallow heavy oil reservoirs are generally not economically amenable to normal waterflooding. Steam injection reduces the viscosity of trapped oil or partially cracks heavy hydrocarbons into lighter, more mobile components which then flow to production wells. In-situ combustion projects rely on the burning of a portion of the oil in the reservoir by injecting air or oxygen. The thermal front, or burn zone, moves through the reservoir heating and displacing oil in front of it.

Even successful EOR processes leave considerable amounts of oil unproduced. All EOR processes are only effective in the portion of the reservoir actually contacted, so the oil (both mobile and immobile) in uncontacted areas remains. Some residual oil remains in the reservoir even after EOR techniques have contacted the zone. In chemical flooding, only a trivial amount remains in the portions of the reservoir actually contacted by the flood; in gas miscible flooding, slightly more oil is left, but it generally consists of heavy components of little commercial value. In the case of steam flooding, however, this can be a substantial portion of the remaining oil. The oil immobile to steam is trapped at remaining saturations as high as 15 to 20 percent of the pore volume. However, no known process can technically produce this residual oil volume due to the combination of high operating temperatures and low reservoir pressures that prevail in steam injection projects. Furthermore, there are light and heavy oil reservoirs for which no currently known process can technically or economically produce the immobile oil, including those with low permeability or that are highly fractured. Some of these may be quite large and present a target for future techniques to be developed.

Secondary and tertiary recovery processes require an understanding of the reservoir heterogeneities and flow paths unique to each reservoir to achieve predictable and cost-effective results. Reservoir description itself requires advanced technology. Architectural and petrophysical modeling of outcrops and reservoirs in the subsurface improve the understanding of compartmentalization and fluid flow paths. Statistical description of rock properties facilitates performance prediction within the reservoir and extrapolation of results to analogous reservoir types. Exploratory vertical, directional and horizontal drilling, and subsequent logging and well testing can directly extend critical characterization knowledge between production and injection wells. Geophysical and engineering techniques (e.g., tracers and pressure transient analysis) improve our ability to characterize reservoirs. Improved description of reservoir architecture will lead to improved oil recovery for all processes and resource types — including light and heavy oil.

The mobile and immobile oil resource that remains in known U.S. reservoirs represents the largest domestic source of potential supply. The continuing development of advanced secondary and tertiary recovery techniques by the collaboration of the states, industry, and the Oil Research Program presents an opportunity to produce a significant portion of this resource. Greater understanding of the resource and further development of advanced

technologies can increase production significantly from new and existing reservoirs under a wide range of economic conditions.

Considerable effort has already been expended in attempting to realize this potential: the Federal Government has supported an EOR research program since the early 1970's; the industry has conducted R&D and has initiated a large number of field projects on its own and in response to incentives; some states have encouraged R&D and have recently enacted tax incentives to encourage advanced extraction projects. Despite all this activity, EOR has made a relatively small contribution to total domestic production. Even when oil prices were very high in the early 1980's, EOR contributed only about 600,000 barrels per day. Virtually all of this production was from certain uniquely favorable geological situations. It has become increasingly apparent that complexities of reservoir architecture and our limited understanding of them represent formidable barriers to achieving the full potential.

While the potential to increase U.S. production is great, the opportunity is vanishing rapidly. Since the 1986 collapse in oil prices, the rate of well abandonments has been unprecedented. Abandoned wells are plugged permanently, and the cost to redrill or replace them is high enough in many cases to prevent the future application of more cost-effective recovery technologies. If the lease is not held by production from other wells abandonment may completely foreclose future recovery opportunities when the lease is lost. With as much as two thirds of the remaining U.S. oil resource at risk of abandonment by 2000 (discussed below), it is urgent that we prevent or reduce the scale of abandonments to preserve the opportunity we have to increase oil production.

The Oil Research Program addresses the remaining oil resource with research, development and demonstration (RD&D) in reservoir engineering, geology, geophysics, geochemistry, and environmental science. Throughout the history of U.S. oil exploration and development, the products of research and technological development have played a vital role in sustaining and increasing domestic production. The efficacy and continuing need for technical RD&D are particularly evident today. The National Petroleum Council study, *Enhanced Oil Recovery*, identified the great potential of EOR processes to unlock immobile oil, and stressed the need for process research and field testing to "reduce the technical uncertainties that currently delay commercial development."[2]

The 1986 collapse in oil prices, and its resulting impact on the U.S. oil resource and the industry, has motivated a re-examination of the Oil Research Program. Its emphasis during the previous decade on long-term, high-risk research was intended to complement a strong industry R&D program. This approach assumed that there would be ample time for basic research to be converted to technology and for this technology to be disseminated to operators of all types.

The price collapse profoundly affected the U.S. oil industry, forcing many companies to leave the business while others reoriented their exploration and production strategies to remain as viable producers. To reduce costs, many producers have cut spending on R&D and adopted a preference for lower-cost production technologies. To replenish reserves, large companies have shifted their exploration focus to Alaska, offshore, and increasingly to foreign regions, reducing their commitment to the U.S. Lower-48 resource, and especially to the intensive reservoir management techniques needed to produce the known remaining oil resource. Throughout the U.S. resource, but especially in the Lower-48 states, lower prices have increased the production level necessary for producing wells to remain economic, bringing them closer in time to the point when

revenues no longer cover costs and operators must abandon the wells. This leaves less time for the dissemination of newly developed, cost-effective technologies, while the need to solve technical and economic constraints on production is pressing.

As a result of these developments since the price collapse, the Office of Fossil Energy (FE) has been evaluating its program to assure its effectiveness in the new economic environment. Several important studies have assessed the issues and proposed strategies to address them:

- *Energy Security.*[3] The 1987 DOE report to the President described the economic and security implications of rising oil imports and identified strategies to address them, including highly focused R&D to increase production from known oil reservoirs.

- *Geoscience Research for Energy Security.*[4] This 1987 report by the Energy Research Advisory Board (ERAB) stressed the need for greater integration and coordination of geoscience and extraction research. ERAB gave its highest research priority to oil and gas out of the entire range of energy sources, because "the major energy problem facing the nation in the intermediate future is a shortage of domestic liquid hydrocarbon fuels."

- *EOR Initiative.*[5] This 1987 Fossil Energy study identified through discussion with the industry and states the need to expand the existing research program to include near-term measures to enhance domestic producibility, to broaden the context of oil recovery research by addressing mobile as well as immobile oil, and to develop technology transfer, recognizing the key role of independents in the domestic industry.

- *Hydrocarbon Geoscience Research Strategy.*[6] The 1989 report by the Hydrocarbon Geoscience Research Coordinating Committee recognized the urgency of maintaining access to reservoirs at risk of imminent abandonment, and the need to balance near-, mid-, and long-term research toward the goal of increasing economic producibility of oil and gas resources. This strategy recognized that an understanding and quantification of reservoir heterogeneities is critical to improving producibility, and stressed the key role of interdisciplinary, problem-oriented, field-based RD&D on carefully prioritized classes of reservoirs to providing rapid, cost-effective technology advancement. The strategy was developed in conjunction with a major study of geoscience research priorities by the Geoscience Institute for Oil and Gas Recovery Research.[7]

Based on these documents and recent developments, current guidelines for FE's oil research include: the program must be mission-oriented, with well-defined goals and objectives and with each project within the program addressing the mission; research must clearly address the near- and mid-term needs of the oil and gas industry, complementing the program's historical emphasis on long-term R&D; the program must reflect the nation's growing concern for the environment, by assessing the environmental impact of advanced recovery techniques and developing mitigation techniques if found to be necessary; and the results of the program's research activities should be actively disseminated to the states and industry, requiring that technology transfer be integrated with other program activities.

These guidelines and the analysis of research needs define a new Oil Research Program, articulated by this Implementation Plan. This plan reflects the cumulative effort of analysis and experience in the U.S. oil

industry to date, but recognizes that more study of the U.S. resource and the industry is needed. In particular, the unique constraints to increasing production from the vast heavy oil resource have not been adequately studied, nor has extensive reservoir data been collected from all producing states. These activities have been planned or are already in progress. This Implementation Plan is intended to be an evolving instrument, to be revised annually, and future editions will incorporate the implications of new analyses (such as for the heavy oil resource) and the results of the R&D as it progresses. However, the rapid rate of abandonment of the light oil resource, and its implications for U.S. oil producibility, demand that the new program take effect as soon as possible, providing the overall framework of which elements will be adapted as the results of new research and analysis become available. The following section presents the analysis of the U.S. oil situation that motivates the new plan.

THE POTENTIAL AND URGENCY OF THE REMAINING OIL RESOURCE

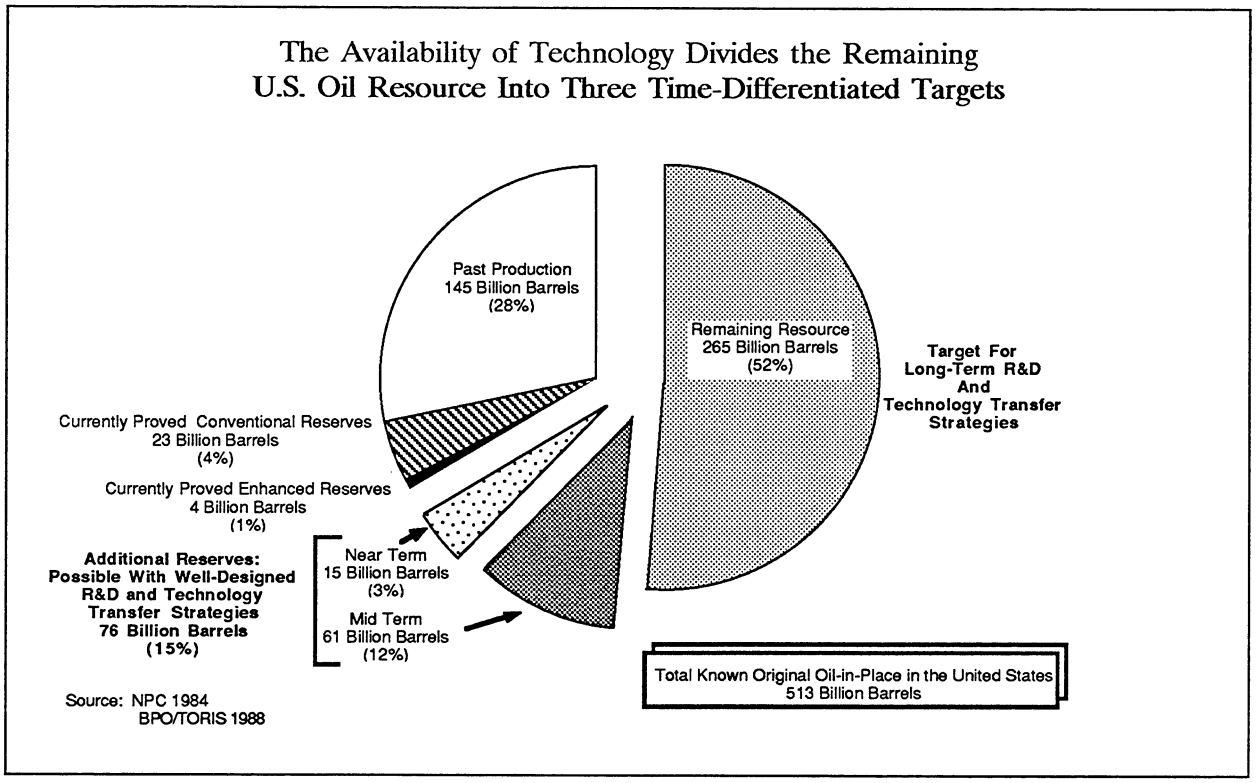
From 1982 to 1984, the National Petroleum Council (NPC) developed a database and analytical models to estimate the potential for enhanced oil recovery (EOR) from known reservoirs in the United States. That study focused on the incremental recovery of known, *immobile* oil by specific EOR processes — chemical flooding, gas miscible flooding, and thermal recovery — applied after primary/secondary recovery. Enhancements to the database and analytical models have since allowed the NPC methods to be extended to include *both immobile* and *mobile oil*. Detailed data on more than 3,700 individual reservoirs (collectively accounting for over 70% of the nation's original oil-in-place), the original NPC cost and process models as updated by recent findings, and new models of advanced secondary recovery (e.g., targeted infill drilling, polymer-assisted waterflooding, and permeability profile control using gelled polymers) have been used to estimate the potential incremental reserves and the remaining oil resource after production of these reserves.

Figure 2 divides the 341-billion-barrel remaining oil resource into components requiring substantially different levels of technology performance to produce them.[8]

- *Near Term.* Up to an additional 15 billion barrels, primarily mobile oil, could be recovered at present economic conditions with *currently available and proven* technologies. This requires a well-designed technology transfer program to reach operators that do not yet utilize them. Widespread application of these technologies to reservoirs before they reach their economic limit is essential to prevent premature well abandonments and to preserve economic access to the resource for subsequent application of advanced technologies. Much of the mid-term reserve target for light oil is in danger of abandonment unless technology transfer is effective in the near term.

- *Mid Term.* An additional 61 billion barrels may become recoverable in the mid term with the application of *currently identified, but yet-to-be-proven, advanced* technologies. This will require significant, but definable, advances in technology through focused RD&D efforts, and subsequent aggressive technology transfer to promote widespread application. This total, an additional 76 billion barrels of potential reserves recoverable by *currently identified* technologies, represents a 52% increment over the cumulative production of oil in the U.S. over the last one hundred years. This is enough to sustain current levels of U.S. production for the several decades needed for an orderly transition to alternative transportation fuels.

Figure 2



- *Long Term.* If this full 76-billion-barrel-potential were developed, it would still leave approximately 265 billion barrels in known reservoirs after application of near-term and mid-term technologies and in reservoirs not amenable to technologies that are currently defined. Unlike the above estimates, this is *not* an estimate of potential reserves but of a resource with unknown recovery potential. The long-term target requires basic research to stimulate new geological description techniques and insights and the invention of new and novel recovery technologies. The huge size of this resource justifies the high-risk effort required to develop these technologies.

Producing the near-term component entails only slightly higher levels of technical risk than conventional production; the technologies are contemporary, proven, and available. That is not to say they are risk-free, but that their risks have been demonstrated to be within the range customarily borne by the industry. Producing the resource component described as mid-term, however, entails substantial technological risk. Each of the constituent technical objectives that must be achieved represents a relatively modest advance in the state-of-the-art; the advances hypothesized as resulting from an RD&D program had all shown some degree of success in the laboratory or field by the mid-1980's. Achieving these advances *in cost-effective combinations,* however, substantially increases the technological risk. If, for example, the probability of success of each of (1) improving the predictability of reservoir flow paths; (2) accurate estimation of permeability of the respective oil-bearing strata; (3) ability to place infill wells; (4) improved temperature

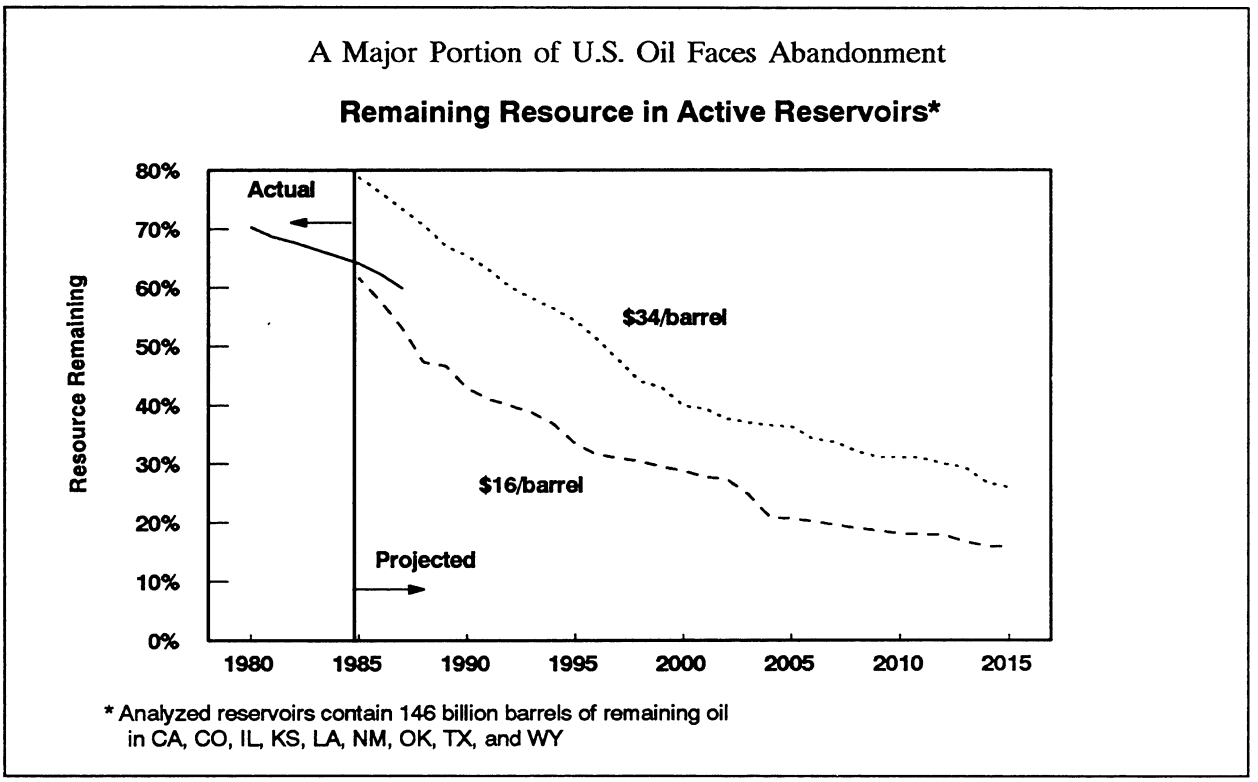
and salinity stability of polymers; and (5) improved surfactant absorption properties were 0.8, then the overall probability of achieving a successful chemical flooding protocol would be about 33%. The combination of advances chosen for the assessment were those hypothesized by the National Petroleum Council study, completed in 1984, and are still regarded as highly likely.[9] However, the design of a research program to realize these advances must carefully manage the inherent technological risks. Going beyond the mid-term resource to the long-term resource moves from the domain in which technological risks can be estimated to the domain in which the basis for such calculation does not yet exist.

Identification of the near-term, mid-term, and long-term resource targets was based on the data base and analytical models developed and validated by the NPC, with substantial recent enhancements which have been peer reviewed. This analytical base, collectively called the Tertiary Oil Recovery Information System (TORIS), analyzes individual reservoirs in a summary reservoir engineering fashion, quite sufficient for the estimates of recovery potential on a national scale and as a basis for developing the research program plan. The program described below entails considerable site-specific RD&D, which would also use substantial quantities of additional, highly specific data obtained at each reservoir site. This work will result in a more detailed reservoir data base — a substantial benefit to be used to fine-tune the program as it progresses. It is important to note that in using TORIS, the best available data source on the U.S. oil resource is being put to work for program planning. This data base and the analytical models will be improved as a result of program activities and will contribute to assessments of program results and overall direction.

Well abandonments create the additional risk that low-cost access to the resource will be lost. The extent of well abandonments and their impact on the potential future application of advanced technologies has been evaluated using actual well reports and reservoir-by-reservoir decline curve analysis. DOE's Bartlesville Project Office assessed the principal reservoirs in nine states, representing over 75% of the remaining resource in the Lower-48, to project the quantity of remaining oil in reservoirs reaching their economic limit over time for different price levels.[10] The methodology to project abandonment trends was cross-verified with historical data from Petroleum Information (PI) Services. Figure 3 presents the study results. By 1987, actual reported well pluggings showed that access to 40% of the remaining oil-in-place had been abandoned, with the rate of abandonment accelerating in recent years from 1% to 2% per year. If low oil prices persist and technology advances are delayed, as much as 65% of the remaining resource could be in abandoned zones by 1995, and over 75% could be abandoned early in the twenty-first century. Even if prices return to the high levels of the early 1980's, wells providing access to nearly 60% of the resource could be abandoned by 2000.

These results have substantial implications for the future application of advanced technologies. For environmental and economic reasons, when a well is abandoned, all salvageable equipment and field infrastructure are removed, cement plugs are placed in the wells, and the land is restored as close to its natural state as possible. While permanent plugging is sound economic and environmental policy, abandonment reduces the economic viability of future advanced recovery projects that could use these wells as points of reservoir access for testing, injection, and production. After abandonment, only two options exist for contacting the remaining resource in a reservoir — drilling new wells or re-entering plugged wells. Either case requires substantial investment in wells and

Figure 3



infrastructure comparable to start-up costs for beginning production in a new field.

A recent DOE analysis estimated the impact that redrilling would have on domestic EOR potential.[11] The increased investment required to redrill had the same economic impact on EOR potential that an $8/bbl drop in oil prices would have on projects able to use existing wells. At $20/bbl, the domestic EOR potential would drop from 6.1 billion barrels to 2.6 billion barrels if existing wells were plugged and redrilling were required. The severe reduction in advanced recovery potential caused by well abandonments attests to the urgent need to preserve resource access in critical reservoirs as they reach their respective economic limits.

The preceding analyses identify the time constraints that drive the program: availability and application of cost-effective technology before the imminent abandonment of critical light oil reservoirs. Further development of advanced technologies will require five to ten years to identify and solve the constraints that now limit their application. While conducting this RD&D, access must be preserved at least to the most promising reservoirs, to maintain their economic potential for recovery with advanced processes. Some of these reservoirs are near their economic limit and may be abandoned before the relevant advanced technologies are available. Their urgent need for attention leaves time only for the application of technology that is currently available and proven to keep them in operation until more effective technologies become available.

This leads logically to the need for balance among the program's time perspectives.

Neither the near-term nor the mid-term orientations alone can achieve significant improvement in oil recovery. Currently available process technologies can improve recovery efficiency by another 2% to 4% in significant light oil reservoirs. This is an important increment, but does not achieve the major gain that the program seeks. Identified, advanced technologies can improve recovery efficiency by another 10% or more. However, during the 5 to 10 year period of RD&D required to make them available, reservoir abandonments will erode this potential substantially unless access is preserved in critical reservoirs. In many cases, the application of currently available technologies can accomplish this, by reducing production costs and hence extending the well life to the point where advanced technologies are available to achieve more significant increments to production. In other cases, available technologies may not be able to delay abandonment, but environmentally sound, economically reversible well plugging techniques may help retain economic access to reservoirs that will be amenable to more effective technologies when they are available at a later time.

The near-term objective — to preserve economic access to the resource — responds to the significant projected abandonment rates in light oil reservoirs revealed by decline curve analysis, and to the need to preserve the mid-term recovery potential anticipated from advanced technologies. Whereas the recovery potential from heavy oil reservoirs is not threatened by abandonment, other factors have been identified that may inhibit future production using thermal EOR techniques. In spite of years of application, the basic heavy oil recovery technology of steamflooding remains in need of improved tracking and control of the distribution of injected heat and fluid movements. At the same time expanded technology application can be blocked by emission restrictions on steam generators in the same locations and processing constraints faced by refiners that limit the marketability of heavy crudes. To realize the potential of advanced heavy oil recovery technologies in the mid term, there may be distinct near-term activities that the program could undertake. These have not yet been identified, although funds for a detailed analysis of the constraints on heavy oil recovery are included in the Oil Research Program's FY 1990 program. That analysis will provide the basis for developing specific near-term and mid-term program objectives that may be appropriate for enhancing the producibility of heavy oil reservoirs, while existing R&D projects that already support the mid-term and long-term objectives described in this Implementation Plan will continue.

The integration of near-term and mid-term program activities is essential to achieve the full potential of currently defined technologies: maintenance of production or reversible plugging is prerequisite to full application of the advanced technologies that will be made available in the mid term. A large portion of remaining oil-in-place will still be unrecovered after the mid-term technology advances have been applied. Techniques are not yet defined to recover this oil. This resource will be addressed by basic research with the aid of reservoir information and advances obtained during the course of near- and mid-term program activities.

The potential benefits of near- and mid-term technologies can be estimated with some confidence, but the long term presents a vast resource target for which the technical and economic recovery potential cannot be accurately projected. Beyond currently proven reserves, currently available recovery methods and currently defined advanced technologies could ultimately produce another 76 billion barrels of mobile and immobile oil at moderate oil prices — enough to stop the decline in U.S. production for three to four decades. This additional domestic supply would generate more than $400 billion in

revenues to state and federal treasuries, reduce the trade deficit by more than $2 trillion, and improve the nation's energy security. However, these benefits can only be realized through a timely, thoroughly integrated RD&D program that is carefully coordinated with the industry and the producing states. It is recognized that the industry, producers, consulting engineers and geologists, and service companies not only have the intellectual property needed to assure success, but that their ultimate business decisions will determine just how much of the potential oil production can be achieved. The producing states can also contribute greatly to creating a regulatory environment conducive to realizing this additional production potential. Some states have already taken significant steps, such as by extending the period required before shut-in wells must be permanently abandoned, or by instituting tax incentives to stimulate production.

The number of possible combinations of RD&D applications, in terms of the numerous U.S. reservoirs multiplied by the number of operators in each, multiplied by the number of advanced recovery techniques and their combinations for mobile and immobile oil, clearly exceed the capacity of any orderly program. For example, the 3,700 reservoirs in the Bartlesville Project Office's (BPO) data base represent only the largest in the nation; literally tens of thousands of smaller ones are still not in the data base. Depending on definitions, the nation can boast of 9,000 to 24,000 certified oil producers. And, of course, dozens of recovery processes and variations are available. Clearly, this is too large a number of possibilities for an RD&D program with limited budget and time to address production constraints at each individual reservoir or for each operator. However, some reservoirs will need more urgent attention than others; some are larger or more amenable to the application of advanced technologies than others. While analysis can identify potential and urgency in individual reservoirs, a scheme is needed to aggregate and assess potential in a way that establishes priorities for RD&D that will maximize recovery.

Reservoirs grouped into larger families, called plays, often show similar production characteristics because they have similar heterogeneities.[12] [13] Plays are "genetic" groups of reservoirs that are similar because they share a common geologic (depositional, diagenetic, and tectonic) history and are proximate to one another in a relatively confined area. Reservoirs in a play exhibit common rock and hydrocarbon sources, trapping mechanisms, and reservoir and fluid characteristics. The reservoirs within a play, being geologically similar, often exhibit similar production problems. The advantage of such groupings is that the characteristics of well-understood reservoirs may be extrapolated to others within the same play.[14]

Reservoir plays may be further characterized according to depositional and diagenetic origin, which influences the pattern of oil accumulation and subsequent recovery. Galloway and others grouped nearly 450 of the most productive reservoirs in Texas into 48 oil plays.[15] Tyler and others characterized these 48 Texas plays into 11 depositional systems in a 1984 study.[16] This describes a classification hierarchy based on geological history: reservoirs that are geologically similar based on hydrocarbon source, reservoir rock, fluid properties, and trap characteristics are grouped into plays, while plays having the same depositional environment are grouped together as classes. In Texas, about 80% of the original oil-in-place was concentrated in 5 of these 11 depositional systems, or reservoir classes. In addition to this geologically determined pattern of oil accumulation, the reservoir classes also showed broad trends in production characteristics. Reservoir genesis determines the lithology, permeability, continuity, and other basic rock properties which are important variables affecting

ultimate recovery efficiency. Figure 4 shows well-defined efficiency ranges for primary recovery when reservoirs are grouped according to their genesis and drive mechanism. The demonstrated effects of reservoir genesis and drive mechanism on primary recovery efficiency established a basis for identifying target reservoirs for improved oil recovery in Texas.[17]

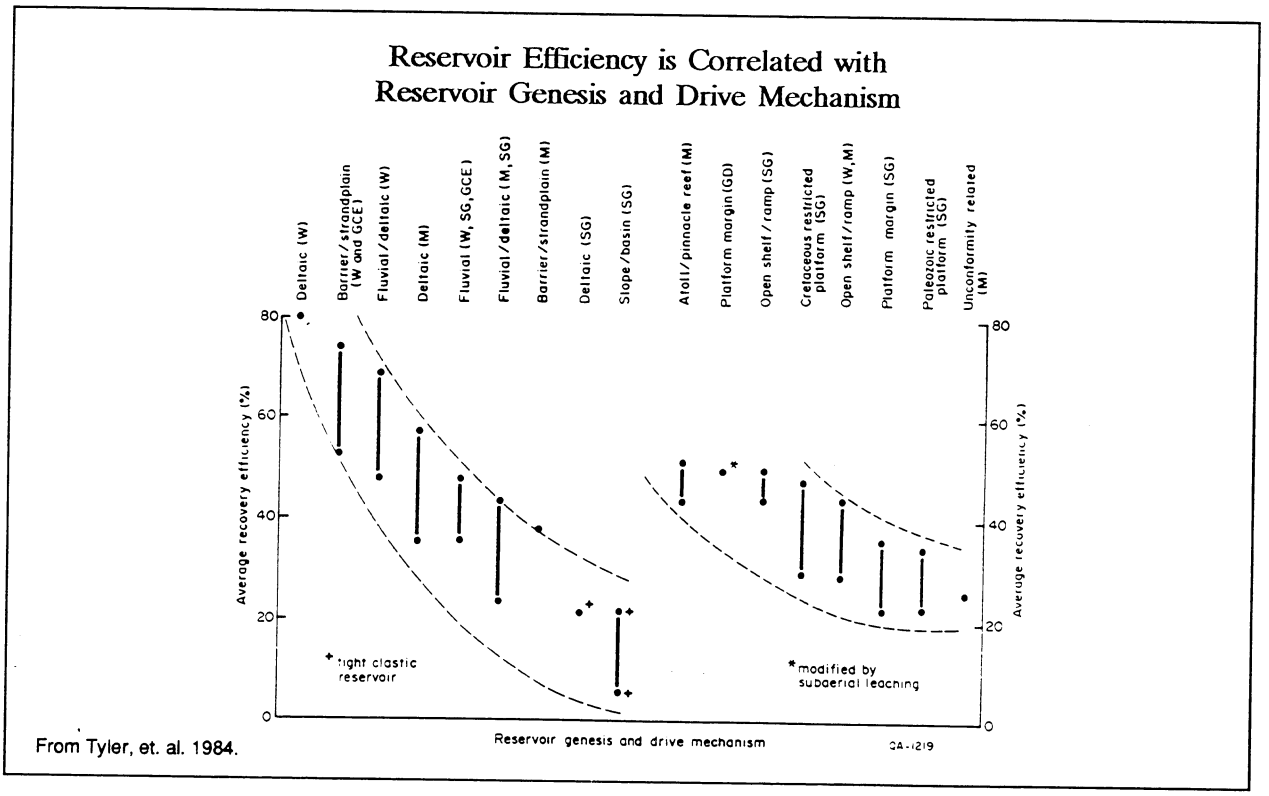
In estimating economically recoverable reserves at various oil prices, a subsequent analysis of the same 48 Texas plays found that 67% of the secondary and tertiary recovery potential was concentrated in the top 10 plays.[18] Geological properties and architecture of a reservoir have a profound effect on the recovery performance of both secondary and tertiary extraction operations. Understanding of the geological history of reservoirs, including the original depositional environment and subsequent post-depositional modifications, thus provides important information concerning the ultimate efficiency of advanced extraction processes, as well as to the kinds and extent of the heterogeneities that must be overcome to achieve increased production levels.

The critical role of geologically determined factors on oil recovery and the ability to group individual reservoirs into geologically similar plays and classes combine to provide the scheme necessary to establish RD&D priorities that will maximize recovery of the known domestic resource. Behind this approach is a theory of reservoir similarity. The reservoir similarity theory submits that reservoirs with the same or similar depositional, diagenetic, and tectonic history should have similar heterogeneities, and hence should exhibit similar production constraints. A classification system based on geological history should capture the essential features of heterogeneity,aggregating reservoirs into groups having common production constraints and common RD&D requirements to relax or overcome them. Such a system requires detailed characterization of reservoirs, but focuses RD&D efforts on specific, well-defined problems rather than broad, "generic" issues.

Note that this concept offers quite a different perspective from that of earlier oil research programs. The revised effort seeks to focus on the identification and resolution of specific problems limiting oil recovery in reservoirs with high recovery potential. The previous work concentrated on specific advanced extraction processes themselves with only limited reference to the geological constraints which impact their application. This break with the traditional focus was first suggested by the ERAB review, which recommended that DOE adopt an integrated approach in geoscience research and technology development activities to improve the success in their application.[19] The concept has been extended further in the *Hydrocarbon Geoscience Research Strategy*, which identified the single most important technical problem in converting the nation's oil and gas resources into economically producible reserves as "the current lack of understanding of reservoir architecture and how it affects fluid flow," and stressed the need for integration of research efforts.[20]

The similarity theory, if proved to be correct, also provides a lever for the broad application of RD&D results. A corollary of the theory is that once the production response of a recovery method has been determined for a representative reservoir, the results may be transferred to the larger group of reservoirs constituting the reservoir play, and perhaps to the broader grouping of reservoirs in different plays but within the same class. Reasonable levels of program budgets will limit the number of field demonstrations that can be conducted to prove advanced technologies. However, the similarity theory will guide appropriate play- and class-specific extrapolations of research results, focusing technology transfer efforts to

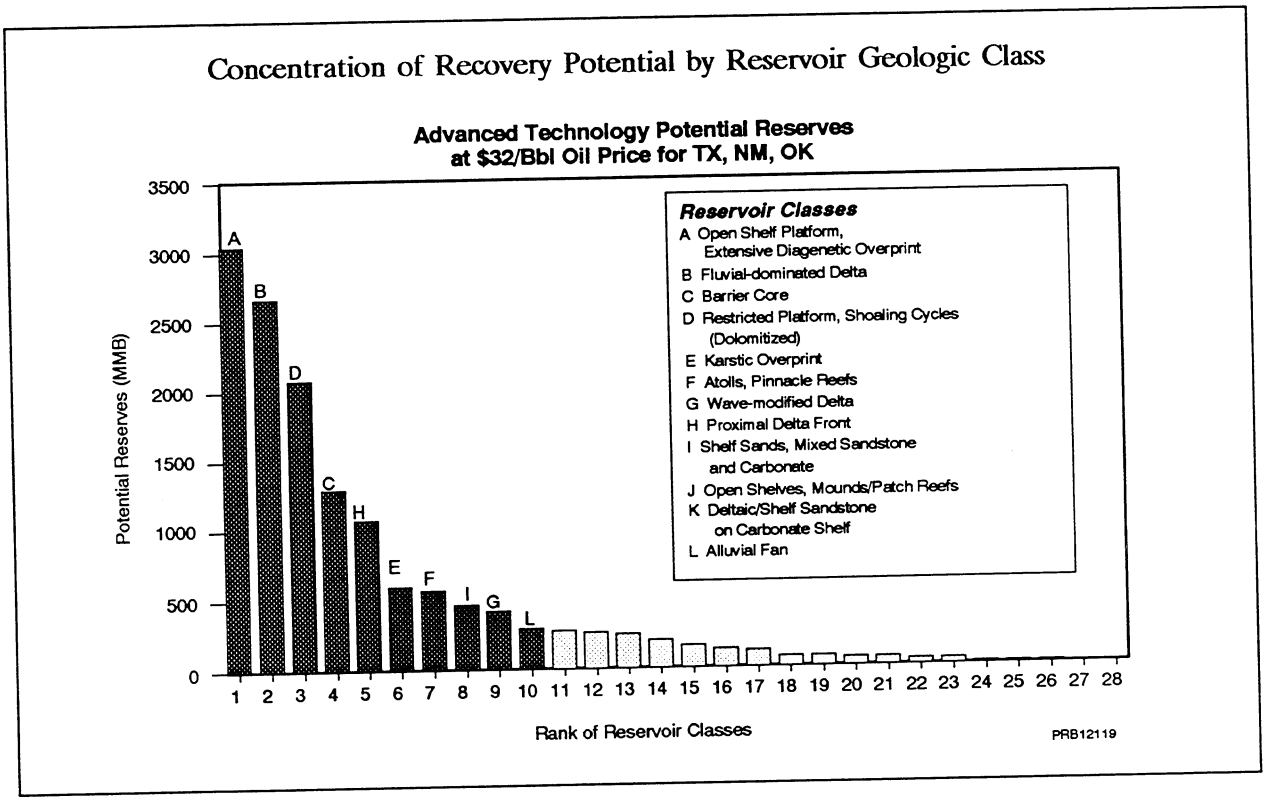
Figure 4



achieve cost-effective application among operators of other reservoirs with similar geological history.

A geologically-based classification system has been demonstrated to differentiate recovery potential and urgency due to abandonments by reservoir class in an analysis of remaining recovery potential in Texas, Oklahoma, and New Mexico by the Bartlesville Project Office (BPO).[21] Data were available for these three states as a result of their initiatives under the Interstate Oil Compact Commission (IOCC) to determine the options each had to improve oil industry operations in their jurisdiction.[22] The BPO study combined the reservoir-by-reservoir results of a prior analysis of the potential recovery of mobile oil with the results of new analyses of reservoir-by-reservoir EOR potential for each geologic class.[23] This potential, estimated under technological advances based on the specific research objectives of the Oil Research Program, represents the full recovery potential of each class. Figure 5 summarizes these analyses for Texas, Oklahoma, and New Mexico combined, ranking the geologic classes by their potential recovery. The potential incremental production due to advanced technology was found to be highly concentrated in relatively few geologic classes. Sixty-five percent of the total potential lies in the five largest classes; 86 percent lies in the largest ten. Work is now underway to extend this analysis to all producing states and, if successful, will result in a National classification system. An expected result is that each producing state will have reservoirs in several classes.

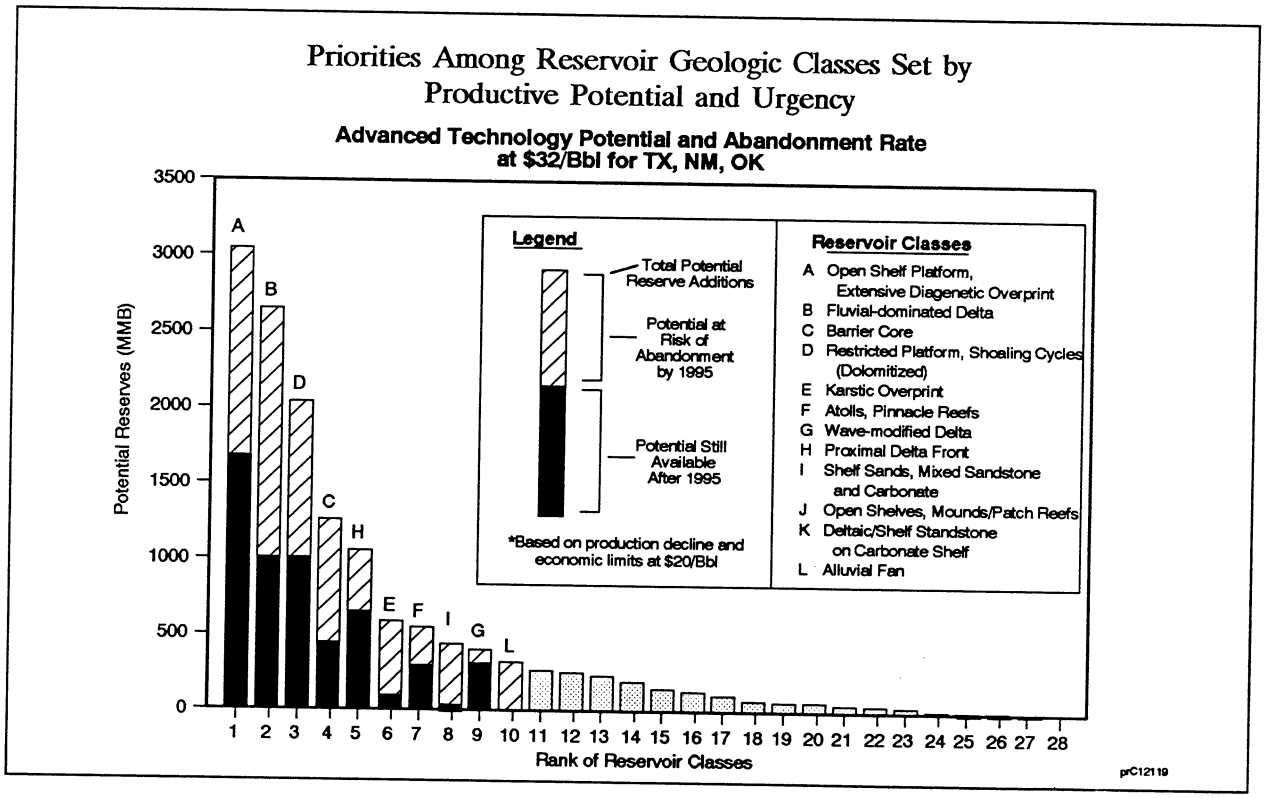
Figure 5



Separately, a decline curve analysis was conducted to estimate the economic limit (abandonment) date for each reservoir. These were also aggregated by the geologic classes. Figure 6 synthesizes the decline curve analysis with the analysis of recovery potential, superimposing the amount of that potential estimated to be in danger of abandonment by 1995 as an indicator of urgency. The urgency of the critical classes that have the greatest potential is dramatically evident: over 55% of the potential reserves in these top ten classes risk abandonment by 1995.

Only three states were included in this assessment because the requisite data were not available for resources in other regions. Thus, there is uncertainty regarding both the extension of the classification system and whether a similar pattern would result when other major regions are considered. However, the three states in question do represent over 40% of the original oil-in-place, and over 40% of the remaining resource target. Thus, it is a reasonable sample to use for initial planning. It is believed that the work required to address other states will require modification and additions to the classification methodology, but that final results will generally support the hypothesis. A major effort on this question is now in progress. Geologic data for all TORIS reservoirs in all producing states are now being collected; the analytical methods have already been through peer review and are in the process of being improved, while an expanded classification system is under evaluation. Although these activities are in progress, it has been assumed that the trends seen for the three states will generally apply; their implications are clearly important for planning a mission-oriented oil program:

Figure 6



- The extreme concentration of potential economic recovery in a small number of reservoir classes, a result expected also at the national level, suggests that the program can achieve greatest benefits by focusing on the classes with greatest potential.

- The impending rates of abandonments of some of the high-potential reservoir classes underscore their urgency. In some cases, essentially the full potential is at risk. This imposes stringent requirements for near-term steps to maintain access to these reservoirs.

- Although work is now in progress to classify the full domestic resource, the effort is not expected to be completed for some time. A best estimate of schedule for the work is given on page II-3, and the work phases are explained in Figure II-2 on page II-6. The urgency of the problem suggests that it may not be prudent to wait until all of the classification has been completed before initiating the next steps. Fortunately, progress should be sufficient by early summer of 1990 to permit identification of two classes that will clearly be among the most significant and urgent. The plan proposes to start work in these two while the classification and analysis effort proceeds. The initial steps of holding meetings with those most familiar with these classes to determine the actual production opportunities and technical barriers will lay the foundation for developing more specific program projections and plans.

Three steps have been taken since early October, i.e., in FY 1990, to prepare the

analytical approach for nationwide application. The analytical methodology, including the economic and process models used to analyze the resource, was presented in November 1989 for peer review and confirmation by industry and academic experts, and is now in the process of revision.[24] This process is establishing the credibility of the methodology, communicating to industry and the research community the direction that the Oil Research Program is taking, and will assure the cooperation that is vital to achieve the advancements in technology and application to existing reservoirs that the program seeks. Under an existing contract, the Geoscience Institute for Oil and Gas Recovery Research has convened a distinguished industry-academic panel of geologists to review and revise the geological classification scheme for application beyond the initial three states. This will further delineate the classification process, establishing guidelines so that reservoirs in other states may be properly added to already-defined classes or grouped into new ones. A draft classification scheme has been completed and is currently undergoing evaluation.[25] The final report on the classification system developed for nationwide application will be extensively peer reviewed, and will be further refined in practice as we define class-specific problems and conduct field RD&D. Third, the Interstate Oil Compact Commission is initiating a study to bring the light oil reservoirs of the next several largest producing states to the same level of assessment as those of Texas, Oklahoma, and New Mexico so that the prioritization can proceed for all the major lower-48 onshore light oil resources. As these three efforts proceed, successively larger portions of the full national resource will become amenable for prioritization, focused research, development, demonstration, and technology transfer.

Subsequent studies will be needed to examine the rest of the U.S. resource after these efforts — light oil resources in Alaska, Appalachia, and offshore, and heavy oil resources. The abandonment risk of the offshore resource must be evaluated; it is potentially greater than for onshore resources because its associated operating costs are higher, although the rapid production rate needed to recover costs may leave a remaining resource that is too small to recover economically. Well abandonment has not occurred at a rapid rate in heavy oil reservoirs, hence the reduced urgency compared to many light oil formations. Shallow depths and economic viability of current technology have maintained production levels despite reduced prices. However, in addition to the collection of reservoir data, the assessment of heavy oil resources will include analyses of the impact of environmental and market considerations on increased future production. Emissions from steam generators are restricted by air quality regulations in California, limiting the initiation of new steam driven EOR projects. The market for heavy oil is restricted because of special processing requirements. Research is planned to determine the extent and economic impact of these constraints and to identify supporting R&D requirements for environmental mitigation, on-site upgrading, and refinery processing.

At the conclusion of these studies, the full U.S. oil resource base will be represented. Analysis of the national resource will identify the top 12 reservoir classes nationwide by recovery potential and urgency to focus RD&D activities.

PROGRAM GOAL AND OBJECTIVES

The goal of the new Oil Research Program is *to maximize the economic producibility of the domestic oil resource.* This follows from current policy and the opportunities presented by the vast resources of mobile and immobile oil remaining in existing reservoirs, much of which can be recovered with advanced technologies if industry, the states, and the

federal government cooperate in a well-designed program of RD&D and technology transfer. The term *"producibility"* is used in the goal to denote the *capacity* to produce; actual production will depend not only on this capacity but also on factors outside the scope of this program, including oil prices, tax and regulatory policies at several levels of government, and the willingness of industry to invest in domestic oil production in comparison with alternative investments. This goal also supports far-reaching national goals being articulated toward the formation of a National Energy Strategy. They include: improvement of the balance of payments, achievable by displacing oil imports with enhanced domestic production; improvement of global competitiveness, achievable by developing exportable technologies in oil recovery and exploration; improvement of national security, also achievable by reducing the level of oil imports; and improving the quality of the environment by developing advanced waste management techniques.

The Oil Research Program will focus on relaxing both technical and economic constraints on producibility from the mature domestic resource to realize its enormous potential benefits. It will also address real world constraints that include potential loss of access caused by the rapid pace of well abandonments, the lead time required for RD&D before advanced technologies can be made available for widespread application, and the requirements that the technologies be environmentally sound. The program's goal implies three time-specific, strategic objectives, in which technology availability defines distinct time horizons for the widespread application of advanced recovery techniques:

- *In the near term (fully effective within five years), preserve access to defined, high-potential classes that are rapidly approaching their economic limits* so that later, more advanced technologies may be applied cost-effectively. The principal strategy is to sustain production in reservoir classes that are targeted nationally on the basis of urgency and large potential, through the broader application of *currently available, economic* technologies. In conjunction with industry and the states, the program will identify technologies that have proven effective in economically extending well life, and will facilitate their broader adoption. To address reservoirs where currently available technologies are not feasible or are uneconomic, the fallback strategy will be to develop environmentally sound alternatives to plugging of oil wells with cement.

- *In the mid term (fully effective within ten years), develop and transfer the best currently defined, advanced technologies to operators in the high priority reservoir classes.* The strategy is to work with industry to identify the specific technical barriers to the successful application of advanced technologies in each high priority class, mount an effort to solve them, and if successful, demonstrate that they have been solved and follow through with aggressive technology transfer. RD&D at specific field sites will involve interdisciplinary problem solving — reservoir description, simulation and extraction process design, and field testing of the processes; discipline-oriented, fundamental and applied research would support the site-specific field activities; technology transfer would be directed at operators and at the consultants, service companies, state officials, and others who assist them.

- *In the long term (fully effective beyond ten years), develop sufficient fundamental understanding to define new recovery techniques for the oil left after the most advanced mid-term processes, and in major classes of reservoirs for which no mid-term advanced technologies were feasible.* Fundamental research and in-depth

investigation into the characteristics of the target reservoirs are the principal strategies to meet this objective. By supporting universities in the performance of this research, the program will also seek to sustain the U.S. lead in technology development and maintain the supply of academic talent necessary for the domestic oil and gas industry.

These three objectives are to be pursued simultaneously; it is the expected timing of results that differentiates them. Time is one of the principal constraints in conducting the RD&D for application to the diminishing resource target. Thus, work against each of the objectives should occur simultaneously to minimize the time for results to be achieved.

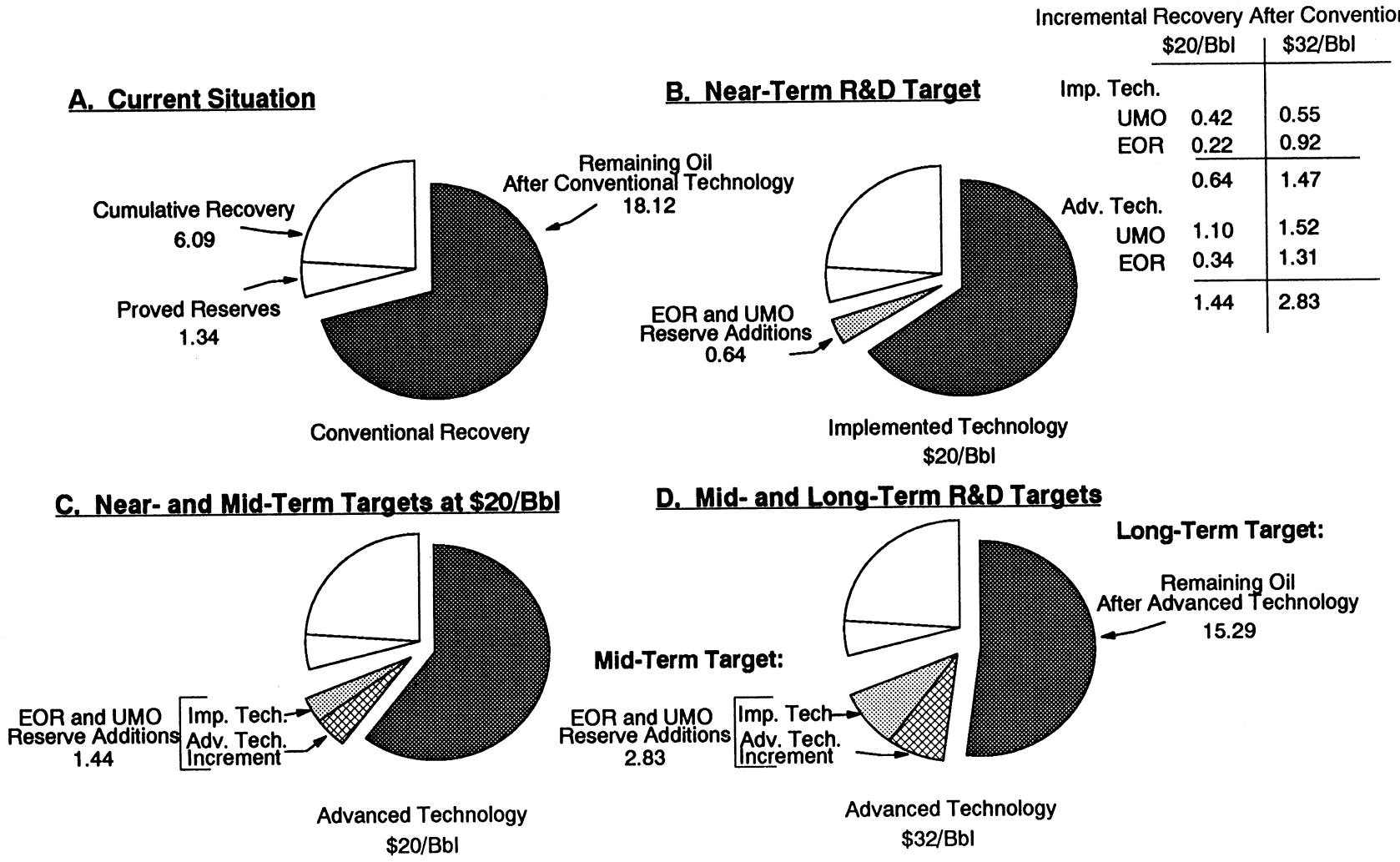
In addition to these three, time-specific objectives, the program has an implicit mission to promote U.S. competitiveness in the global economy that may be a direct result of its activities if properly managed. American innovation in the oil and gas industry has led the world for a century. Under the program's sponsorship, new reservoir description and recovery techniques will be developed and proven, providing opportunities for export by U.S. companies. The Oil Research Program will also continue to work with other countries on research projects, as it has done with Canada and Venezuela in the past, having adjunct benefits for American companies that market overseas.

One consequence of defining the time-specific objectives is that the associated resource and potential reserve targets and the appropriate technologies are clearly differentiable. Again using the data from the three states already studied as an example, Figure 7 illustrates this and helps to explain the estimates displayed earlier in Figure 2. In Figure 7, each "pie" represents the same 25.55 billion barrel original oil-in-place for the Open Shelf Platform System, a group of carbonate reservoirs with the highest mid-term potential ranking in Texas, Oklahoma, and New Mexico. Figure 7A shows the current situation of the original oil: 6.09 billion barrels have been produced and the 1.34 billion-barrel proved reserve will be produced by conventional technology, leaving a "remaining" oil target of 18.12 billion barrels. Figure 7B shows the *near-term target* of the R&D program: an incremental reserve of 640 million barrels (roughly two-thirds mobile oil and one-third immobile oil) that can be produced by available technologies at an assumed oil market price of $20/bbl. Assuring that this development and production occur requires working closely with the states and the industry, assisting them as the Bureau of Mines did in the early days of waterflooding. In some cases, demonstration projects may be required.

By maintaining access in this way, the reservoirs may be exploited later to realize the four-fold larger potential of the mid-term strategy — the 2.83 billion barrels recoverable at an oil price of $32/bbl with advanced technology illustrated in Figure 7D. (Figure 7C illustrates the similar advanced technology potential — 1.44 billion barrels — if the oil price fails to rise above $20/bbl.) Figure 7D also displays the *long-term target* resources: in this case, the 15.29 billion barrels for which no currently defined, economic technology is feasible. It is important to note that the targets for near- and mid-term strategies are stated in terms of *reserves* potentially producible at specific oil prices, whereas the target for long-term research can only be defined as a *resource*, of which only a portion can be expected to be converted to reserves and, thence, to production. Thus, each of the time-specific objectives of the strategy has clearly differentiated target resources and technologies, but they are highly interdependent.

Figure 7

Distribution of Original Oil in Place for Open Shelf, Platform System (TX, NM, OK)
(All Volumes in Billions of Barrels)



Original Oil in Place = 25.55

Source: TORIS Data Base, May 1989

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PROGRAM STRATEGY

The *Hydrocarbon Geoscience Research Strategy* identifies the major issues to be addressed by the Oil Research program: preserve access to the remaining oil resource currently in danger of abandonment, and address the reservoir properties limiting the amount of oil that can be economically produced. The first is clearly a near-term issue that must be successfully addressed to assure potential application sites for the mid-term results of the second. The program also recognizes the Department of Energy's increased emphasis on contributing to the national effort to improve the environment.

A great deal of experience has been accumulated under the Oil Research Program since the 1970's, and the lessons learned have been used in developing this implementation plan. The first major oil RD&D management plan focused on a suite of field tests of advanced EOR processes that were cost-shared with the industry. This program produced a great deal of information and has contributed greatly to the current appreciation of the formidable problems to be overcome before EOR can be widely used. This program also stands as a vivid demonstration of the willingness of the producing industry to enter into cost-sharing projects of this nature. In general, there is a willingness to share advances in production technology. This philosophy was reaffirmed many times during the discussions that led to the *EOR Initiative* that was published in 1987.[26]

The DOE initiated a large number of projects with the EOR Incentive Program. Many of them were joint ventures unitizing properties operated by both large and small producers. These efforts showed that, under the proper circumstances, large and small companies can work together for mutual benefit. In most of these cases, the actual project was designed and operated by the larger company in the partnership. Most of the operators continued to file annual reports on progress even after the requirement was changed from mandatory to voluntary. This, again, shows a willingness to share experience with advanced production technology.

Technology transfer activities have also provided a useful forum for the continued exchange of experience and information. Beginning in 1975, the Oil Research Program has published a quarterly progress review of all sponsored work. Initially the reports covered the cost-shared field tests. The reports have evolved along with the program so that more recent editions have focused on research in chemical and gas flooding, thermal recovery, geoscience, resource assessment, emerging microbial technology, and environmental science. Nearly 60 volumes have been published to date, and the reports have been well received by industry and academia.

The current broadening of the effort to include near- and mid-term objectives results in greater emphasis on information of immediate oilfield use, such as reservoir simulation software for personal computers and polymers for mobility control and profile modification. The availability of this information is noted in regular publications lists that are given wide distribution throughout the petroleum industry. In addition, there is a continuing effort to establish closer contact with the many independent producer organizations. Regarding this work, the Interstate Oil Compact Commission (IOCC) has recently completed a series of surveys and workshops to determine the best approach to reaching this important audience.[27]

Annual meetings, initially sponsored by the oil program to report on all supported activities, have since been combined into a highly successful series of biennial symposia on EOR, jointly sponsored with the Society of

Petroleum Engineers (SPE). These meetings have attracted a large international attendance and show the degree to which the public and private sectors can cooperate for mutual benefit.

The Oil Recovery Technology Partnership, a cooperative research venture between the Sandia and Los Alamos National Laboratories, oil companies, and research organizations, was formed to adapt advanced technology developed under the weapons program to uses in the oil industry. The Partnership is currently operating two field projects with independents to assess the effect of fractures on production, and coordinates the Crosswell Seismic Forum, a multi-company consortium focusing on the development of improved downhole seismic instruments for crosswell tomography.

Another major example of cooperative experience is the National Petroleum Council (NPC) study of domestic EOR potential that was published in 1984.[28] This major study was the result of hundreds of man-hours of effort by both industry and government professionals. The participating companies all contributed to the creation of a reservoir data base that represents about 70% of the oil found, essentially all of the larger fields defined as those with over 50 million barrels of producible oil. In addition, the member companies provided the data used to calibrate the EOR process predictive models used in the study. DOE's Bartlesville Project Office (BPO) has maintained that system, called the Tertiary Oil Recovery Information System (TORIS). The reservoir data base itself is available from the NPC for reproduction costs, and BPO has published the models in both mainframe and PC versions.

TORIS has been made available to support specific states as they have evaluated their own options for managing the future of their oil resources. Under the auspices of the Interstate Oil Compact Commission (IOCC), Oklahoma, New Mexico, and Texas have each analyzed in detail various policies and their impact on future state oil production. These analyses were conducted and paid for by the states themselves, but were supported by DOE through provision of the required TORIS computer runs at no charge. With the support of the states, principally Texas through its Bureau of Economic Geology, DOE has gone on to examine the potential for producing additional mobile oil in the three states. This example of a cooperative effort between the producing states and DOE has also been considered in the development of the RD&D program plan.

The strategy pursued by the new Oil Research Program to meet its goal and objectives integrates current policy direction, the understanding of the potential, urgency, and constraints of the remaining known oil resource, and the substance of the objectives themselves. This integration follows five simple and direct tenets:

- *Be Selective.* The mid-term component of the program will concentrate selectively on the reservoir classes having the greatest recovery potential taking the most urgent first, on the basis of projected abandonments. Program activities will be driven by the characteristics of each of these high-potential reservoir classes. Following the classification and ranking of the entire domestic resource, DOE will work with industry and the states to identify the problems and promise associated with each class for the near term (preserving access) and the mid term (recovering the next crop of oil using advanced technologies). Preparatory analysis and consultation with industry and states will assure that program activities will address a large enough fraction of the resource to have a significant impact on domestic production capability, and that there is a reasonable probability of success *within* recognized time constraints (i.e.,

resource access and technology availability).

- *Do Field Work On Selected Classes.* Field work is necessary to prove advanced technologies that have already been tested in the laboratory or partially tested in the field. The problems encountered in applying advanced processes to complex heterogeneous reservoirs can best be solved by an interdisciplinary approach in the field. By concentrating on solving the problems of specific sites, scientists and engineers from the respective disciplines are encouraged to overcome disciplinary barriers for integrated, practical technological advances. DOE will rely on industry to participate in the selection of demonstration sites. Use of consortia representing both the technical disciplines and the geographical extent covered by each class will be encouraged as a mechanism to address the actual problems identified. Field trials will focus RD&D on the problems that will critically influence the success of widespread application of these technologies among operators and will demonstrate the extent to which the reservoir similarity theory holds.

- *Support Field Work With Targeted and Discipline-Oriented R&D.* Research will support field work by including both *discipline-oriented* projects that have cross-cutting application to multiple reservoir classes and *targeted* projects designed to solve specific technical constraints encountered during field trials at actual reservoir sites. In general, the geological and engineering constraints that are encountered in the field work will serve as problem definitions for the more disciplinary research. Priorities among such problems will be derived based on the significance of the constraints in the field work and the priority of the reservoir class(es) affected. Success in supporting research will be defined by the extent to which its solutions reduce the original constraints in the field or contribute to the understanding of basic processes and reservoir properties, permitting progress toward maximized producibility. Note that this Implementation Plan does not define the scientific research program in detail, because this must be developed in response to the problems that will be identified as work begins on specific reservoir classes, and will be documented in future implementation plans.

- *Exploit the Available Interdependencies and Synergies.* Some critical interdependencies are inherent in the strategic approach:

  — Success in the mid-term objectives, for example, presupposes a high degree of success with the near-term objective of maintaining access to the reservoirs.

  — It is clear that some of the technical constraints that currently limit producibility are common to a number of high-priority reservoir classes, suggesting major synergies in the supporting research. A matrix organizational structure is proposed to capitalize on these interdependencies.

  — The evolution of long-range research is partly based on the findings of mid-term activities both in the field and in supporting research.

  — Synergies can be found in considering both mobile and immobile remaining oil as simultaneous targets of integrated reservoir development plans. Preliminary work by BPO and Exxon point to production synergies and/or cost savings from integrated development.[29] Currently, only the most sophisticated operators routinely view both targets together; most operators consider only one or the

other target in evaluating intensive reservoir management.

— The program will seek synergies in dealing with the states, in that state initiatives can make great contributions toward advancing the program goal, in a mutually beneficial manner. Such potential initiatives include true, risk-based assessments of recovery potential, regulatory reform such as in well spacing requirements, and regulations affecting well abandonment procedures.

- *Focus Technology Transfer Activities.* Technology transfer will be integrated across all three time orientations, oriented to the individual problems and opportunities of each reservoir class. Each class is likely to have members in many states, requiring consideration of regulatory, environmental, and other issues. In the near term, the program will concentrate on the identification and then wide application of successful, available technologies, working closely with the operators, service companies, consultants, state agents, and others active in the highest priority reservoir classes. DOE will keep them informed of the progress of advanced technology R&D, transferring that technology in the mid term as the experience with field RD&D allows an evaluation of reservoir similarity. The research community will be kept abreast of developments in both mid-term RD&D and long-term research.

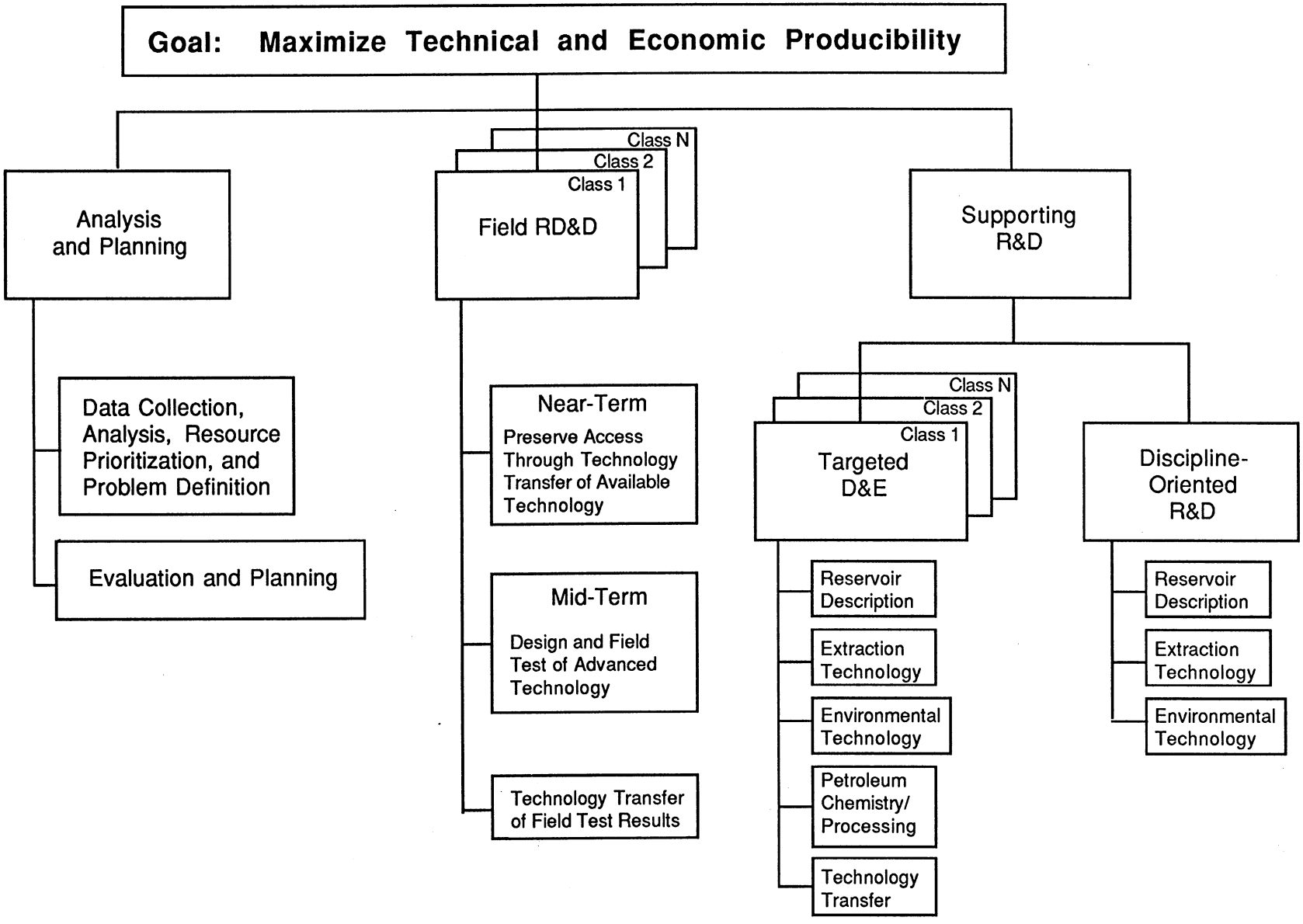
These basic tenets of the program strategy define a Work Breakdown Structure (WBS) for the program, illustrated in Figure 8. The three major components are: Analysis and Planning, Field RD&D, and Supporting R&D. Technology transfer and environmental work are integrated within each of the latter two components. Evaluation and Planning, a subcomponent of the analytical component, addresses the management function of monitoring and integrating the three components and adapting the program based on progress and relevant external developments. Each of the three principal WBS components spans the three time frames that have been described, though each also has a focus of activities. Thus, the analysis strategy is operational throughout the elements of the program, but many of the critical tasks in data collection, analysis, and problem definition will take place in the near term. Field RD&D focuses on the near term and mid term, but is most extensive in the latter. Supporting R&D, while providing vital support for mid-term field RD&D through targeted development and engineering (D&E), also carries a long-term focus for much of its discipline-oriented work.

Analysis Strategy

The strategy for Data Collection, Analysis, Resource Prioritization, and Problem Definition is to collect detailed reservoir and performance data on as much as practical of the entire U.S. resource, categorize the reservoirs into distinct classes in terms of geological history, analyze the reservoirs individually to estimate their potential and urgency, rank these classes according to criteria that will effectively target the program's R&D and field activities, and then hold technical meetings involving industry and the states to identify problems and opportunities specific to each class. These individual tasks are described in the Program Logic section below. The result of this work will be a 13-volume set of reports that covers the methodology and the 12 highest priority reservoir classes, developed with the active participation of industry and the states. This effort is now underway and is scheduled for completion in FY 1993. It will result in a useful product on its own, to be completed regardless of the actions taken for other program elements, and will become a national assessment of the domestic oil resource that

Figure 8

Summary Work Breakdown Schedule



can be used by a variety of organizations for regulatory, tax, and other types of policy analysis.

The classification system that underlies the analysis strategy will be extensively peer reviewed, and then refined on a continuing basis as research and field results lead to better characterization and prediction of reservoir heterogeneities. The relationship between geologic history and production characteristics has been hypothesized for decades, while reservoir heterogeneities have only recently been shown to be an important factor in the predictability and success of secondary and tertiary recovery. An initial attempt at reservoir classification based on geologic history was made in the study of the resource in Texas, Oklahoma, and New Mexico,[30] which is now in the process of revision for broader application. This process of iterative refinement will continue until a system evolves that predicts heterogeneities and flow paths reliably and hence leads to much higher recovery efficiency.

The selection of the twelve high potential reservoir classes will be based on priorities established with multiple criteria, following the analysis described in the preceding section. The most important technical ranking criteria are the potential for incremental recovery by advanced technology and urgency, which is defined by how much time remains before access is lost to a large part of the class because of well abandonments. Other criteria may also be applied to classes with similar potential and urgency, including: a) the quantity of the total remaining resource, because classes with large remaining resource after advanced recovery will provide relatively larger targets for long-term research; b) technological uncertainty, because RD&D's ability to relax constraints within the mid-term may vary with different technology options; c) industry structure within the class, because the number or size of operators within a class may influence the effectiveness of technology transfer activities; and d) geographical distribution, because classes with reservoirs in several oil producing provinces will allow program benefits to be shared widely.

With the twelve highest priority reservoir classes identified, and the problems defined for each, decisions can be made regarding the number to be actually addressed through focused field work. For planning purposes it has been assumed that ten of the twelve will actually be addressed. The actual number can only be determined after the problem definition step has been completed.

Geographical considerations are listed among the criteria for consideration because the participation of the widely dispersed industry segment of independents is vital to the success of the program. The majority of the highest potential classes of reservoirs will have members in each of several producing regions. Efforts to reach a broad spectrum of independents may best be addressed in the selection of specific sites for field work and the methods of coordinating technology transfer with operators and others in the respective states.

There are very real technical risks associated with achieving the mid-term production potential. The analysis strategy and overall implementation plan deal with these risks in a number of ways. First, the program will identify the problems associated with the twelve most significant classes. While some may present problems that ultimately prove to be too difficult to overcome, some should be easier than expected. Second, within each class, the plan calls for addressing at least two distinct geologic plays; here too, having two opportunities spreads the risk. Third, at least two reservoirs will be addressed within each play. Finally, the reservoirs will be chosen to assure that they, individually, represent significant economic potential.[31] Thus, even if the similarity hypothesis is not verified, demonstration will have been

accomplished in reservoirs with significant potential. Recognizing the urgency of this problem, the portfolio approach is considered the most prudent.

Near-Term Strategy

The first order for Field RD&D is to preserve access in the most urgent reservoir classes, to assure that the opportunity for additional recovery is not lost or severely restricted. Once the top priority reservoir classes are identified by data analysis, problem definition will commence with a technical meeting for each class. Operators, service companies, and others will participate in a discussion of industry experience with projects in the class, to identify the actual opportunities consisting of the most effective, *currently proven* technologies, and the target audience for increasing their application. Participants who have conducted these projects will be approached to provide more detailed, project-specific information. This information will be used in two ways: first, it will directly support the technology transfer efforts and second, it will be formulated and analyzed in the form of ex-post experiments that attempt to define key elements in making the respective technologies successful. The technology transfer activities carried out to disseminate waterflooding technology by the Bureau of Mines (BOM) in the 1950's is an example of how to use existing projects, site visits, and "success stories" to transfer technology rapidiy. Three issues typically limit application of "unfamiliar" technologies: lack of information, lack of expertise, and lack of capital. The program can most effectively address the first of these, giving impetus for operators to seek assistance from consultants and service companies for the second, while a better publicized record of success (and financial incentives which many states are implementing) will address capital needs. The BOM reports provided detailed data of selected waterflood projects, which we can use as a guide in reporting field work. Additional guidance can also be obtained from various state technical assistance efforts to independents, such as the very successful work in Kansas under their Tertiary Oil Recovery Program (TORP). Most independents need more information on a wide range of reservoirs to stimulate their implementation of recovery techniques they have not used before. Working directly with the state agencies, service companies, consultants, operators of high priority reservoirs, and others will maximize the application of the most cost-effective current technologies.

While the near-term strategy clearly focuses on the transfer of currently proven technologies, some field work and laboratory research will also be employed. In some reservoir classes or some specific plays within classes, promising, currently available technologies may never have been demonstrated. In such cases, limited, highly visible demonstrations, generally cost-shared with operators, states, or others, will be conducted to complement the on-going technology transfer efforts.

Consistent with the near-term goal to demonstrate and promote more widespread application of state-of-the-art technology, the program will assist domestic service companies and equipment suppliers on a cost-share basis to improve international competitiveness. Government-supported foreign companies have taken over much of this industry; working closely with domestic service companies and suppliers to facilitate the application of technologies that the Oil Research Program is striving to achieve will stimulate the industry and further support domestic producibility.

Because of the short lead-time imposed on the near-term strategy — the results of the work to be fully effective within five years — the role of supporting development and engineering (D&E) or discipline-oriented research of a fundamental nature will necessarily be limited. Some assistance is

anticipated in assessing apparently effective, existing projects or in consultation and laboratory support in the design of demonstrations of currently available technology. Environmental work, however, is expected to have significant near-term impact.

Even under the best of circumstances, some reservoirs near their economic limits will not be amenable to extending production by currently available technologies. To preserve access to the resource in such reservoirs, technology transfer efforts will be complemented by near-term, discipline-oriented research to develop and demonstrate environmentally sound, cost-effective ways to avoid well plugging with cement. Techniques such as fluid level monitoring, retrievable bridge plugs, and logging to detect fluid movement could be combined with area-specific risk assessment to determine sound ways of extending the period before plugging and abandonment is required. Where there is no alternative to plugging, environmentally safe, economically reversible plugging technology could serve as a fallback. These methods include the use of alternative materials to cement for sealing the well bore after the casing and surface equipment have been salvaged by the operator. The benefit of reversibility would be that, as the mid-term research yields more cost-effective technologies that would be viable in such reservoirs, the high cost of re-entering or replacing the wells could be avoided. Re-entry operations, including removal of the plugging material and well workover, could be initiated by the same operator or by a new producer, perhaps after renegotiation of the lease. These program activities related to temporary well plugging will take place on a class-specific basis in close association with EPA, the states and their regulatory agencies with authority over abandonment procedures.

To the extent that the near-term strategy is successful, economic access is maintained to the reservoir classes with the highest potential for application of technology to be developed under the mid-term strategy. While the incremental potential reserves attributable to the near-term strategy are significant in their own right, the largest benefit of the near-term strategy is maintaining the potential of the mid-term strategy. Thus, these two strategic components are inherently and intimately interdependent. To be fully successful in either requires success in both.

Mid-Term Strategy

The mid-term strategy focuses on resolving the technological and economic uncertainties that limit application of currently defined advanced technologies in specific reservoir classes. Again it must be stressed that both urgency and the development of advanced technologies must be addressed to achieve the program goal. Advanced technologies must be improved to achieve the significant addition to producibility that represents the opportunity now present. But urgency must also be addressed, to preserve that opportunity before much of the potential vanishes.

The mid-term strategy will entail a significant commitment to field work. While the advanced technologies that will be selected for mid-term RD&D have generally already been verified in the lab, field work is needed to improve and demonstrate their cost-effectiveness and predictability. Some of the phenomena of critical importance, especially the effects of large-scale heterogeneity, can only be examined at the reservoir scale. Furthermore, the industry is not likely to invest in advanced technologies at any significant level until they are proven; field RD&D is essential to achieve the potential of advanced technologies in the time frame specified by the urgency of the problem.

Mid-term field RD&D is scheduled to begin as soon as possible. The FY 1991 budget contains a request to initiate field work in two reservoir classes, as described in the

Tactics section later in this Implementation Plan. Technical meetings with industry will be held for each of these classes in FY 1990 for the problem definition step necessary to plan field activities. The management plan developed to carry out the mid-term strategy for these and subsequent reservoir classes are also described in the Tactics section. This plan is not yet definitive with regard to specific field activities, because we have not yet identified the first reservoir class, nor held the meeting required for problem definition. However, we have developed a detailed *example*, described in Appendix D, that is suggestive of the process of defining initial field RD&D activities.

The similarity theory, if it holds, will permit the extrapolation of results from a few reservoir sites to many. Therefore, the number and structure of field sites selected will support testing of reservoir similarity, to provide a basis for effective, widespread application of advanced technologies. The field strategy will be to select at least four specific sites (two reservoirs in each of at least two geological plays within each high priority class) to provide a basis for evaluation of the theory with respect to each class. The selection of sites may be based primarily on recovery potential. The selection of the reservoirs with the largest amount of the resource and recovery potential in each class will assure that the most important segments of the domestic resource are addressed by the program regardless of whether the similarity theory proves to be correct.

The greatest potential for effective problem-solving will be highly site-specific. Much of supporting R&D will respond directly to requirements defined during reservoir description, simulation, and process design at specific reservoir sites, with time constraints to assure implementation of the advanced technology in the mid term. Site-specific problem definition permits the focused contribution of the respective disciplines and their interactions on a limited set of concrete problems. Only by selecting specific sites to test the reservoir similarity theory will it be possible to formulate generalizations about the heterogeneities and their effects for whole classes of reservoirs. This relationship of specific experimental sites to the class as a whole is critical to developing advanced techniques and defining the conditions under which they may be applied.

Field work at each site will begin with in-depth reservoir description to define internal architecture, heterogeneities, and flowpaths. This information will be used with the best available simulators to define the conditions that must be met for cost-effective incremental production. The probability of meeting these required conditions in a timely manner will be evaluated before making a commitment to proceed. Some targets may shift from mid to long term as a result of this analysis. A positive decision will result in starting specific research and field projects. Results from this initial work will be evaluated before a final decision is made to proceed with the actual field demonstration. If the probability of success is found to be too low at any point, other sites or even other reservoir classes may be chosen. This approach is one of the major risk management mechanisms incorporated in the program.

The field work at each site, generally cost-shared with states and/or operators, will be conducted in an interdisciplinary fashion, integrating detailed reservoir description, reservoir simulation, extraction process design and testing, and post-test evaluation. Reliance on site-specific interdisciplinary units is anticipated to help bridge disciplinary differences, to focus and refine the possible solutions, and to achieve the advances in technology anticipated. As this field work proceeds, certain technical constraints will be encountered that exceed the capabilities of the site-specific team of geologists and engineers. These constraints are posed as requirements

for solution by separate, more traditionally disciplinary, supporting research. As this research yields solutions, they are incorporated back into the field work. Priorities among these requirements for solutions are determined by the number of classes they might benefit and the magnitude of that benefit in each.

Supporting research will be conducted in five principal categories: (1) Reservoir Description methods, tools, instrumentation, and modeling; (2) Extraction Technology in each of the major recovery techniques, including drilling, secondary, and tertiary processes; (3) Environmental Technology covering air, water, solid waste, and wetland management techniques; (4) Petroleum Chemistry/Processing covering constraints on heavy oil production such as refining problems; and, (5) Technology Transfer, particularly in addressing the needs of the smaller producer. This defines an interdisciplinary strategy involving both discipline-oriented research that addresses technical constraints in more than a single reservoir class and targeted D&E designed to address site-specific constraints encountered during mid-term field work.

The discipline-driven R&D will broadly support field work. It will be defined in an interdisciplinary approach to assess the existing reservoir description and extraction process technologies to identify and prioritize research requirements. Discipline-driven research will include algorithm development to support geologic and process modeling, development of advanced instrumentation techniques, improved understanding of rock-fluid flow properties, and other projects that will broadly support the reservoir description and process design activities conducted in field RD&D. The results of this research will cross-cut the reservoir strategies, and research design will seek synergies in addressing the research needs of multiple classes.

As in the near-term strategy, technology transfer is a critical part of the mid-term field work/supporting D&E/demonstration process. To assure an effective transfer program, federal managers responsible for each high priority class will work directly with the appropriate agencies in each state containing that class of reservoir. In collaboration, federal and state officials will reach out to operators, service companies, consulting geologists and engineers, and other researchers to develop and refine effective technology transfer mechanisms. To gauge the effectiveness of these mechanisms, field applications of the emerging technologies will be extensively monitored and evaluated. Results can be measured by tracking the application of advanced technology within the reservoir class and its effect on production and the rate of abandonment. Then the technology transfer approach may be modified if results are not satisfactory. Clearly, novel approaches to technology transfer will need to be developed to home in on what will be most effective; the current program focuses technology transfer efforts primarily on the research community, whereas operators, consultants, and others must be targeted to effect production directly. The Bureau of Mines experience with transferring waterflooding technology to independents in the 1950's will be instructive in this regard.

Near-term technology transfer activities will lead into the transmission of mid-term field results due to the forging of personal relationships with key parts of the industry. Technology transfer is not an end product in this program, but is part of an ongoing process that provides a vital link between the time orientations of the field and supporting R&D activities and the ultimate users of results. In preserving access to the resource, it also establishes an important link with operators for ongoing work. As R&D progresses, this link can be used to report on developments in advanced technology, preparing operators, service companies, and

others for the next step in technology application. In transferring mid-term results, the results of the evaluation of the similarity theory in the particular class will establish the conditions for application of advanced technology, first to other reservoirs within the play and then to similar reservoirs in other plays within the class. This approach will minimize failed applications of the technology and maintain a credible link with operators, which will in turn be important for the future application of technologies developed to recover the remaining resource.

Long-Term Strategy

The long-term strategy involves primarily research activities: fundamental research in geoscience and extraction technology that is expected to have benefits cross-cutting many reservoir classes, and research focused on improving the understanding of oil that cannot be recovered using currently defined technologies. The program will continue to conduct the fundamental research that has been the traditional Federal role. This is still necessary. The oil program must maintain a strong basic research component in extraction technology and geoscience to support the more applied, problem-oriented R&D that will take place during field demonstrations, and to hold the door open to potential breakthroughs that could significantly reduce costs or increase recovery efficiency. The program will continue to work extensively with universities and National Labs to carry out this research. University research is vital both in terms of the scientific results which maintain the nation's technology lead in the oil industry, and in the training it provides for engineers and geoscientists who will be needed by industry in the future.

The program plan must have flexibility to encourage innovation, the potential breakthrough concepts sought in the long term strategy. A small fraction of the total resources — about 10% of the discipline-oriented R&D budget — should be set aside for new ideas and windows of opportunity to stimulate such breakthroughs. The program must not be so constrained that it has no flexibility to take advantage of new opportunities.

The second important focus for long-term research is the oil that remains after application of advanced secondary and tertiary recovery technologies. This resource includes two major target categories: large reservoirs not amenable to currently defined near-term or advanced technologies, such as low-permeability, fractured, and deeper heavy oil reservoirs; and oil remaining in reservoirs that are technically amenable but were not completely swept by advanced technology recovery processes, such as the many CO_2 projects with low recovery efficiency of the targeted immobile oil, and residual oil left after successful thermal recovery operations. This resource is so vast that it justifies a high-risk search for breakthrough technologies, though technologies are not yet defined that can recover this oil. Some of this research will consist of detailed descriptions of the problem reservoirs to attempt to refine the definition of the constraints that an effective extractive technology would have to overcome. Also included would be initial evaluation of highly innovative techniques for possible application in any of the time frames. Long-term research will also provide the opportunity to follow up promising technical leads identified in the mid-term supporting research. Much of this long-term research will be discipline-specific with synergies applicable to mid-term field work in reservoir classes. Technology transfer for the long-range strategy will concentrate primarily on the dissemination of scientific results to other researchers (including federally sponsored researchers focusing on the near and mid terms), who can then refine the findings into means for improving the producibility of this most difficult-to-recover oil.

PROGRAM LOGIC

The program logic describes the flow of tasks within the program's major structural components and the interactions between the components. Whereas the program strategy describes what will be done to work toward the program goal, the logic describes how these tasks will be linked together. The major structural components — Analysis and Planning, Field RD&D, and Supporting R&D — are those of the work breakdown structure illustrated previously in Figure 8. Principally, the logic flow describes how tasks are linked and the order in which activities will occur. However, in practice the tasks within the major structural components are proceeding in phases, allowing many activities to proceed simultaneously and benefits to be realized early for reservoirs needing urgent attention. The phasing and working schedule of activities are described in the following section and in detail in the tabs attached to this implementation plan.

There are several basic issues that pervade the program logic and deserve mention in introduction. First, at each step undertaken in the sequence of tasks that constitute the overall plan, the industry will be called upon to play an important participatory role to assure that Federal efforts are pragmatic and consistent with the real constraints, opportunities, and events that are shaping the domestic oil industry. This plan, while a significant expansion of past Federal research activities, seeks not to overstate the Federal role nor to "interfere" with industry practice, but to facilitate joint cooperation, recognizing that the Federal government, the states, and industry each have important strengths to offer. Second, program activities will be consistent with the priorities to be put forward in the National Energy Strategy (NES), now being developed. Whereas the principal program goal and time-specific objectives of the program are not expected to change, additional objectives may be incorporated in response to the release of the NES in December 1990, and will most likely be articulated in the Implementation Plan for FY 1992. Finally, it should be emphasized that many of the activities described in the Program Logic are already underway. The first phase of data collection and analysis is already complete, and work on the remainder is already in progress. Much of the existing program is consistent with the objectives of Supporting R&D described in this plan. The problem definition work for each class will permit better, more active use of results from the existing program.

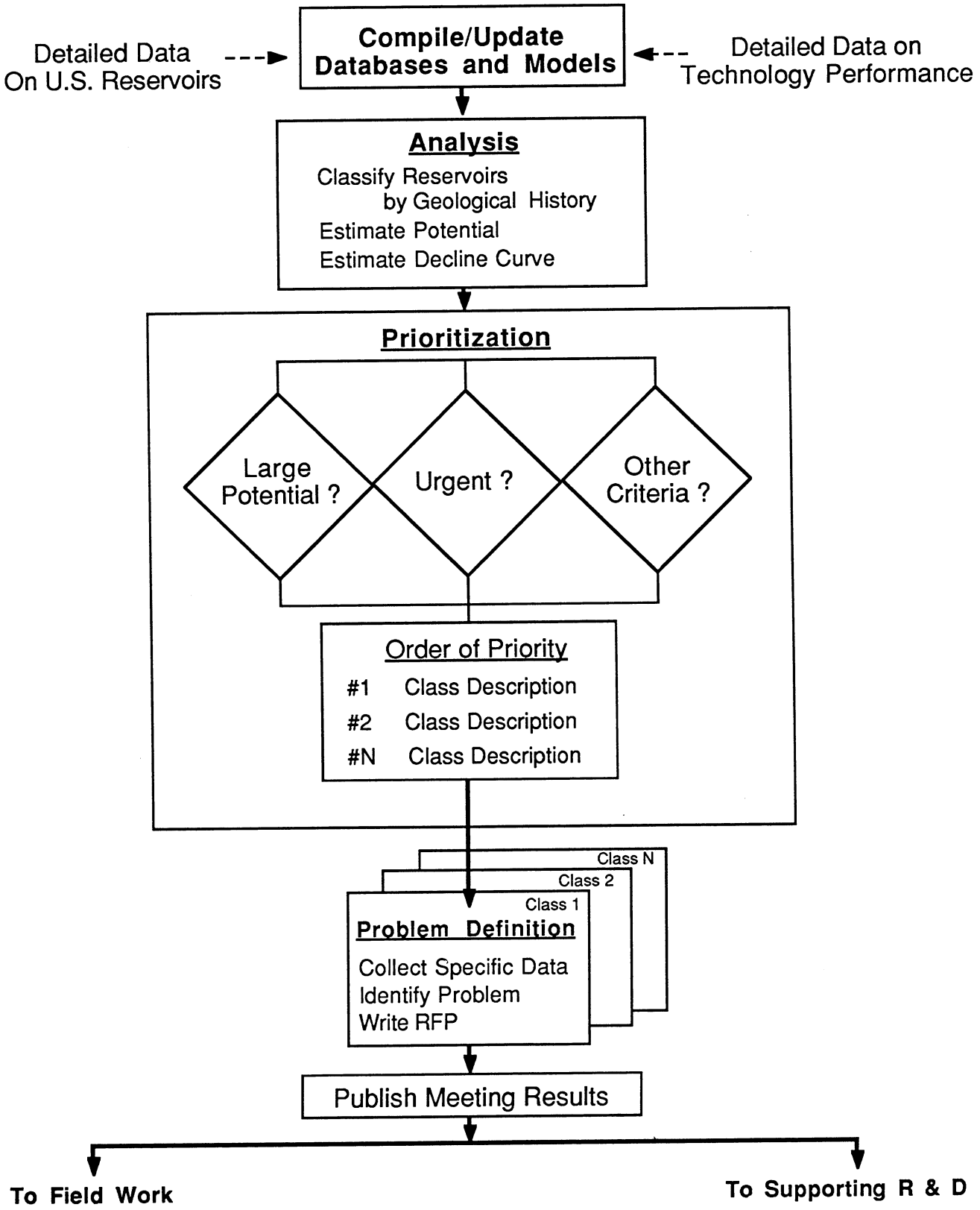
Analysis and Planning

The identification and prioritization of reservoir classes precedes all other activities in the program's logic flow. Data analysis targets the field RD&D and supporting research activities to maximize the program's impact on resource producibility, focusing on the issues of urgency and incremental potential recovery. Figure 9 shows the logic flow of data analysis activities.

Detailed information on U.S. oil reservoirs and on technology performance are being collected to characterize and rank the resource. Thus far, data collection is complete for three states — Texas, Oklahoma, and New Mexico — representing over 40% of the remaining U.S. oil resource. With a few notable exceptions, the vast majority of the needed data is available but is not complete for the entire U.S. The initial funding has already been obligated for the classification and analysis of all Lower-48 onshore reservoirs that are already in the TORIS data base. Classification and analysis of large onshore reservoirs that are not yet in TORIS will follow. The state of Alaska already has a data collection task in process under a state MOU, while data collection efforts are scheduled to be initiated for the Appalachian states and Federal offshore areas in FY 1991.

Figure 9

Data Analysis Logic Flow



The database is being expanded to include reservoir data representative of the entire U.S. resource. As a practical matter, the process of collecting data on the full U.S. resource is being limited to only the largest reservoirs and is being conducted in four phases, focusing first on the onshore Lower-48 resource so that the most urgent reservoirs are incorporated into program planning early. Once the data is available, these four phases drive the critical analysis, as shown in Figure 10. Each phase includes data collection, analysis, and ranking of reservoir classes using the expanded database. This process has already been completed for the first phase, which included Texas, Oklahoma, and New Mexico.

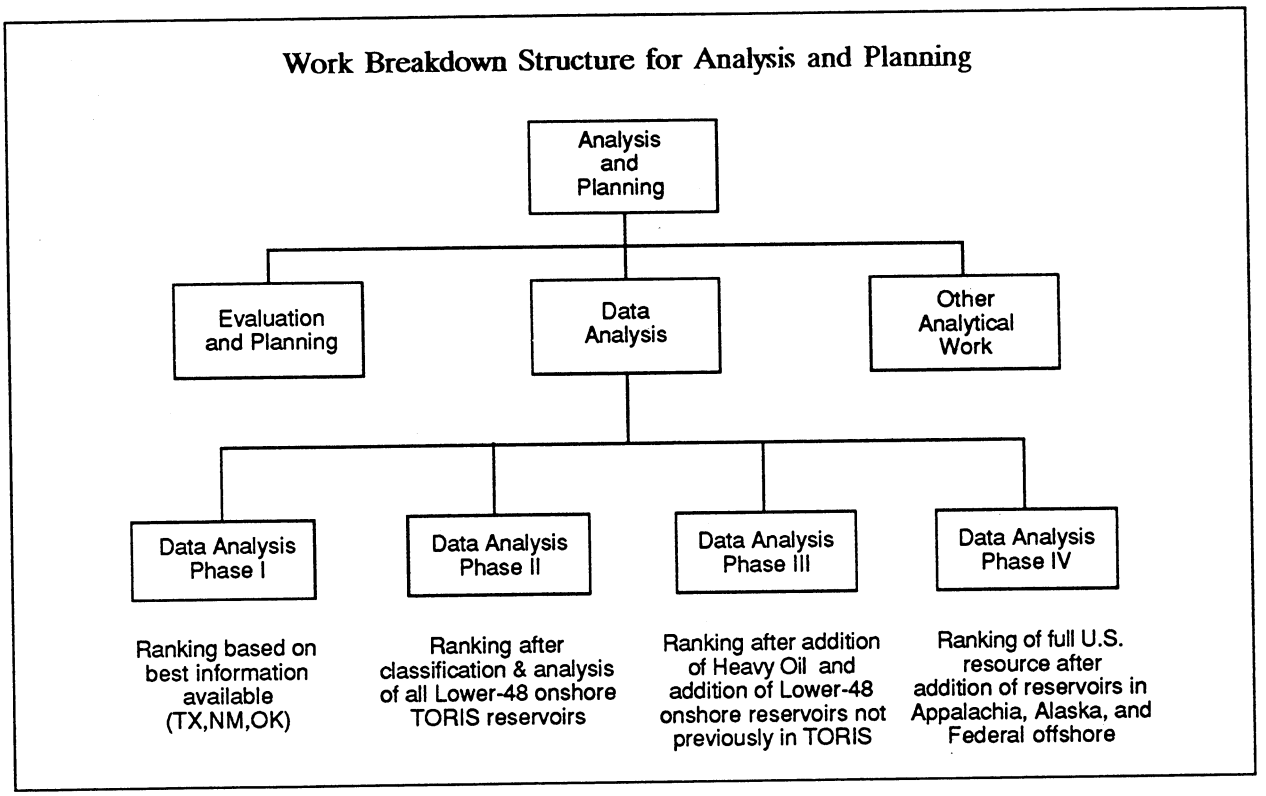
Data collection begins by working with individual states to enhance DOE's Tertiary Oil Recovery Information System (TORIS). Each state's geological survey, or other appropriate state agency, locates the major reservoirs and classifies them into plays and classes, using TORIS and the classification system that is now undergoing revision. TORIS is used to assess the potential incremental recovery of each class, and urgency is evaluated using production reports and Petroleum Information (PI) Services data. The states thus perform a vital role in this step of the program plan, and will also be developing an important resource in TORIS. The Interstate Oil Compact Commission, itself an agency of the producing states, is integrating the current phase of the data collection effort.

The reservoir data are assessed according to the criteria which are used to prioritize the reservoir classes. The principal criteria are the technical and economic potential of mobile and immobile oil recovery using both implemented and advanced technology, and the estimated effect of abandonments on reserves and production as a function of time. Other prioritization criteria may include the total quantity of remaining resource, geographic distribution of the reservoir class, technological uncertainty of the processes that will be applied to the class, and the industry structure of operators in the field. Reservoirs will be grouped by class and play, and plays grouped into classes based on geological history — characterized by deposition system, diagenesis, and tectonic history.

Having classified the resource, reservoir classes will be ranked using an objective function that weighs the relative importance of the prioritization criteria described above. The highest priority classes will have the greatest potential reserve additions with advanced technology and the greatest urgency due to prospective loss of access. After the full U.S. resource has been characterized and prioritized, it is anticipated that two or three of the top ten reservoir classes will be heavy oil reservoirs, at least one class may be in the offshore Gulf of Mexico, and the rest will be onshore, light oil reservoir classes. The initial selection of reservoir classes for field work before completing the full analytical effort, but using the best available information and process/economic models, with periodic updates, represents an important risk management approach to maximize the impact of a focused RD&D program.

The data collection, classification, and prioritization of the entire U.S. resource will take place as quickly as possible, so that the high priority classes can be identified and problem definition can begin. DOE will hold a technical meeting for each class to define its potential, promise, and problems. The intent is to rely on industry input in these meetings — through invited papers and working sessions — to identify the problems and issues for the full class. Use will also be made of published reports from earlier work that identified major geoscience requirements.[32] Most classes will include several states, and we expect representatives from all the involved states to participate in these meetings, including representatives from industry, state and local government, and academia. Results of each

Figure 10



meeting will be consolidated and published as a document that will become the source for program planning for the class and for anyone interested in the class (operators, state regulators, etc.). This full problem definition task will be completed for each of the 12 most significant national classes, resulting in a 13-volume set of reports (including one to describe the methodology). These published reports will be necessary to proceed with the next steps of RD&D, but will also be valuable ends in themselves.

The results of the problem definition task will be used to launch research and field activities. The technical meeting results will provide the information needed to proceed with procurement actions for the required field work. Emphasis will be given to the use of cost-sharing arrangements and the use of consortia of industries and universities already active in the class. This would provide maximum leverage of Federal funds and assure the most effective transfer of the resulting technology. With the daily activities managed by an appropriate industry group, operational efficiency would be assured. Oversight would be provided by the DOE managers. This role is described in the Tactics section. At least two reservoirs in each of at least two plays will be selected for field RD&D. In general, the sites will reflect the largest plays and reservoirs, although other criteria (e.g., geographic distribution) will also be considered. Project data and technology options available to the class, determined during the technical meeting, will define the requirements for near- and mid-term field work and discipline-oriented supporting research. These initial task definitions are important to develop budget requests and a

direction that will guide the early efforts of the field and research activities that follow.

The definition of initial tasks will be conducted in parallel with the data collection effort (Phases II, III, and IV) for the first two reservoir classes. Because the rate of abandonment is increasing and the budget formulation and approval process takes about 18 months while major procurements can take nine months or longer, it is important that work proceed in parallel rather than in series. Thus, it is proposed to begin the problem definition meetings before the second phase of data collection and analysis has been completed. If problem definition were delayed until this work is complete, projected to be in October 1992, then field RD&D could not begin until FY 1995, and valuable time would be lost. Accelerating the start by holding the first technical meetings in Summer 1990, during the second phase, allows field RD&D activities to begin in FY 1992. There is some risk that such early technical meetings would have to be repeated because of new findings, but this is a reasonable risk given the time bought by this approach.

A strawman has been developed for the site selection and initial R&D task definition that follow the technical meeting. This example is described in Appendix D, based on the two reservoir classes with the largest recovery potential in Texas, Oklahoma, and New Mexico: the Open Shelf Platform with Extensive Diagenetic Overprint and the Fluvial Dominated Delta. Appendix D describes the selection criteria, the plays and reservoirs, and initial research requirements. This example is provided for illustrative purposes only; the actual sites for the two classes selected will probably represent a wider geographic distribution once data from additional states has been collected and analyzed. Such a model, although tentative, was used to test the viability of the technical approach and to estimate the time and costs required to achieve program objectives. Future editions of the plan will incorporate more definitive plans based on actual problem statements.

Data analysis will be an ongoing activity, initially supporting field work and supporting R&D as the resource is characterized and later supporting program management to evaluate results. The Evaluation and Planning function performs two principal roles. First, it monitors program performance (relative to plans) and events in the field for effects of the program's efforts. This monitoring is the principal basis for program evaluation and the sources of corrective reprogramming to increase program effectiveness. Second, it prepares updated plans and budgets at the strategic and implementation levels.

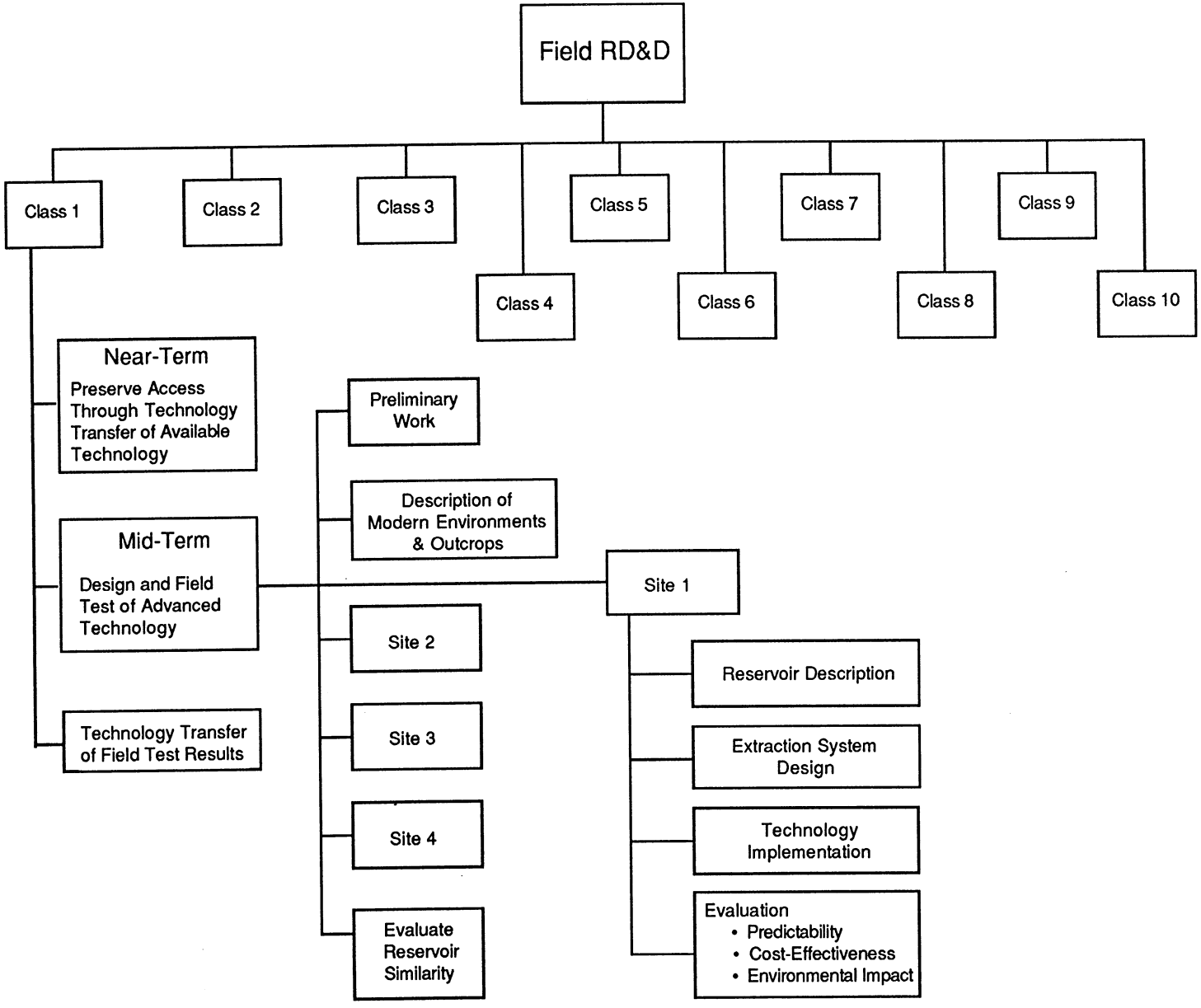
Other analytical work arises from the significant analytical capabilities that, while developed to support the research and reservoir prioritization, have significant application in projections, forecasts, and analyses of concern to other DOE and federal offices. The Oil Research Program will perform the analyses as requested by these offices.

Field RD&D

Field RD&D in carefully selected reservoir classes is the core of the new program's logic. All field activities will be class-specific; the entire logical sequence of tasks described below will occur for each reservoir class selected by the program. The work breakdown structure for Field RD&D is shown in Figure 11. For planning purposes, it has been assumed that field work will be conducted in ten of the twelve major classes identified, and that the work in each of these classes will have the internal structure detailed for Class 1, including near-term field work (primarily technology transfer), mid-term field tests, and technology transfer. The work breakdown for mid-term field tests includes preliminary work (site selection, evaluation of projects), description of modern environments

Figure 11

Work Breakdown Structure For Field RD&D



and outcrops for the class, work at each of the four sites selected, and evaluation of reservoir similarity. Each site has major tasks that include reservoir description, extraction system design, technology implementation, and evaluation of results. These major tasks will proceed in series, with each major phase of RD&D funded incrementally depending on the progress in the preceding phase.

Figure 12 illustrates the logic flow and linkages to the other program components. The technical meeting, with participation of states and industry representatives active in the class, will provide the critical input for determining the near-term activities needed to preserve access to the class. Current technologies will be selected for transfer based on those working economically in the field. Verification tests will be conducted when they are judged to be necessary to support effective technology transfer. The costs of field tests will generally be shared with states or operators. However, existing applications of the technologies will be used to the maximum extent possible.

The technical meetings on each class are also expected to identify the target audiences for technology transfer. Whereas the Bureau of Mines experience with transferring waterflood technology in the 1950's will provide an initial model, innovative approaches to technology transfer will be sought to achieve the rapid penetration needed to preserve access in as many reservoirs in the class as possible. We will be responsive in our efforts to what seems to be needed following broad-based input. To home in on effective approaches, results will be closely monitored.

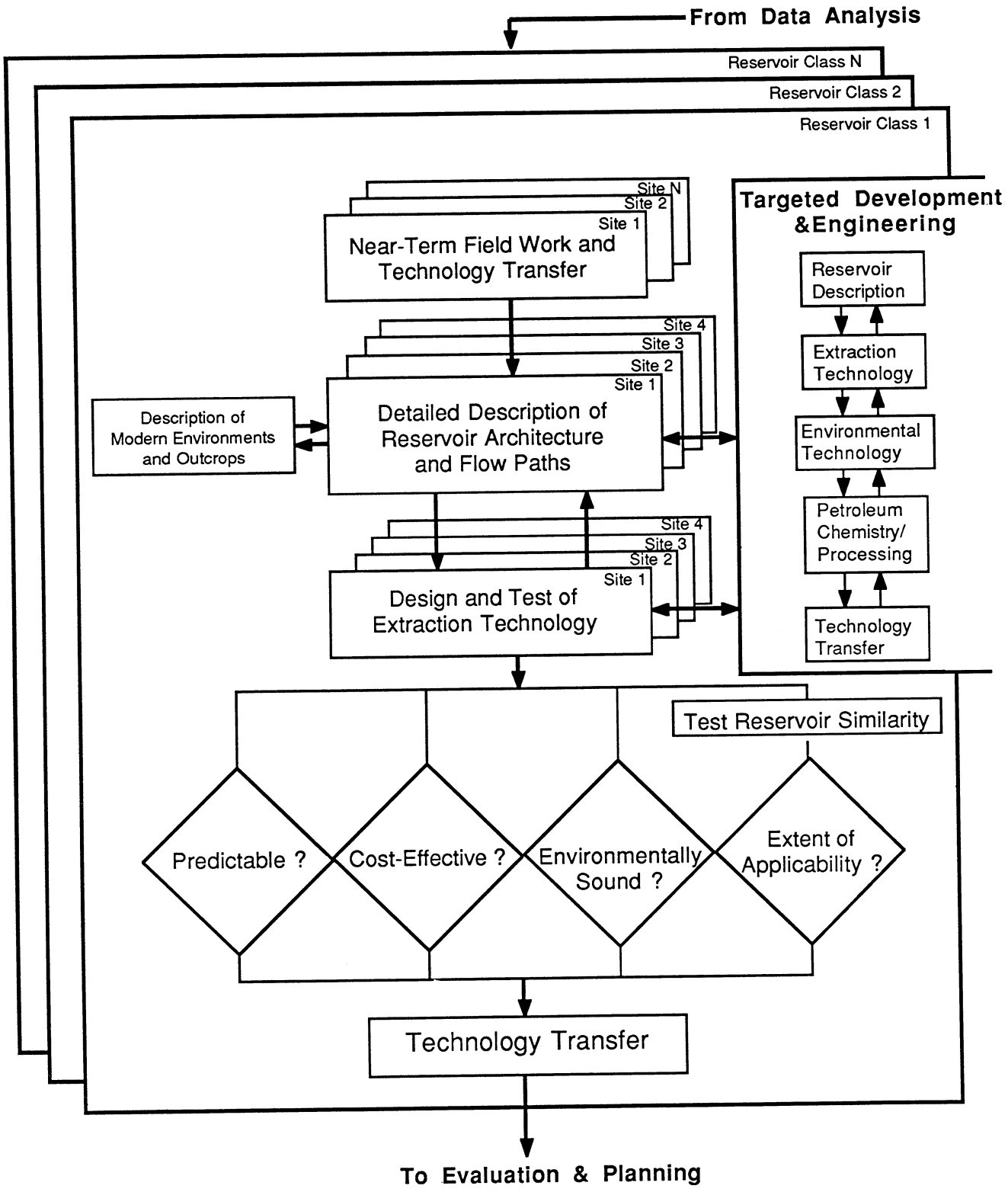
The technical meetings will present the first of several opportunities to discuss and assess the potential applicability of the reservoir similarity theory to the class. This will take place in the review of current projects. The second opportunity comes with the evaluation of near-term field demonstrations and broad application of current technologies. The results of these evaluations will provide guidance for the initial technology through efforts that follow mid-term field RD&D.

For mid-term field activities, at least two reservoir sites will be selected in each of two plays within a class, to provide a good test of the reservoir similarity theory. Sites within each play will generally be selected on the basis of the potential addition to reserves and production from the application of advanced technology. While other criteria may be used, this selection criterion guarantees that the largest amount of the resource in the class will be addressed, regardless of whether the reservoir similarity theory proves to be correct. Actual site selection will consider several factors, such as cost sharing, information that would result, general peer review results, and actual budget considerations. Selected sites will address the scales, styles, and dimensions of reservoir heterogeneity in the class at reservoir, outcrop, and modern environment levels, also to provide representative characterization of the class to support the similarity test and subsequent transfer of field results. Existing projects may, in some cases, meet the requirements of one or more of the required four tests indicated in Figure 12.

Preliminary field work will involve the quantitative description of outcrops and modern environments that characterize the class. Study of modern surface environments is critical if the impact of reservoir genesis on resource recovery is to be fully understood. This study involves the classification of areal and vertical sediment patterns according to potential reservoir flow paths and barriers, and measurement of the volume and geometry of major depositional features. Evaluations at outcrops are important as they allow direct assessments of the geometry and continuity of reservoir compartments, and measurement of vertical and lateral variability in petrophysical parameters if they can be adjusted to account

Figure 12

Field RD&D Logic Flow



for unique erosion and other surface-induced alterations. This preliminary work will primarily involve analysis of existing data.

Field activities at the selected reservoir sites will begin with geological work to describe the reservoir architecture, heterogeneities, and flowpaths. The definition of reservoir heterogeneities is critical to the subsequent design of the extraction system and to the ultimate success of the project. As technical constraints are encountered during geological work, they define requirements for supporting development and engineering of instrumentation and interpretation techniques, and for basic research in heterogeneity description. At this point, history matching of primary/secondary recovery efforts to alternative descriptions of the geological structures will be a key tool to defining the reservoir architecture and to the subsequent step of calibrating the reservoir simulation for design of the extraction system. In some cases, the efforts at resource description to quantify heterogeneities may not succeed or may indicate that the complexity of the reservoir architecture at a particular site would severely limit the technical potential and cost-effectiveness of the extraction technology. The probability that supporting research and further field work could adequately resolve these conditions would be evaluated before the commitment to continue with the design of the extraction process. If this probability is too low, then another site may be chosen. If similar conclusions are being reached at other sites in the class, then an alternative reservoir class may be selected. This procedure is one of the major risk management techniques incorporated into the program. This will be one of the issues taken up in annual meetings on activities in each reservoir class, which will review progress and develop future plans with input from industry.

The design of the extraction system will depend on advances in reservoir simulation. Specific process designs will be site- and reservoir-specific. Lab testing and advanced process simulation will follow the preliminary design of the recovery approach. Technical constraints encountered during these activities will define requirements for supporting development and engineering (D&E) to obtain timely solutions as well as for discipline-oriented R&D. Another risk management evaluation would take place at this point. If the probability is too low that D&E will fail to relax process constraints sufficiently, and simulation indicates that the application of the process will not boost recovery cost-effectively, then the specific site can be abandoned at that time. This procedure allows an alternate site, or reservoir class, to be selected before the substantial commitment of funds to field demonstration.

As supporting D&E provides solutions to these constraints, the technology can be implemented in the field. This process of heterogeneity description, extraction system design, and field implementation will be closely integrated. This essential interdisciplinary collaboration is the key to the success of this plan. There may be some iteration of the process if unanticipated constraints are encountered during implementation. Careful management will be required to keep these activities on schedule. Time and cost constraints may limit these field tests to non-commercial scale, though they will be comprehensive enough to define commercial-scale application. Costs will be shared with industry or states to the maximum extent possible.

Progress of the field work will be monitored to assess environmental impacts and the effect of the technology on recovery efficiency. At this point, results from the field test will be evaluated to determine when the technology is ready to be transferred to industry. To support routine application of the technology, the recovery efficiency, hence ultimate production, and costs must be predictable with sufficient accuracy that

operators, consultants, service companies, and others can evaluate a potential project's economic viability. Predictability and cost-effectiveness are the key criteria. Discrepancy analysis will evaluate technical and economic performance, comparing the forecast to actual results. This evaluation addresses one of three critical questions that must be answered for successful technology transfer:

- Can the technology be made sufficiently predictable and cost-effective to permit routine application?
- Is there sufficient similarity among reservoirs (by play or class) to permit valid extrapolation of field-specific results?
- What is the best and most effective way to prepare the results and transfer the technology to the audience that can apply it to increase production?

The second of these questions will be addressed by evaluating the similarity theory for the class. The similarity theory will have already been evaluated with respect to the application of currently available technologies as a near-term activity. In the mid term, this evaluation will take place in two stages: first, when the descriptions of reservoir, modern environments and outcrops are complete for all field sites within a class, and second, when the field work is complete. This evaluation will support simulation of heterogeneities and the extraction process in other reservoirs in the class. The types and extent of similarity within each class will be refined to determine the extent and conditions in which technologies may be transferred.

Technology transfer of the field results will fit into the ongoing communication with industry in the reservoir class begun with the technical meeting and the near-term field work. Targeted operators, state agencies, and others will be kept informed while the field work is in progress. When the field work is complete and results are evaluated, a technology transfer strategy will be developed for each technology option with input from industry and the states, taking full account of the technical limitations to avoid "overselling" or misapplications of the technology.

The technology transfer effort will focus first on state agents, operators, consultants, and others at similar reservoirs in the same play as the field site. The effectiveness of the transfer approach will be monitored and evaluated, measured by the extent of technology application and the impact on reserves and production. Once an effective approach has been proven, the transfer target can be extended to other plays, incorporating the results of evaluation of the similarity theory for the class. Technology transfer will also make field results available to the research community, to support long-term and cross-cutting research.

Results from the mid-term field work will provide valuable information to researchers about the reservoirs, to improve the understanding of constraints on the recovery of oil remaining after the application of advanced technology. Long-term field work will address large reservoir classes which are not addressed by mid-term field work because they are not amenable to currently defined advanced technology, such as low permeability and fractured reservoirs. Drilling will provide the reservoir data necessary to further define the problems to be addressed by research.

Supporting R&D

The logic flow for supporting research proceeds from problem definition that occurs in the technical meetings, on an ongoing basis during mid-term field work, during interdisciplinary evaluation of cross-cutting R&D needs that will support multiple classes, and in response to new and promising ideas.

The structure of R&D work will include five broad categories, shown in Figure 13. The categories are oriented toward research disciplines but include projects developed in response to requirements defined in field work as well as more broadly applicable, discipline-oriented R&D:

- *Heterogeneity Description* includes geological, geophysical, and geochemical research. Three broad subcategories of R&D that will support field work include advanced instrumentation, advanced interpretation techniques, and fundamental geoscience research, each having project areas such as those indicated in Figure 13. These are examples that reflect the technical constraints that have been cited in the literature and in industry. The constraints of the highest priority reservoir classes will drive the R&D program as they are defined.

- *Extraction Engineering* also has three broad categories of R&D: reservoir performance simulation research, advanced primary/secondary recovery, and advanced tertiary recovery, each with project areas such as the examples in Figure 13. Generally, each reservoir class has a dominant recovery process associated with it. Thus the selection of high priority reservoir classes will also focus extraction engineering R&D on the applicable processes to support mid-term field work.

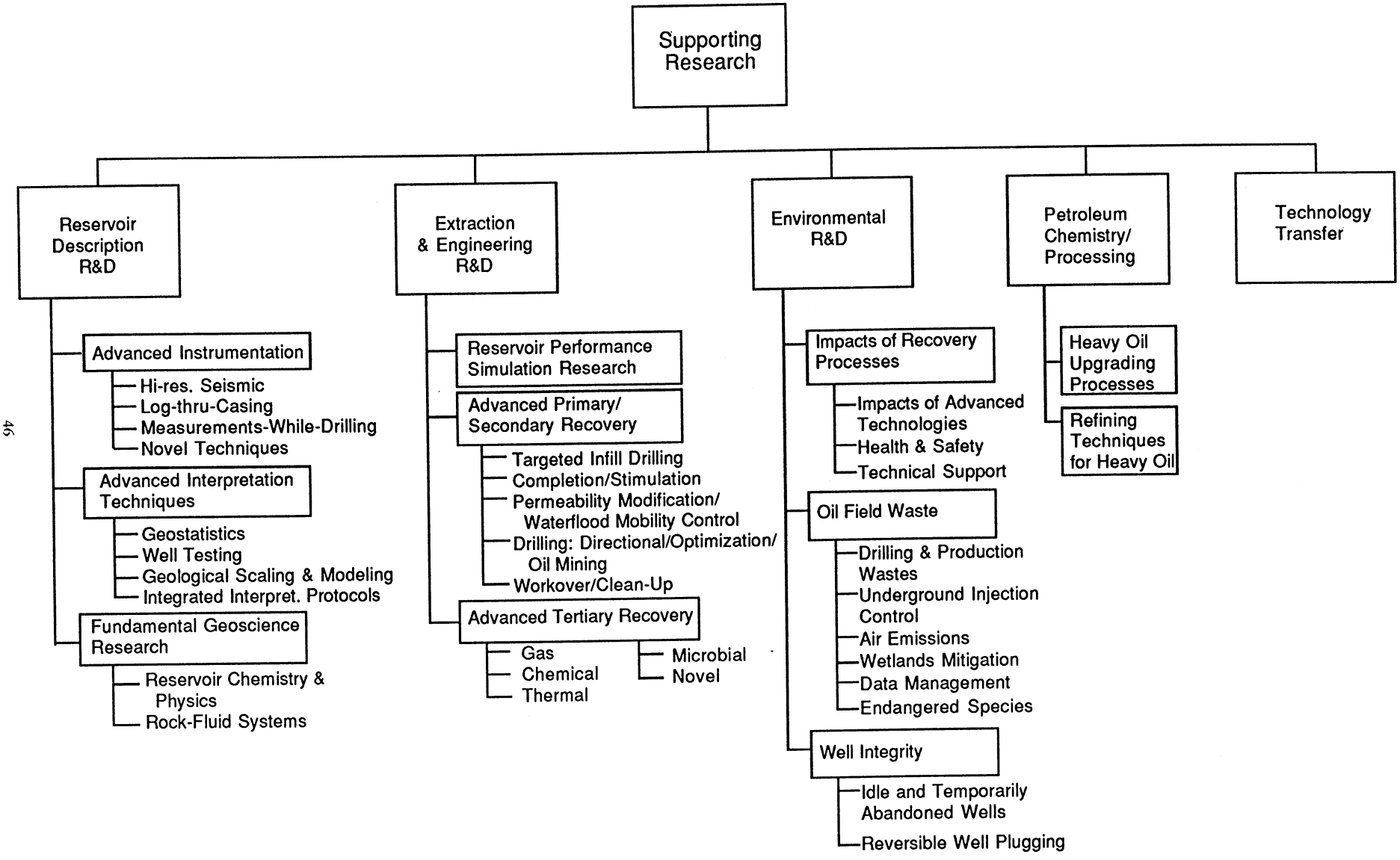
- *Environmental R&D* includes projects needed to improve the cost effectiveness of environmental protection, manage drilling and production wastes and emissions, determine the impacts of advanced recovery processes (including the fate of injected fluids) and develop technologies to minimize those impacts, develop cost-effective environmental data management systems, develop environmentally acceptable methods of drilling and production in wetlands, delineate requirements for the protection of endangered species, and address the issue of reservoir access by evaluating environmentally acceptable methods for maintaining idle or temporarily abandoned wells and for economically reversible plugging. There is also a significant role for the program in providing technical support to small operators faced with changing environmental and other regulations and rising regulatory costs. The program can also work with and provide data and analysis to federal and state regulatory agencies that are evaluating current environmental protection programs and technologies and are considering new requirements.

- *Petroleum Chemistry/Processing* is expected to include projects in heavy oil upgrading processes and refining techniques for heavy oil, to be defined after a detailed study of the constraints on heavy oil recovery which is now being initiated.

- *Technology Transfer*, as envisioned in this program plan, is part of a continuing process and not an end result. The initial activities will be to facilitate and expedite efforts now in existence by the industry to expand the application of proven, more effective recovery technology, such as improved water flooding. The goal is to maintain the high priority reservoirs in production until the mid-term demonstrations of more advanced technology can be completed. Contacts made in the near-term phase will be helpful in keeping the target audience current on the demonstration projects so that they will already be familiar with them by the time results are sufficient to encourage broader adoption. Once the demonstrations are complete, technology transfer and follow-up with operators will be initiated.

Figure 13

Work Breakdown Structure for Supporting R&D



To complement the defined projects within each category, the research program must have a margin of flexibility. The state of technology is changing constantly as R&D progresses, research results become available, and new ideas are presented that had not previously been considered. To be viable, the R&D program must reserve funds to respond to unsolicited proposals that present promising opportunities and to encourage innovation by project managers. This reserve should be limited to about 10% of the total supporting R&D budget. Including this margin of flexibility, the three categories describe a comprehensive oil research program.

The subcategories for research indicated in the work breakdown structure are an indication of constraints needing R&D based on the current understanding of the resource. In the program's transition from FY 1990 to FY 1991, they will be revised with the identification of technical constraints specific to the top four priority reservoir classes, and in consideration of the research projects in the current program. As the program progresses, the supporting R&D work breakdown structure will be revised periodically to reflect the definition of requirements during field work and their solution as that occurs.

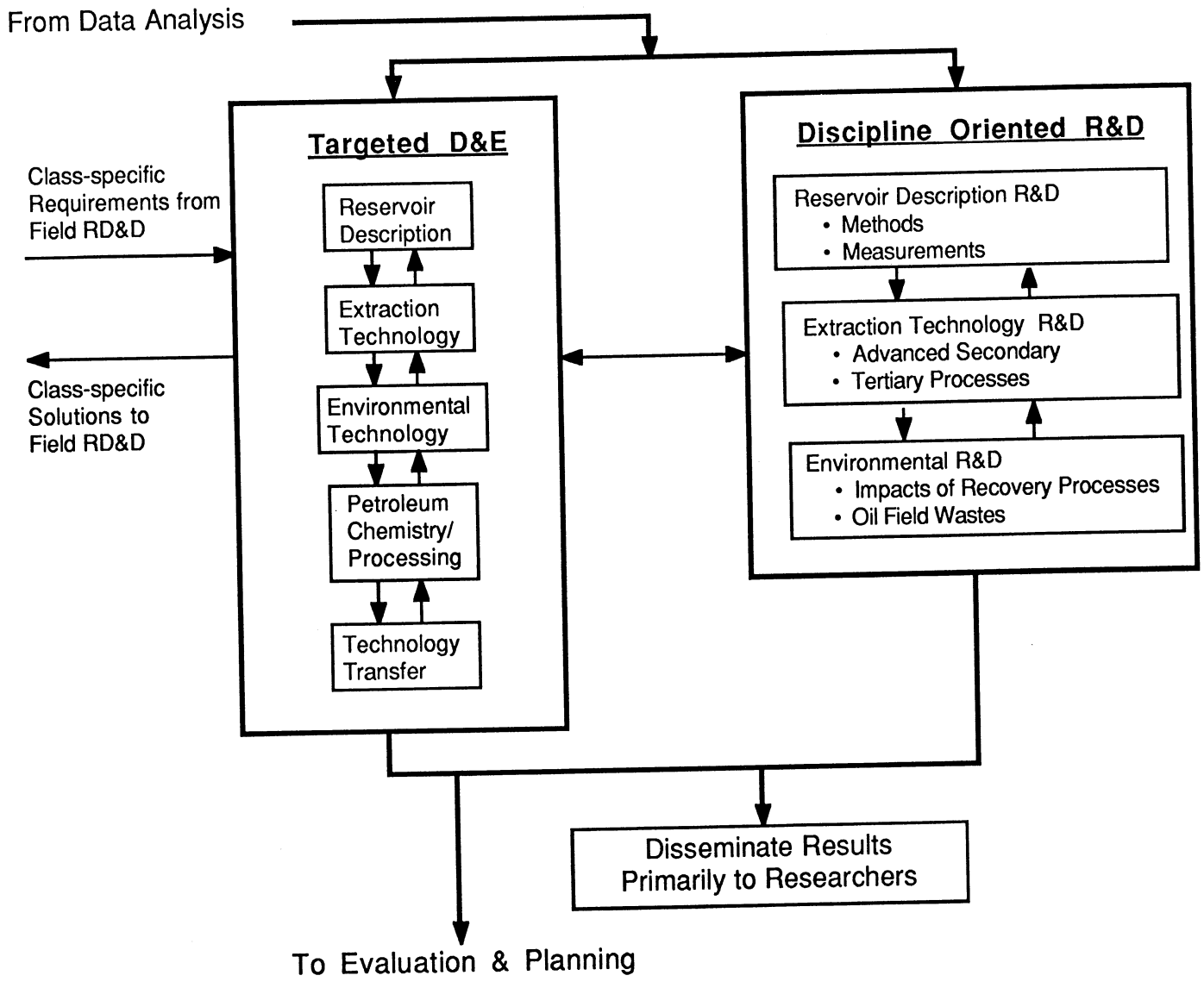
Figure 14 shows the logic flow and linkages to other program activities. Near-term supporting research is determined by data analysis and program planning. At this stage, only environmental R&D has been associated with a near-term goal to obtain results. Near-term environmental R&D will occur in parallel with near-term field activities to support the objective of preserving access. Its principal focus will be to address the many uncertainties faced by smaller operators regarding changes in environmental regulations (e.g., RCRA, UIC program) and requirements. In addition, the program will evaluate the technical, economic, regulatory, and institutional issues associated with wells that have ceased production. In keeping with the objective of preserving access, it would be desirable to maintain these wells in an idle or temporarily abandoned state if this can be done in an acceptable manner. Techniques such as fluid level monitoring, retrievable bridge plugs, logging to detect fluid movement, and wellbore modeling could be combined with area-specific risk assessment to determine acceptable methods and allowable time periods before permanent plugging is required. Where there is no alternative to plugging and abandonment, environmentally safe, economically reversible plugging technologies could serve as a fallback, particularly if technology transfer is ineffective or too late. DOE will work closely with EPA and the relevant state agencies to evaluate the technical and regulatory feasibility of temporary abandonment and reversible plugging, recognizing that such technologies must cost no more than current plugging and will apply only where geologic, engineering, and leasing conditions permit.

The logic flow indicates that both discipline-oriented and targeted R&D will support mid-term field activities. Priorities for supporting R&D will be based on resolving technical barriers to the application of advanced technology. This requires two primary approaches to the definition of R&D projects. Discipline-oriented R&D will focus on problems that are not class-specific but which, when reduced, will more broadly support heterogeneity description and extraction engineering: instrumentation and interpretation techniques, fundamental studies of reservoir properties and rock/fluid systems, simulation algorithms, etc. Much of this research will have a long-term orientation, though intermediary progress will have benefits for mid-term field work also. The discipline-oriented R&D will cut across classes, and results will have value for multiple classes simultaneously.

The logic flow of discipline-oriented R&D will be closely linked with other activities in

Figure 14

Supporting R&D Logic Flow



the program. Project managers will define discipline-oriented projects with class needs in mind, to seek synergies across multiple classes. Thus, as reservoir classes are prioritized and their technology options and production constraints are broadly identified, discipline-oriented research projects will be evaluated to assure that they address these issues.

Targeted D&E (development and engineering) will be defined as constraints are encountered during site-specific reservoir architecture description and design of the extraction process. The logic flow will be well-defined: constraints being defined first during field work, solutions obtained by class-specific D&E teams and transferred to field operations to facilitate the implementation of the technology. As solutions are obtained, both in targeted and discipline-oriented R&D, technology transfer activities will be initiated for the research community to benefit other R&D projects.

A final logic relationship relates long-term supporting R&D with field work. Long-term supporting R&D requires better understanding of the reservoirs that cannot be addressed by currently defined technologies. Much of the mid-term field work will provide superior reservoir description information than is now available to support long-term research. In other cases, some reservoirs that cannot be addressed at all by advanced technologies, such as low-permeability and fractured reservoirs, have not been adequately drilled. Long-term field work activities may entail drilling test wells to collect information and further define the problems which need to be addressed by research.

Program Management and Overall View of Logic Flow

Program management will integrate the activities of data analysis, field work, and supporting research. The monitoring, evaluation, and planning functions that comprise program management fit within the Analysis and Planning work breakdown structure, shown previously in Figure 10. Figure 15 shows the principal logic flow within the major program activities and the logical relationships between them.

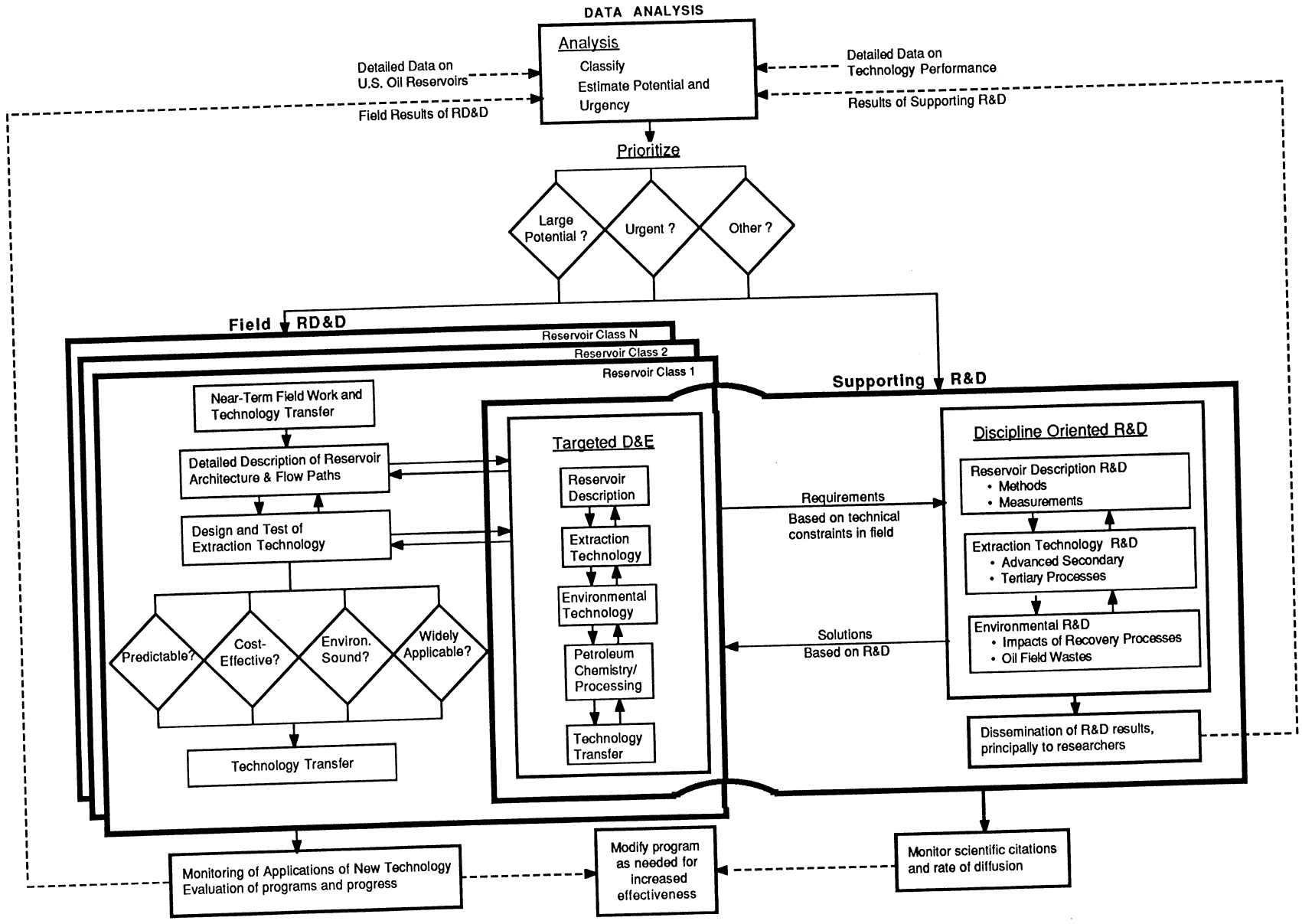
Monitoring data from each of the major activities will flow back to program evaluation to influence program planning, schedule management, and budget formulation. The program must remain flexible to allow for changes in strategy if that is indicated by the actual progress of any of the major activities. The schedule must be continually updated, and managed to ensure that the program maintains its focus on priority reservoirs and that advanced technologies are made available before access to the resource is lost. Finally, actual progress will affect budget formulation, while the program plan and scheduling must be adapted to actual budget appropriations.

TACTICS

To implement the new oil program with its significant near-term component, progress must be closely monitored and tactics must be devised to meet practical constraints while following the program strategy. This section differs from the preceding ones, strategy and logic flow, which describe objectives and the logical flow of tasks required to achieve them, in that it confronts the real implementation constraints that must be resolved for the program to flow smoothly. These include the lag imposed by the federal budgeting, formulation, and approval process, the lengthy process of data collection, the transition of the existing R&D program, the need to facilitate integration between field and supporting R&D activities, and the management of technical and economic risks of RD&D that affect the program's ability to realize potential benefits. A sixth issue, the need for scheduling options to plan for various funding scenarios, requires

Figure 15

Overall Program Logic Flow



more attention and is described in the following section.

Federal Budget Cycle

For the RD&D program discussed above to be realized, funds must be appropriated. The program is designed to be responsive to the timing and requirements of the annual Federal budget formulation and approval process. The budget cycle is 30 months long: 9 months for the Administration request to be prepared, reviewed, finalized, printed, and submitted to Congress; 9 months for the authorization and appropriation process; 12 months for implementation over the fiscal year. To assure the timely and efficient implementation of the effort, tasks must be identified 18 months before they can be started. While not critical for a long-term research program, this is significant when near-term targets are involved as they are in this Implementation Plan. Furthermore, complex procurements can take 9 to 12 months to complete. There is, therefore, a real need to assure that the annual budget formulation is explicitly incorporated into the program's planning and monitoring system. Program decisions must be made on a timely basis: where possible, tasks need to be undertaken in parallel rather than in series, to save time. This has already been accomplished in the analysis of the U.S. resource and early initiation of RD&D activities in top priority reservoir classes.

While much of the supporting R&D matches EOR requests over the last few years, new and more costly field work is sufficiently different that it must be carefully and broadly reviewed before initiation. In light of the urgency of the program's objectives, the first such requests are planned to be formalized as soon as possible, and will be included in the FY 1992 budget request.

Matching the progress in near- and mid-term work with the budget cycle is a difficult task to accomplish. An approach has been developed to facilitate meeting this need: the proposed program is modelled using critical path methodology (CPM). The model uses a commercial CPM program and is installed on a DOE personal computer. There are many advantages of such a model. First, it summarizes what has been accomplished and shows the current activities as they relate past achievements to the specified mission. Assuming success of current projects, the following year's effort can be specified, and rational budget requests formulated. Finally, it presents the decision maker with an estimate of the future consequences of both current and proposed actions.

As constructed for this plan, the model contains considerable detail on the analysis effort. This work, as explained above, is already in progress, and there is high confidence that the effort will achieve success as presented. The model also contains a suggestive field RD&D section that is based on best available information. The effort represents a good estimate of the work to be done and the length of time required to accomplish it. Estimates of associated costs under various assumptions regarding cost sharing and the availability of data on existing and completed projects indicate that budget requirements are consistent with existing appropriations. These estimates of schedule and cost can be used to evaluate the out-year consequences of current program activities.

The model plan has a critical milestone scheduled for June 1990: the identification, on the basis of best available information, of the first two reservoir classes. Once this has been accomplished, it will then be possible to fill in more precisely the out-year requirements and their consequences, effectively modifying the current model and corresponding plan for field work and supporting R&D. This will be done at least on an annual basis, in conjunction with Fossil Energy's Spring planning call.

The model is not a promise to succeed. Rather, it is a status summary and a reasonable estimate of what will be required as a consequence of current activities. It permits a continuity not otherwise achievable. It also facilitates the identification of the real compromises between expenditure level and rate of progress.

The CPM model has been used to develop the schedules and budget requirements for the new oil program. It has already effectively captured past related accomplishment and current activities. It is being used now to relate the FY 1991 request to the requirements of the new program. It will be revised again during the next budget formulation and planning cycle.

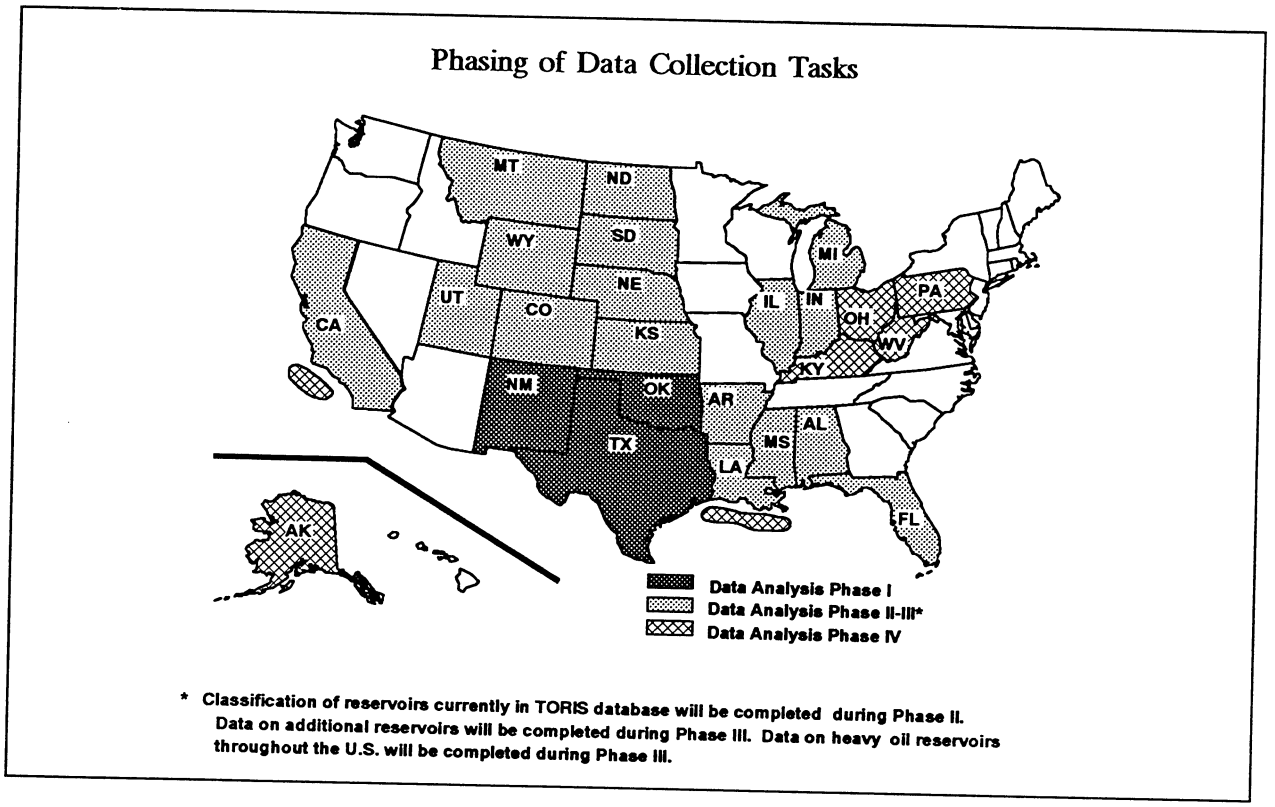
Phasing of Data Collection Tasks

The analytical tasks required to characterize and rank the major reservoirs in the TORIS data base are time consuming. Even so, it will take only a few years to characterize the entire U.S. resource. Waiting to complete this task before identifying and beginning field work does not address the urgency of the problem. However, knowing that abandonments are most severe in the lower-48 states, we can begin near- and mid-term activities on reservoir classes identified from a representative sample of the remaining U.S. resource.

The data collection effort will therefore proceed in phases, focusing first on the onshore Lower-48 resource, where the top priority reservoir classes are most likely to be located because of the size of the resource and the high rate of abandonments. The first two reservoir classes will be identified from the results of this work before the end of FY 1990. The reservoir class ranking may change as more of the resource is characterized, but there is great confidence that these first few selected will still remain in the top priority classes. As data collection and analysis proceed, the plan calls for the identification of the top twelve reservoir classes, and addressing the top ten with field work and supporting research.

To characterize the resource as soon as possible, the four phases of data collection and analysis will occur simultaneously, each with successively greater durations due to the complexity of the data collection tasks. Figure 16 indicates the coverage of the U.S. resource attained by each phase. The first phase consisted of the study of Texas, Oklahoma, and New Mexico, for which the bulk of data collection and analysis is already complete. The second and third phases include the remaining Lower-48 onshore resource, excluding only Appalachia. These two phases are divided on the basis of data availability. In Phase II, additional data will be added for all Lower-48 onshore reservoirs already in the TORIS data base for classification and analysis. In Phase III, data in heavy oil reservoirs and other Lower-48 onshore reservoirs not previously included in the TORIS data base will be added. Funds have already been obligated and Phase II is underway, with completion scheduled for October 1990. The Lower-48 onshore resource will be classified and assessed by April 1991, excluding only the remaining Appalachian states. The fourth phase includes Appalachia, Alaska, and Federal offshore. Characterization of the Alaska resource is now underway under a state Memorandum of Understanding, while the offshore data collection effort has not begun. The strategy for obtaining data on Appalachian reservoirs will be developed soon, as will the strategy for characterizing the heavy oil resource in Alaska and Federal offshore reservoirs. The completion of Phase IV, and classification of the full U.S. oil resource, is scheduled for October 1992.

Figure 16



Transition of Supporting R&D

The existing R&D program emphasizes long-range, high-risk research, much of which is focused on the critical disciplines. Several near-term projects have been added since 1987 in response to changes in the industry resulting from the collapse of oil prices. This evolution is expected to continue, even accelerate, as progress is made through reservoir class meetings and problem definition. Success in problem definition will permit more targeted, focused procurements and projects.

DOE project managers will work with R&D performers in the national laboratories, universities, and private laboratories to assure a smooth evolution of the work as the problem definition efforts proceed. This will occur during FY 1990-91. By FY 1992, all R&D projects will be consistent with the new program goals and objectives. The evaluation of current projects against requirements identified in field work and by supporting R&D project managers will be an annual exercise for the duration of the program.

Field RD&D Procurement

The FY 1991 budget includes a request for funds to initiate field work in two reservoir classes. The request is consistent with progress to date and assumes that the classes can be identified from results of the current classification effort and that the critical problem definition meetings can be held during August and September 1990.

Following these meetings, DOE will publish the proceedings as an initial technology transfer step. These reports

documenting the state of the art in the class and identifying research requirements should be of broad, general interest. Again, water flood reports published by the BOM in the 1950's were of wide interest to those working in the states covered. The results will also be used to develop a procurement strategy for implementing the next steps in each class. While specifics await completion of the problem definition phase, we anticipate competitive actions with emphasis on actual experience throughout the broad geographical coverage of each class and with the full spectrum of technical issues. Field RD&D contractors would probably consist of joint ventures comprised of operators, field service companies, consultants, university researchers, and state agencies with combined broad experience in the class over its full geographical distribution. Cost-sharing is also expected. DOE will assure that major decisions, for example those associated with actual field tests, are appropriately reviewed.

It should be noted that no decision has been made as to which, if any, demonstration projects will be funded.

Matrix Approach to Field RD&D and Supporting R&D

Supporting research and field activities must be effectively integrated to solve technical constraints and demonstrate advanced technologies within the mid-term time frame. It will be important to assure effective communication and interdisciplinary problem-solving. A field work matrix, supported by analysis and research functions, is an option that could meet this need.

The matrix approach establishes two-way information flows that will facilitate the solution of class-specific technical constraints. For each reservoir class, the information flow begins in the field as the attempt to describe reservoir heterogeneities encounters technical constraints that define requirements for supporting R&D. When the problems have been relaxed, researchers will communicate them to those working at the field site, though there will likely be frequent feedback as the research progresses.

The same interaction between field work and research will occur to address environmental and extraction technology constraints. The progress from reservoir description to testing of the extraction technology and to technology transfer describes the principal interdisciplinary flow of field work. Two-way flow of information is also necessary between these major field work activities — reservoir description, extraction technology design and testing, and technology transfer. Reservoir description, extraction system design, and field implementation must be highly integrated to improve recovery efficiency significantly, while the application of advanced technology promoted in transfer activities must be consistent with research and field test findings to avoid misapplications.

While targeted R&D is tied very closely to field work in each reservoir class, discipline-oriented research will cross-cut the classes. As results are obtained, or extraction processes and heterogeneities are better understood, this research will have synergies benefiting the field work occurring in more than one class.

The matrix approach clearly shows the key functions and their relationships necessary to implement and integrate the program. Each reservoir class will have its own project manager responsible for coordination of field work with supporting research, budget formulation, and all work relating to technology transfer, environmental and regulatory issues for the class. The project manager's first task will be to define the requirements to conduct the field work in the specific class, and to implement the necessary procurement actions.

The program will also require two types of supporting managers. The analytical support manager will develop priorities for the ranking of reservoir classes. Using the database of reservoir information and technology performance, this manager will provide the information used to establish the order in which reservoir classes will be considered. Decline curve analysis will define the time frame for near-term and mid-term field work in each class. As the results of field work are available, the analytical support manager will obtain this information from the reservoir class project managers to update the analytical models.

Supporting R&D project managers will be differentiated by discipline. They will define the discipline-oriented R&D requirements to integrate projects and perform cross-cutting work that has applications to more than one class. Working with the reservoir class project manager, they will define the time frame and project scope to address site-specific constraints. The supporting R&D project managers will also be responsible for defining long-term R&D projects: being aware of work done by researchers, responding to new and promising ideas, and defining data collection needs for reservoirs that need to be understood better. These managers will maintain the vital link between the mid-term and long-term orientations of the program that will define the future thresholds of oil recovery.

These managers also have the difficult assignment of looking across the field work in the multiple classes to identify common technical constraints and translating these technical constraints into problem statements and requirements for supporting research. Conversely, they help translate scientific findings for supporting research into practical solutions for the field work. As liaison personnel, they stand "halfway" between the field work and supporting research and report to the general manager of the program.

Risk Management

Technical and economic risks are inherent in any RD&D program; they must be managed effectively to assure the program's success. Risk management strategies have been described in the Strategy and Program Logic section of the Implementation Program and are summarized below. From classification of the resource to development of technologies and widespread application, the program involves a great many steps. Each has a relatively high probability of success. But, it is the combined risk associated with all activities in the strategic effort that constitutes the program's challenge. For example, R&D may have an 80% probability of developing a surfactant that is cost-effective and provides predictable recovery at high formation salinity, a 90% probability of developing one effective for displacing lower viscosity oil, and an 80% probability of developing one that is stable at a high reservoir temperature. When the reservoir presents all three conditions, the constraint is more difficult and the overall probability of success is only 58% (80% x 90% x 80%), though the individual probabilities are relatively high. In addition to these technical risks, there are probabilities of success associated with the ability to describe heterogeneities sufficiently for effective process design, the cost-effectiveness of the process at the expected oil price, the environmental safety of the process compared to regulatory standards, and the extent to which the technology can be applied to other reservoirs. All of these risks weigh on the chance of success for the overall program.

The Oil Research Program will apply risk management tactics that will reduce each of these component risks substantially, to maximize the overall effectiveness of the program:

- *Goal risk.* The program is expected to meet the significant technical uncertainties

associated with the 76 billion barrel near- and mid-term target with success in some classes and failure in others, including the full spectrum of results in between. The portfolio approach, working with several reservoir classes, assures a significant payoff with the highest probability. The planning of this approach to maximize producibility will be founded on extensive analysis, theoretical principles, and evaluation of program results as they occur:

— In-depth analysis of the known U.S. oil resource and determining the detailed problems associated with 12 reservoir classes will assure that the program concentrates its efforts where the potential for additional recovery is greatest. Those reservoir classes to be addressed are expected to have 80 to 90% of the remaining known U.S. oil resource.

— The portfolio of several geologically differentiated reservoir classes will diversify RD&D commitments while simultaneously allowing synergies to be exploited as technical constraints are identified that are common to several classes.

— Near-term program activities represent a two-pronged approach to manage the risk that well abandonments will erode the potential of advanced recovery techniques: (1) rapid transfer of currently available technologies to extend the economic life of wells until advanced recovery techniques are available, and (2) development of environmentally sound approaches to maintaining uneconomic wells that are not amenable to implemented technologies.

- *Transferability risk.* The reservoir similarity theory is expected to be proven in practice, magnifying the impact of the program's demonstration projects substantially by guiding the transfer of results to other reservoirs. But similarity may not prove out in *every* class or play considered, and the program deals with this risk also:

  — Plays and field sites will be selected to represent the greatest recovery potential. The similarity theory applies to two levels: play-to-play within a class, and reservoir-to-reservoir within a play. To reduce transferability risk, emphasis will be given to the largest plays in each class, and the largest reservoirs within each play. If project results cannot be extrapolated to similar reservoirs, the field work is justified because the greatest potential within the play has been addressed.

  — The classification system will be refined continually; the concept of geologic similarity will be better understood with each iteration with consequent improvement in the ability to extrapolate field results effectively.

  — The selection of at least two sites in each of two plays in each reservoir class will support a class-specific evaluation of the reservoir similarity theory, determining the extent to which the technology can be successfully applied by the industry; the evidence that justifies widespread application will be compelling to reduce operators' perceived risk and persuade them to invest in advanced technology recovery projects.

- *Technology risk.* In the laboratory, a wide range of technologies have been proven or shown promise when applied to isolated technical constraints. In the reservoir, such constraints frequently occur in combination and make extraction system

design far more complex. The program manages this risk in advanced technology RD&D also:

— Defined, advanced technologies will be evaluated to differentiate those that have been proven in the laboratory and can be field-proven in the next decade with limited R&D from those that require more extensive (long-term) research before they can achieve predictable results in the field. Technologies selected for mid-term field RD&D will be expected to have predictable results and to be cost-effective at the oil price projected over the mid-term period.

— The classification system based on geological history reduces the scope of technical constraints in field RD&D because the sites within a class should exhibit similar heterogeneities. Reservoirs within given plays should have similar rock and fluid properties and depths, further limiting the technical risk.

- *Project risk.* At each step described in the program logic flow, progress is evaluated before going on to the next level of expense:

  — The reservoir description activities at each site occur before process design and implementation to allow an assessment of the probability that heterogeneities and other factors will allow profitable recovery. When that probability is too low, and the site involves insurmountable geological constraints, an alternate site may be selected before committing funds to process design and implementation. If similar conclusions are reached at several sites in a class, an alternate reservoir class may be chosen.

  — Similarly, the field test will be assessed again with respect to constraints on the recovery process after the initial process design and simulation, to evaluate whether funds should be committed to implementation of the technology. If conditions indicate that supporting D&E and intensive field work will not reduce those constraints with a reasonable probability, then an alternate site or class may be selected.

  — The monitoring and evaluation of environmental impacts during field work will determine whether the advanced technologies can be safely transferred for routine application and will identify requirements for the development of cost-effective mitigation techniques.

In addition to these risk management tactics that are incorporated in the Implementation Plan, there will be full management review of the program in real time as activities progress, via the federal budget cycle. The results of this review will be incorporated into the plan through periodic updates, and reported through annual publication of the updated Implementation Plan.

Risk management is pervasive to the design of the Implementation Plan and is critical to its success. The tactics indicated above will increase the probability of success at each stage of RD&D, mitigating technical and economic risk and improving the program's overall likelihood of success to a very acceptable level.

PROGRAM BUDGET AND SCHEDULE

As the program implementation plan is designed, the annual budget level can have a dramatic effect on the program schedule. Delaying the start of various tasks within the

program may be necessary if the annual appropriation is not adequate to cover all of the tasks which could technically be scheduled to begin in a given year. These delays push the attainment of the program goal further into the future. Compromises exist between budget levels and achieving key goals which can be expressed as funding alternatives. Several funding options have been defined for the program and are presented later in this section.

Fiscal year 1990, already underway, is a transition year for the program. Funds appropriated for FY 1990 incorporate the preliminary work necessary to begin program formulation. The FY 1991 budget, as requested, includes funds which will allow work to begin in the first two reservoir classes, primarily near-term technology transfer. Actual field tests cannot begin earlier than FY 1992. The first opportunity to request funds for mid-term field work will be in the FY 1992 budget request.

Table 1 presents the base case program budget by fiscal year. The base case budget covers actual field work in ten of the twelve major classes identified, with all work beginning as soon as technically possible because of the urgency of preserving access to selected reservoir classes and the serious threat posed by rising import dependence. Over the 15 years of the program, the base case budget averages $36 million per year, an increase of about 30% from the current appropriation for EOR in FY 1990. The base case budget peaks in FY 1995 at just over $105 million due to the fact that field demonstrations can be started in the first four classes. The FY 1996 budget is also high, at $93 million, but after that the required annual expenditures fall dramatically. In nine of the fifteen years of the program, budget requirements are at or below the current FY 1990 appropriation.

For budgeting purposes, reservoir classes have been assumed to be generic. In reality, the amount of information already available, and the size of the field tests required, will vary by reservoir class. For many classes, some of the work outlined will already have been completed and the data available. As such, total costs for some reservoir classes may be over- or understated somewhat.

Major program milestones indicate the program schedule for addressing ten of the twelve highest priority reservoir classes in the most timely manner. Data analysis activities in the first phase provide needed classification of the entire U.S. resource base. This classification could be complete with all class requirements documents published in March 1993. By this time, the top twelve reservoir classes will be identified, with field RD&D and supporting research needs defined for each. Technology transfer and supporting research can begin in FY 1991 for the first two classes. Field RD&D for the first reservoir class started would be complete in September 1997. Field work for all ten classes could be completed by January 2000. On-going monitoring, evaluation, and technology transfer activities would continue over the next five years.

Funding Options

With the cost of individual program components identified, an infinite number of funding options could be created. In identifying realistic funding options, several items must be remembered. Many of the reservoir classes have a high risk of abandonment if steps are not urgently taken to preserve access to the resource. Near-term and mid-term are integrally related. If mid-term field work is delayed excessively, gains from the near term could be lost. The sooner field work is completed and technology transfer begins, the sooner producibility can be increased to help meet domestic demand and reduce imports. These factors must be

Table 1

BASE CASE BUDGET

$000

	Analysis & Planning	Field RD&D	Supporting Research(1)	Total	Other Analytical Work(2)
FY 90	1,650	0	20,823	22,473*	0**
FY 91	2,755	10,240	9,474	22,469	0**
FY 92	730	13,260	13,400	27,390	500
FY 93	1,475	25,000	13,400	39,875	500
FY 94	880	30,200	13,400	44,480	500
FY 95	880	91,000	13,400	105,280	500
FY 96	880	78,500	13,400	92,780	500
FY 97	880	41,550	13,400	55,830	500
FY 98	880	6,850	13,400	21,130	500
FY 99	880	8,200	13,400	22,480	500
FY 00	880	5,450	13,400	19,730	500
FY 01	880	3,600	13,400	17,880	500
FY 02	880	2,850	13,400	17,130	500
FY 03	880	2,100	13,400	16,380	500
FY 04	880	700	13,400	14,980	500
Total	16,290	319,500	204,497	540,287	6,500

Average Program Cost Per Year = $36,019

(1) Total of targeted R&D and discipline-oriented R&D.
(2) Funds cover use of TORIS in support of activities not directly related to the plan, such as NES development.
* This is equal to the total for light oil for FY90. Much of this amount supports mortgages developed under previous implementation plans.
** Included in the total at left.

MAJOR MILESTONES

	Date
Classification of Full U.S. Resource Base	October 1992
Identification of Top 12 Reservoir Classes	October 1992
Class 1 Field Work Complete	September 1997
Class 10 Field Work Complete	January 2000

balanced against the need for funding in times of budget deficits, and the feasibility of obtaining budget increases.

The base case budget assumes work in ten of the top twelve reservoir classes, and is expected to represent 80 to 90% of the remaining U.S. resource. The base case allows work in these ten reservoir classes to begin as soon as technically possible. Likewise, this option also completes work in all ten reservoir classes more quickly than any of the other funding options presented, and reflects the urgency of abandonments. It is, therefore, the most preferable for achieving the program goals.

To achieve a more level annual budget, two alternative funding options have been developed. Under both options, the near-term work including technology transfer for all ten classes begins as soon as technically possible to assure continued access. Only the more costly mid-term field work is delayed. The first alternative limits the field work starts to two classes each year. This has a noticeable effect on moderating budget peaks at the expense of pushing completion of the critical demonstrations out an additional three years. The second alternative limits field work to start only one class each year. A summary of the annual costs for the base case and these two alternative funding options is presented in Table 2. For each funding option and in each year, the reservoir classes for which field work is *completed* are indicated to the right of the budget amount. The associated major milestones are presented in Table 3. Detailed budgets for each of the funding options are included behind the Funding Options tab at the back of this Implementation Plan.

In comparing these funding options, it should be noted that the later years include a constant $13.4 million per year for targeted and discipline-oriented research. Once the demonstrations are started in each class, the requirements for targeted research activities will decline. However, discipline-oriented research and the long-term efforts (approximately $5 million per year) will continue.

Under the delayed start option (2 classes per year), the peak budget level is $68.6 million in FY 1997. This funding option provides for a slower build-up to the peak, with several years of budgets between $50 and $70 million. Beginning in FY 2000, the budget falls off to less than $21 million per year. The average cost per year of the program under the delayed start option is $34.6 million. Employing this option delays the completion of the field demonstrations in eight of the ten classes by one to two years.

If only one class per year is started, the annual budget never exceeds $44 million. Under this option, the average cost of the program per year is $29.8 million, not substantially different from the current FY 90 EOR budget appropriation. While this option smooths the annual budget, it causes a six-year delay in the completion of the field work for all ten classes. This delay brings into question whether the later classes are started too late to have the full beneficial effect.

The actual number of reservoir classes that will be addressed is not known at this time, and can only be determined after the full resource has been analyzed and problem definition phases are complete. However, the assumption of ten classes is reasonable for planning purposes.

The total Federal cost for the Oil Research Program described to address ten reservoir classes is around $600 million and varying from 15 years in the base case to 21 years in the most restrained case. Production of the 76 billion barrels of oil made recoverable as a result of the Oil Research Program would generate as much as $400 billion in revenues to the public sector from

Table 2

BUDGET SCENARIOS – 10 CLASSES

$000/Year and Completion Date of Field Demos

Numbers to the right of a column indicate that field work for those classes (excl. out-year monitoring & TT) is completed that year.

Assumptions:

	BASE CASE All tasks begin based on earliest CPM start	*Compl. Class*	DELAYED STARTS Class 1 & NT work for all classes begin ASAP. All other classes begin 2 per year.	*Compl. Class*	ONE CLASS PER YEAR Class 1 & NT work for all classes begin ASAP. All other classes begin 1 per year.	*Compl. Class*
FY 90	22,473		22,473		22,473	
FY 91	22,469		22,469		22,469	
FY 92	27,390		26,690		25,690	
FY 93	39,875		35,075		25,075	
FY 94	14,480		39,880		30,830	
FY 95	105,280		68,580		43,530	
FY 96	92,780		66,580		42,280	
FY 97	55,830	1,2	58,130	1,2	42,780	1
FY 98	21,130	3–8	54,230	3,4	41,080	2
FY 99	22,480		53,180	5,6	42,030	3
FY 00	19,730	9,10	19,930	7,8	41,980	4
FY 01	17,880		20,780	9,10	42,080	5
FY 02	17,130		18,830		37,330	6
FY 03	16,380		17,080		35,380	7
FY 04	14,980		15,680		34,230	8
FY 05			14,980		17,530	9
FY 06					17,530	10
FY 07					16,380	
FY 08					15,680	
FY 09					14,980	
FY 10					14,630	
TOTAL	540,287		554,567		625,967	
AVG/YR	36,019		34,660		29,808	

All figures exclude $500 K per year after FY 91 for other analytical work.

Note: NT stands for Near-Term. TT stands for Technology Transfer.

Table 3

Major Milestones – 10 Classes

Comparison of Funding Alternatives

	Base Case	Delayed Start	One Class Per Year
Initial Classification Based on Best Available Data	1990	1990	1990
Classification of Onshore Resource (Excl. LA, AK, Appalachia & Heavy Oil)	1990	1990	1990
Classification of Onshore Resource Incl. Heavy Oil (Excl. AK & Appalachia)	1991	1991	1991
Classification of Full U.S. Resource	1992	1992	1992
Identification of Top 12 Reservoir Classes	1992	1992	1992
Class 1 Field Work Begins	1991	1991	1991
Class 1 Field Work Complete	1997	1997	1997
Class 2 Field Work Complete	1997	1997	1998
Class 3 Field Work Complete	1998	1998	1999
Class 4 Field Work Complete	1998	1998	2000
Class 5 Field Work Complete	1998	1999	2001
Class 6 Field Work Complete	1998	1999	2002
Class 7 Field Work Complete	1998	2000	2003
Class 8 Field Work Complete	1998	2000	2004
Class 9 Field Work Complete	2000	2001	2005
Class 10 Field Work Complete	2000	2001	2006

severance and income taxes. Nine hundred times the cost of the program would be returned to the public sector in tax revenues. The incremental production would stimulate economic activity and employment, creating over 300,000 jobs. In addition, every barrel of oil made producible by the Oil Research Program is a barrel that need not be imported. At $32 per barrel, a reasonable oil price expectation for the year 2000, the incremental 76 billion barrels of domestic production would displace over $2 trillion that would otherwise have been paid to foreign oil suppliers. These estimates of benefits do not include the effect of additional recovery from reservoir classes not addressed by the program in field work, but which would also benefit from the advances in technology that the program will achieve. Nor do they include any additional recovery from the long-term resource target, which cannot now be estimated but is very likely to be substantial as long-term R&D yields results over the life of the program. These estimates also do not include additional recovery for fields yet to be discovered.

These benefits may be achieved with the integrated, focused RD&D program described in the Implementation Plan in cooperation with the states and industry. All elements of the plan must be included to achieve the needed level of integration: data analysis to address the *entire* U.S. resource, the geology-based classification system to target efforts, the near-term elements to preserve access, field work to prove advanced technologies and focus interdisciplinary problem solving, supporting R&D to solve technical constraints, and technology transfer to promote routine and widespread application of the technologies. However, achieving the projected benefits also requires a timely implementation without delay, to attenuate the rapid pace of abandonment that threatens to erode potential benefits if not addressed.

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8. See Appendix B for discussion of estimates of potential reserves and resources under the respective technology and economic scenarios.

9. Appendix C discusses the technological advances assumed in estimating the potential reserves associated with the mid-term technology.

10. U.S. DOE/Bartlesville Project Office, "Abandonment Rates of the Known Domestic Oil Resource," DOE/BC--89/6/SP (DE89000744), November 1989.

11. U.S. DOE/Bartlesville Project Office, "Analysis of the Impact of Well Redrilling on Enhanced Oil Recovery in the United States," Draft Report, September 1989.

12. White, D.A., "Assessing Oil and Gas Plays in Facies-Cycle Wedges," *American Association of Petroleum Geologists Bulletin*, Vol. 64, No. 8, 1980.

13. The terminology used here makes a distinction between the scientific concept of a "play" and the meanings of oil "field" or "basin." A "field" is fundamentally an areal concept: one or more reservoirs that are areally contiguous although the discrete reservoirs within a field may be vertically or laterally distinct, i.e., separated by faults, deposited at different times, etc. A "play" is a fundamentally different concept based on geological history: a grouping of reservoirs with common deposition, diagenesis, and structural events lying in a contiguous geographic area. The specific reservoirs may be components of several fields. Conversely, where "stacked" reservoirs with diverse geologic histories are encountered, these reservoirs may be in the same field but different plays. A "basin" is a depressed area where sediments are deposited and reservoirs may fan. A basin may contain many fields and plays over a broad geographic area and different periods of geological deposition and post-depositional modifications.

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15. *Ibid.*

16. Tyler, *et. al.*, *Oil Accumulation, Production Characteristics, and Targets for Additional Recovery in Major Oil Reservoirs in Texas*, The Bureau of Economic Geology, University of Texas at Austin, Geological Circular 84-2, 1984.

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25. The Geoscience Institute for Oil and Gas Recovery Research, *Reservoir Classification for Analysis of Oil and Gas Reservoirs*, Draft Report, October 1989.

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28. National Petroleum Council, *op. cit.*

29. Magruder, et. al., "A Review of the Means San Andres Unit Full-Scale CO_2 Tertiary Project," SPE/DOE 17349, 1988.

30. ICF Resources Incorporated and The Bureau of Econimic Geology, *op. cit.*

31. Appendix D illustrates the reservoir selection process with an example, focusing on the two reservoir classes with the greatest mid-term recovery potential in Texas, Oklahoma, and New Mexico.

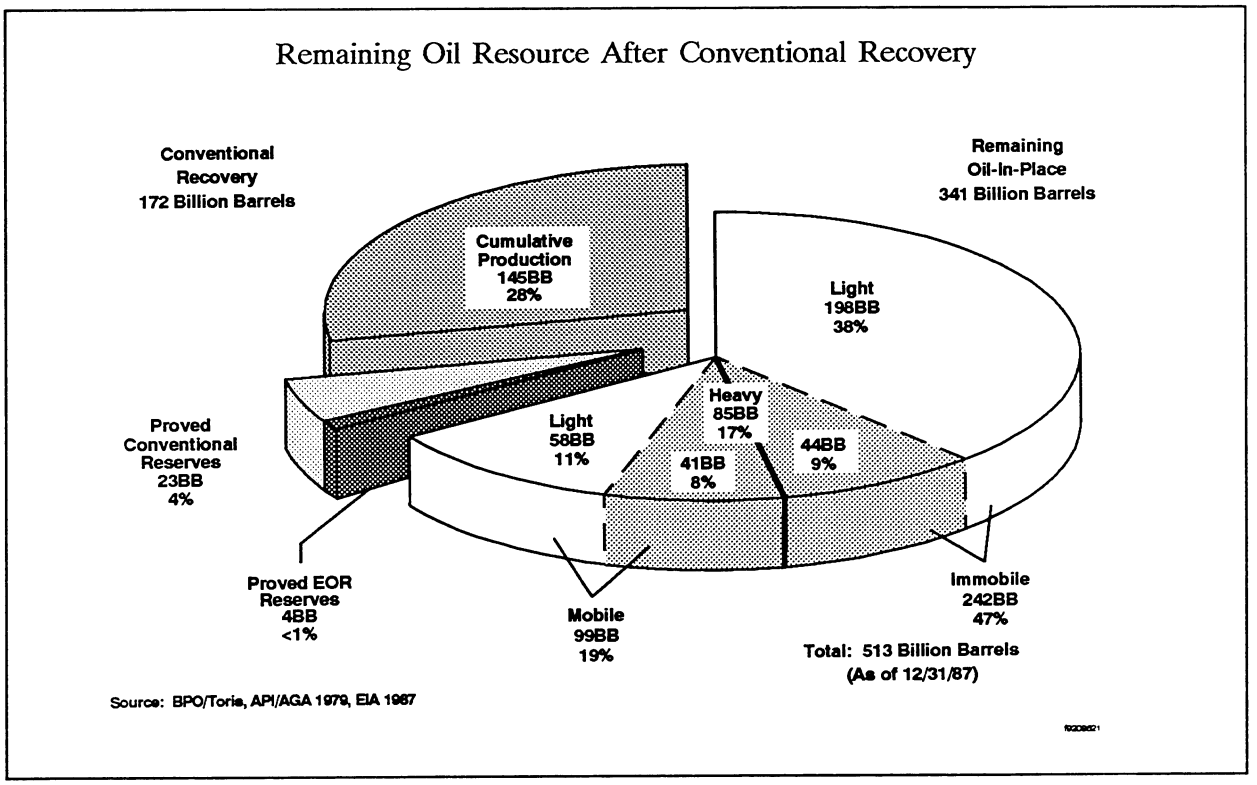
32. The Geoscience Institute for Oil and Gas Recovery Research, *op. cit.*, 1988.

Appendix A
MOBILE AND IMMOBILE OIL RESOURCES IN THE UNITED STATES[1/]

Known Domestic Reservoirs Contain a Huge Untapped Resource Consisting of Remaining Mobile and Immobile Oil:

- Over 500 billion barrels of oil-in-place have been discovered in U.S. reservoirs (Figure A-1):
  - 145 billion barrels have been produced through 1987 and 27 billion barrels, a 9 year supply at current rates, are proved reserves that can be produced within present technology and oil prices.
  - The difference, over 340 billion barrels -- nearly 2/3 of the nation's discovered oil -- will remain in known reservoirs at the conclusion of conventional production.
- This massive remaining oil resource consists of two broad classes:
  - Mobile Oil -- Almost 100 billion barrels uncontacted or bypassed by conventional waterflooding or steam drive as they are conventionally applied.
  - Immobile Oil -- Over 240 billion barrels that cannot be mobilized by water or steam but is trapped in the reservoir pore space by viscous and capillary forces.
- These classes are composed of two distinct types of oil:
  - Light Oil -- 256 billion barrels remaining; 58 billion barrels (23%) mobile to water, 198 billion barrels (77%) immobile. API gravity 20° - 45+°.
  - Heavy Oil -- 85 billion barrels remaining; 41 billion barrels (48%) mobile to water or steam, 44 billion barrels (52%) immobile. API gravity 10° - 20°.
- Portions of both mobile and immobile oil are producible. Both require:
  - Improved understanding and prediction of heterogeneities and flowpaths n the reservoir.
  - Increased predictability and cost-effectiveness of extraction techniques, although different techniques are needed for mobile and immobile oil, light and heavy oil, and for different reservoir settings.
- Ninety-nine billion barrels of mobile oil remains uncontacted or bypassed after conventional operation.
- Mobile oil remains unproduced because it is uncontacted by wells at conventional well spacing or bypassed by conventional fluid

Figure A-1



(e.g., water, natural gas, steam) injection projects at current will spacing.

- Uncontacted Oil (Figure A-2): Reservoirs deposited in certain ways exhibit discrete compartments which:
  - Limit pressure communication and the flow of fluids between discontinuous compartments, limiting production to only those actually penetrated by wells.
  - Must be reached by infill drilling to produce oil trapped in the isolated compartments.
- Bypassed Oil (Figures A-3 and A-4): Even where discrete compartmentalization is not present, or has been overcome by infill drilling, reservoir heterogeneities combine with reservoir fluid properties to cause bypassing of otherwise mobile oil:
  - As fluid is injected, it displaces oil toward production wells.
  - As the injection project continues, the swept zone grows, but differences in the density, viscosity, and mobility between oil and the injected fluid and internal reservoir heterogeneities (e.g., large differences in permeability in different strata) cause 'thief zones,' 'fingering,' 'overriding,' and 'underriding' of the oil by the injected fluid. Gravity 'overriding' affects seam flooding processes particularly.
  - Once a continuous flow path of injectant reaches producing wells, subsequent injection will follow this

Figure A-2

Uncontacted Mobile Oil

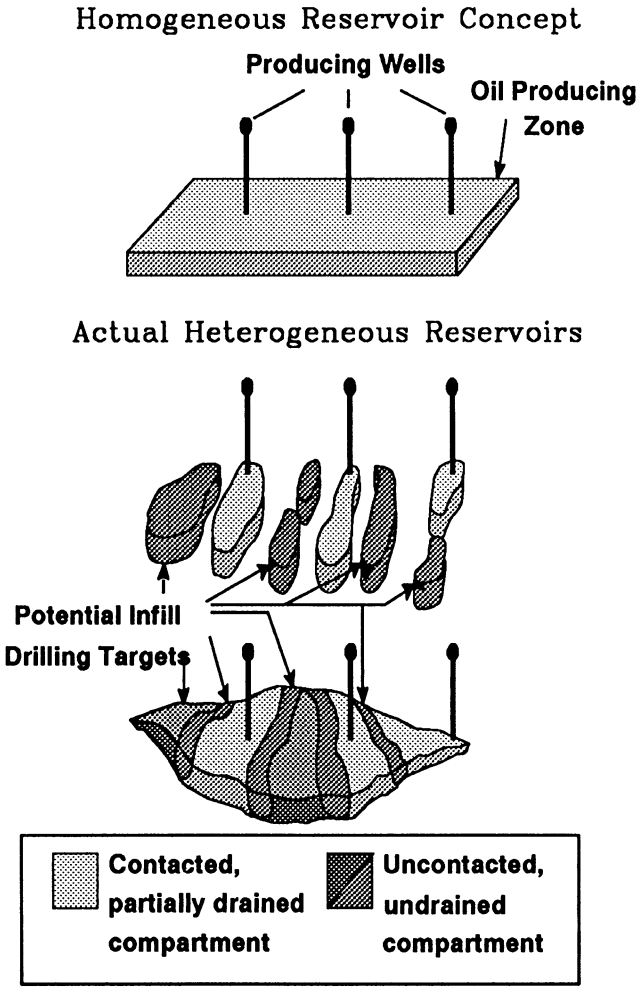


Figure A-3

Vertically Bypassed Mobile Oil

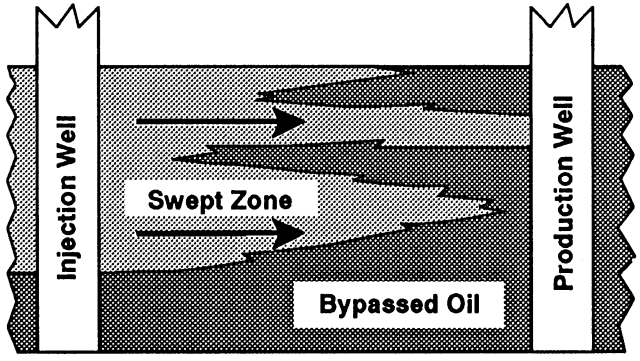
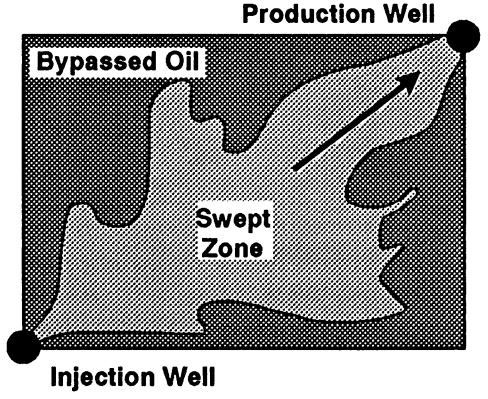


Figure A-4

Areally Bypassed Mobile Oil



path, resulting in high production levels of the injectant -- and bypassed mobile oil.

- This bypassed oil can be produced only by:
  - Reducing the density, viscosity, and mobility differences between oil and the injected fluid, e.g., by adding polymers to water or foams to steam.
  - Isolating the 'thief zones,' perhaps by modifying the permeability differences with gelled polymers or foams to reduce the contrast between strata or by selectively completing zones in the reservoir.
  - Infill drilling to decrease well spacing in secondary recovery projects.

- Two hundred forty-two billion barrels of immobile oil remain trapped in the reservoir, even where swept by waterfloods.

- While the factors causing mobile oil are largely macroscopic heterogeneity -- at the scale of the drilling pattern or strata -- the forces retaining immobile (or waterflood or thermal flood residual) oil are microscopic -- at the scale of the reservoir pore, the void between grains of reservoir rock.

- Water encroachment, resulting from water flood or condensed steam, displaces oil until microscopic forces stop oil flow:
  - Oil is originally a continuous phase in the pore space, sharing it with a small amount of original, or 'connate,' water (Figure A-5(i)).
  - As additional water enters the pore, through natural water drive, secondary waterflooding, or thermal flooding, oil is pushed out.
  - After a certain amount of oil is displaced by water, the oil phase breaks down into discrete droplets or adheres to the walls of the pores due to capillary and viscous forces; additional oil is caught in 'dead end' pores in the rock (Figures A-5(ii) and (iii)).
  - Once water forms a continuous phase, only water will flow; the remaining oil is trapped.

- Recovery of the immobile oil left after water and thermal flooding requires overcoming the viscous and capillary forces and microscopic heterogeneities retaining the oil:
  - Surface-tension reducing agents ('surfactants') overcome capillary forces.
  - Heat (e.g., steam) reduces oil viscosity and sometimes cracks heavy hydrocarbons into lighter components.
  - Solvents (e.g., carbon dioxide, propane, nitrogen, etc.) combine many mechanisms: surface-tension reduction, decreased viscosity, and swelling of the oil to re-form droplets into a more nearly continuous oil phase.

- While these 'tertiary' or 'enhanced oil recovery' (EOR) processes operate at the microscopic scale, their movement through the macroscopic scale of the reservoir must be controlled to avoid fingering, override, etc., as with producing bypassed mobile oil.

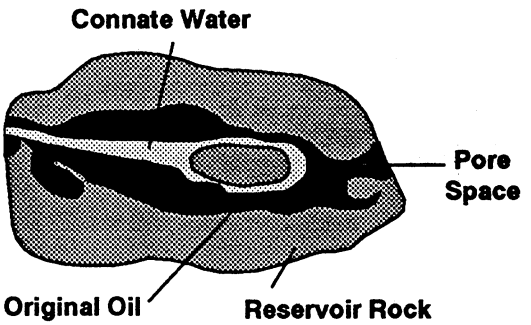
- This massive remaining mobile and immobile oil resource is distributed throughout the U.S.

- The massive resource of known mobile and immobile remaining oil is distributed across all the oil-producing regions of the Nation,

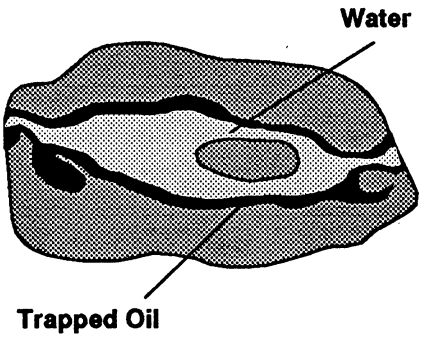
Figure A-5

Reservoir Pore View

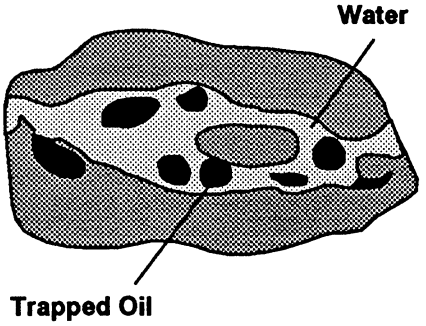
i. Original Condition



ii. After Waterflood - "Oil-Wet" System



iii. After Waterflood - "Water-Wet System"



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roughly in proportion to the amount of oil originally discovered.

- The mobile oil resource -- almost 100 billion barrels in total -- is proportionately greater where reservoir heterogeneities and oil characteristics (e.g., high viscosity) contribute to substantial trapping and bypassing (Figure A-6):
  - Ten states have more than one billion barrels of mobile oil remaining in known reservoirs.
  - Nineteen states have at least one-half billion barrels of mobile oil.
- The immobile oil resource, totaling more than 240 billion barrels is similarly distributed geographically (Figure A-7).
  - Eight states have more than five billion barrels of immobile oil remaining in known reservoirs.
  - Twenty states have at least one billion barrels of immobile oil.
- While the greatest concentration of remaining oil lies in the Southwest, California, and Alaska, a total of 27 states -- including 12 east of the Mississippi -- contain sufficient quantities of remaining oil to warrant serious attention.

Figure A-6

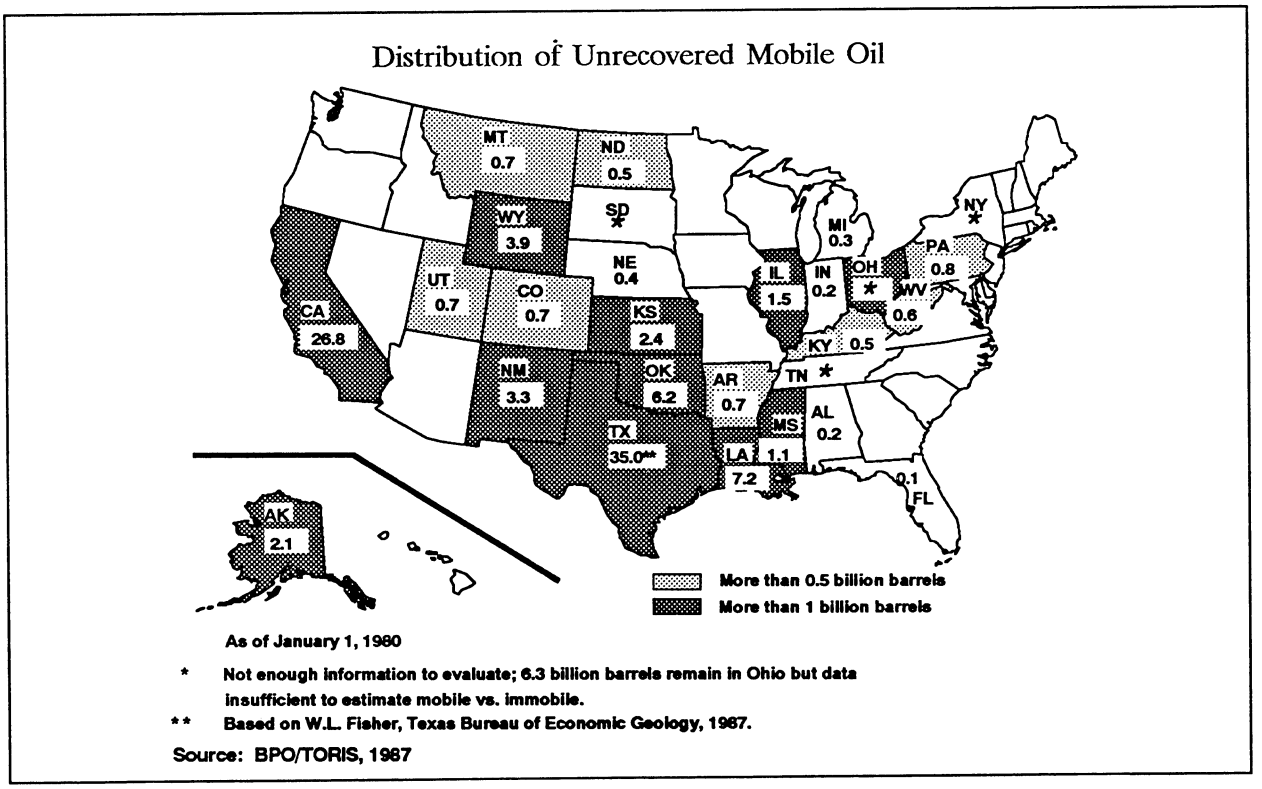
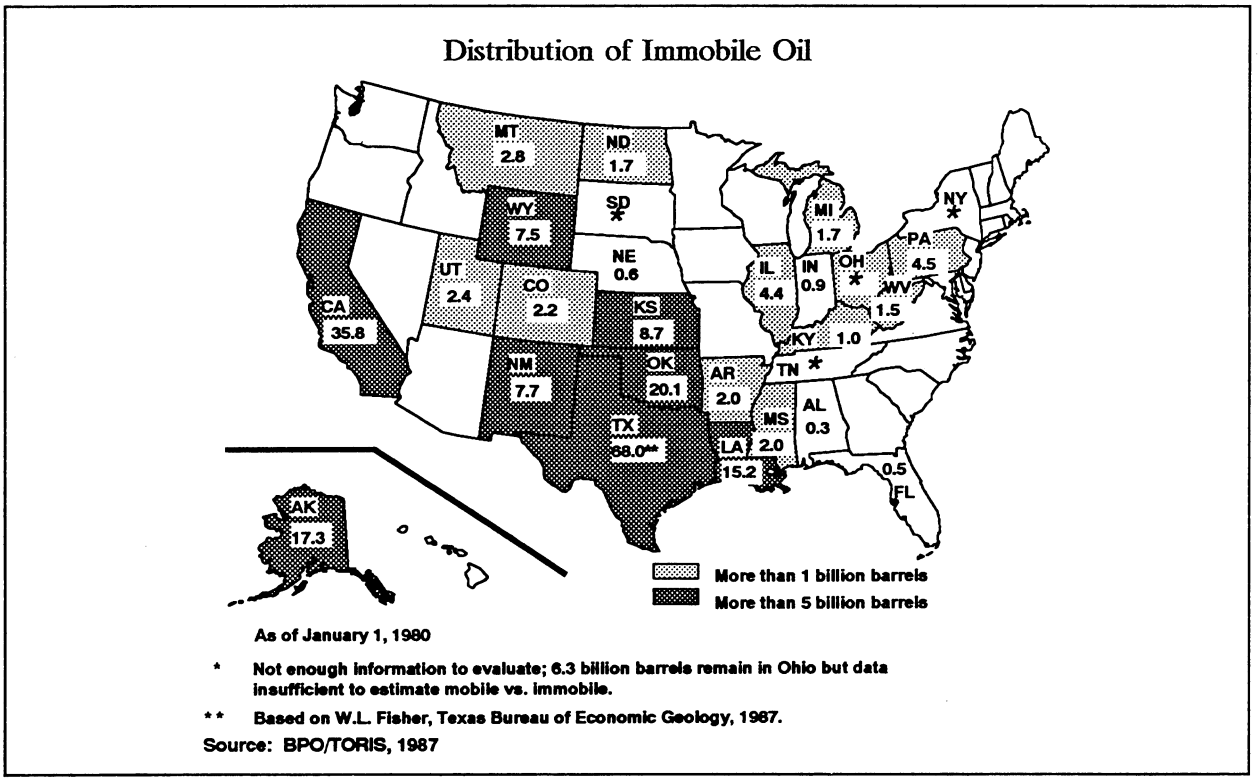


Figure A-7



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Appendix B
CLASSIFICATION OF KNOWN U.S. OIL RESOURCE

As of December 31, 1987, a total of 513 billion barrels of original in place were known to have been discovered in the nation. Figure B-1 shows the cumulative production of crude oil production in the U.S. to date, remaining reserves *producible by existing conventional and enhanced oil recovery techniques, and* potential reserve additions *attainable by well-designed R&D and technology transfer in the near- and mid-term.* This section provides technical detail on the methodology and rationale used in estimating various components of the U.S. oil resource.

Original-Oil-In-Place (OOIP)

In June 1980, the American Petroleum Institute (API) estimated the known OOIP in the United States to be 460 billion barrels[1]. Since then, the API estimate has been revised to include oil resources attributable to new discoveries, and new fields or new reservoirs in old fields, for the period from December 31, 1979 through December 31, 1987. The update is based on information published by the Energy Information Administration (EIA). In its 1988 publication, EIA reported that between 1980 and 1987 the total reserve additions from new discoveries was 2.38 billion barrels[2]. These reserves, however, are based on the estimates in the year of discovery only, and these estimates will be revised as the new fields or reservoirs become fully developed. The U.S. Geological Survey estimates that the first-year reserve estimates for a new discovery will grow by an average factor of 7.58 over the reservoir's productive life[3]. The ultimate reserve growth also includes additional reserves possible by improved recovery techniques such as fluid injection processes (waterflooding and immiscible gas injection). Applying this factor, the EIA reserve estimate from discoveries would increase to 18 billion barrels. This represents only 34% (the national average recovery efficiency, estimated based on API's ultimate recovery information) of total OOIP in the discovered fields or reservoirs; total OOIP in these zones is estimated 53 billion barrels based on this recovery factor. This resource, added to the API estimate of 460 billion barrels, results in the 513 billion barrels of OOIP for the U.S. shown in Figure B-1.

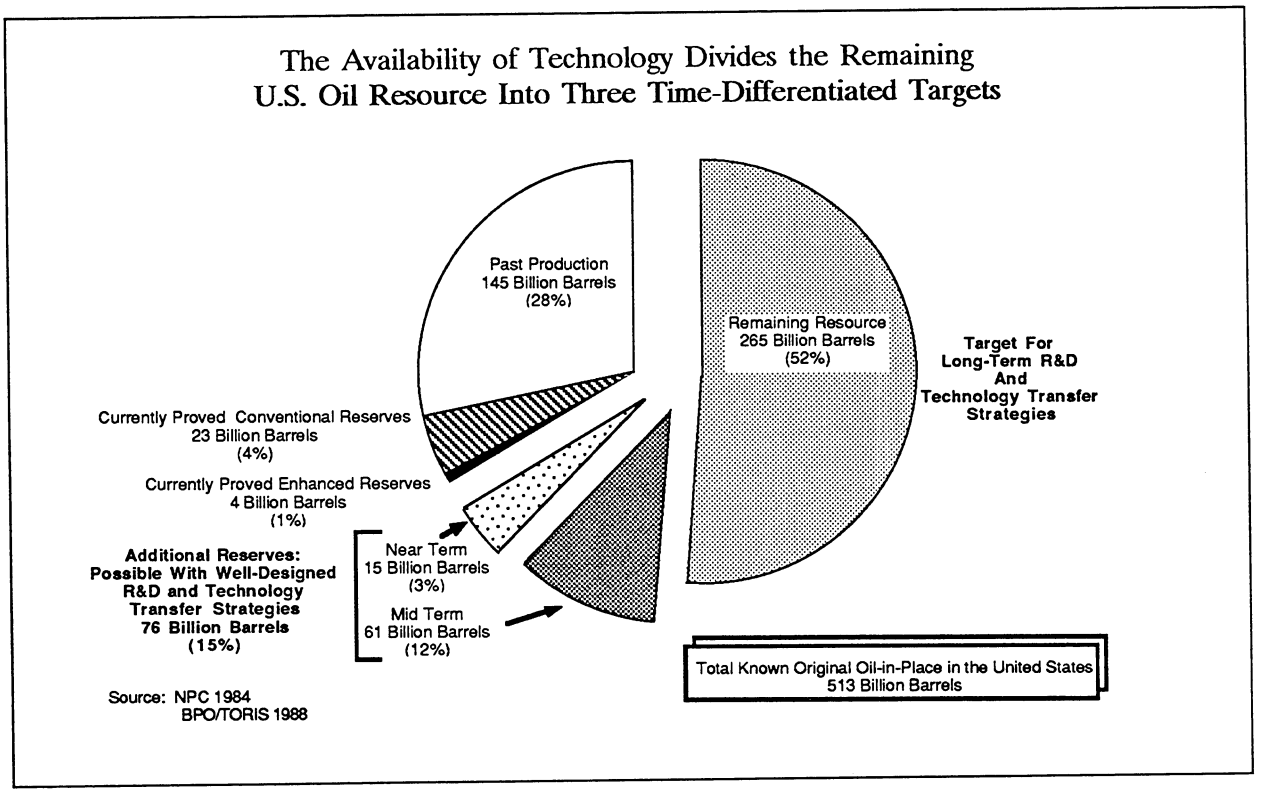
Production and Reserves

The past production estimate of 145 billion barrels is the volume of crude oil produced since the discovery of individual fields or reservoirs in the U.S. through December 31, 1987, as reported by EIA[4]. The proved reserves of 23 billion barrels refer to the volume of oil that is recoverable at existing economic and operating conditions by current primary recovery (natural flow) and water injection techniques. The enhanced oil recovery reserves (4 billion barrels) are attributed to the heavy oil recovery from the ongoing thermal projects in the state of California as reported by National Petroleum Council (NPC)[5]. The proved reserves are based on the EIA reported information less the estimated enhanced oil recovery reserves.

Additional Reserves

Figure B-1 also shows estimates of additional reserves possible with well-designed R&D and technology transfer efforts. The near-term reserves refer to the volume of oil recoverable at current crude oil prices (about $20 per barrel) with improved recovery

Figure B-1



techniques at the existing level of technology. These improved recovery techniques include enhanced oil recovery (e.g., gas-miscible, chemical, and thermal methods) and advanced secondary oil recovery operations (e.g., targeted infill drilling, polymer-assisted waterflooding, and permeability profile modification methods). The mid-term reserves are defined as additional reserves possible at the oil price of $32/Bbl with technology advances that could be achieved within the next decade as a result of a successful R&D program. The potential reserves are based on the NPC's 1984 estimate of enhanced oil recovery and a recent DOE evaluation of advanced, post-conventional secondary recovery potential in the states of Texas, Oklahoma, and New Mexico[6].

In 1982, the NPC began a two-year effort to analyze EOR potential in the U.S. Experts from all parts of industry, government, and private, non-profit organizations contributed to this effort. A national data base containing detailed engineering and geological information for over 3,500 producing reservoirs, representing nearly 60% of total known oil discovered in the nation, was developed for the study. Detailed, engineering-based analytical models were developed to project the recovery potential and associated net cash flow economics for each process analyzed. Individual reservoirs were processed through the analytical models to determine their technical applicability and economic viability under various EOR techniques. The results of individual reservoirs judged to be economic under analyzed conditions were aggregated to arrive at the national EOR reserve estimates reported by the NPC[7]. At $20/Bbl, the NPC reported incremental EOR reserves of to be

3.4 billion barrels (excluding reserves by ongoing thermal projects) with the existing level of technology. The NPC also estimated that its projection of technology advances over the next decade, coupled with an increase in oil price to $32/Bbl, would add over 20 billion barrels to the nation's crude oil reserve base. The NPC's reserve estimates are based on the analysis of only 60% of the U.S. resource; no extrapolation was attempted to determine the full recovery potential nationwide.

In 1988, the Bartlesville Project Office (BPO) of DOE initiated a major effort to evaluate the extraction potential of the unrecovered mobile oil (UMO) resource using improved primary and secondary processes. The NPC analytical models were extensively upgraded to allow evaluation of oil recovery by infill drilling, polymer flooding, and permeability profile modification. The NPC data bases were also upgraded to include additional geological information required for the evaluation of the UMO resource. In its report, BPO projected the advanced secondary recovery potential from nearly 52% of the known oil resource (OOIP) in the states of Texas, Oklahoma, and New Mexico (nearly 22% of total OOIP in the U.S.)[8]. Under the existing level of technology and a $20/Bbl oil price, advanced secondary processes could recover nearly 1.8 billion barrels of additional oil reserves. Additional reserves from the analyzed UMO resource of 4.7 billion barrels are also possible with technology advances assumed at an oil price of $32/Bbl.

Both tertiary and advanced secondary recovery reserves were extrapolated from the resources (OOIP) evaluated in the respective analyses to the total U.S. resource of 513 billion barrels. Even with the substantial amount of past production, plus proven and the extrapolated potential future reserves, a total of 265 billion barrels of crude oil will remain unrecovered in domestic reservoirs. This massive resource is clearly a target for long-term R&D and future technology transfer strategies.

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2. DOE/Energy Information Administration, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquid Reserves*, Washington, DC, 1988.

3. Dalton, *et. al.*, *Estimates of Undiscovered Recoverable Conventional Resources of Oil and Gas in the United States*. Geological Survey Circular 860, Library of Congress Catalog Card No. 82-600010 (1980).

4. DOE/Energy Information Administration, *op. cit.*

5. National Petroleum Council, *Enhanced Oil Recovery*, Washington, DC, 1984.

6. ICF Resources Incorporated and The Bureau of Economic Geology of Texas, Producing *Unrecovered Mobile Oil: Evaluation of Potential Economically Recoverable Reserves in Texas, Oklahoma, and New Mexico,* prepared for U.S. DOE/Office of Fossil Energy and Bartlesville Project Office, 1989.

7. National Petroleum Council, *op. cit.*

8. ICF Resources Incorporated and The Bureau of Economic Geology, *op. cit.*

Appendix C
DISCUSSION OF TECHNICAL ADVANCES POSSIBLE IN THE MID TERM

Analyses of unrecovered mobile oil (UMO) extraction and enhanced oil recovery (EOR) used in the Federal Oil Research Program Implementation Plan consider two possible technology levels: *implemented technology*, which assumes the application of currently available technology, and *advanced technology*, which assumes the use of specifically defined recovery techniques that result from successful research and development. Many of the anticipated technical advances have already been proven in laboratory research. However, a considerable amount of work remains to be done both in the laboratory environment and in the transfer and application of new technologies to the field. This section outlines the projected technology advances that underlie both the UMO Extraction and EOR technology case assumptions used in the evaluations cited in the Implementation Plan.

Enhanced Oil Recovery [1]

Chemical Flooding. New developments will center on research in the two major processes: surfactant and alkaline injection. In addition, the development and refinement of polymers will contribute to enhanced recovery as polymer solutions are used in conjunction with both surfactant and alkaline injection projects to improve mobility. Surfactant research focuses on extending the application of the process to reservoirs with higher temperatures, salinities, crude oil viscosity, and water hardness. Surfactant flooding improves sweep efficiency by reducing the interfacial tension between oil and water, thus enabling easier displacement of the oil. Surfactant floods have been successful only in sandstone reservoirs; research is being conducted to extend its application to carbonate reservoirs. Under current technology, surfactants function in higher temperature reservoirs only after a preflush. Research is underway to develop surfactants which will be able to operate in high-temperature reservoirs without the need for a preflush. Reducing the cost of these surfactants and the necessary polymer solutions, which are injected into the drive water to serve as mobility buffers for displacing the surfactant slug, is a key R&D goal critical to maximizing oil recovery in chemical flooded reservoirs. Other targeted goals include design of more effective slug configurations, increased injectivity (thus speeding the oil recovery and improving project economics), development and testing of chemicals that further reduce the interfacial tension between oil and water (thus improving sweep and displacement efficiencies), and development of chemicals or additives to decrease surfactant retention on reservoir rock (thereby increasing the cost-effectiveness of injection programs compared to current practices). Research on the alkaline flooding process has many of the same goals as that for polymer and surfactant processes, particularly the emphasis on expanding its application to more severe reservoir environments (see Table C-1), improved sweep and displacement efficiencies, and a reduction of the economic cost of the process. The most notable efforts are directed at improvements in slug design, understanding alkaline/rock interactions, and the development of process-accompanying polymers which can operate in more difficult environments. The current analysis assumes that advances in technology can successfully improve alkaline flooding to achieve oil

Table C-1

Screening Criteria for EOR Candidates-Implemented Technology Case

Screening Parameters*	Units	Chemical Flooding		Miscible Flooding (Carbon Dioxide)	Thermal Recovery	
		Surfactant	Alkaline		Steam	In-Situ Combustion
Oil Gravity	°API	--	<30	≥25	10 to 34	10 to 35
Insitu Oil Viscosity (μ)	cp	<40	<90	--	≤15,000	≤5,000
Depth	Feet	--	--	--	≤3,000	≤11,500
Pay Zone Thickness (h)	Feet	--	--	--	≥20	≥20
Reservoir Temperature (TR)	°F	<200	<200	--	--	--
Porosity (ϕ)	Fraction	--	--	--	≥0.20***	≥0.20***
Permeability Average (k)	md	>40	>20	--	250	35
Transmissibility (kh/μ)	md-ft/cp	--	--	--	≥5	≥5
Reservoir Pressure (PR)	psi	--	--	≥MMP**	≤1,500	≤2,000
Minimum Oil Content at Start of Process ($S_oX\phi$)	Fraction	--	--	--	≥0.10	≥0.08
Salinity of Formation Brine (TDS)	ppm	<100,000	<100,000	--	--	--
Rock Type	--	Sandstone	Sandstone	Sandstone or Carbonate	Sandstone or Carbonate	Sandstone or Carbonate

* Other criteria of a geological and depositional nature were also considered. Generally, reservoirs with extensive faulting, lateral discontinuities, or overlying gas caps are not prime candidates for field-wide EOR application. These factors were considered during the manual screening step when they could be identified.

** MMP denotes minimum miscibility pressure, which depends on temperature and crude oil composition.

*** Ignored if oil saturation (S_o) X porosity (ϕ) criteria are satisfied.

Source: NPC, 1984.

Table C-1 (Continued)

Screening Criteria for EOR Candidates-Advanced Technology Case

Screening Parameters*	Units	Chemical Flooding		Miscible Flooding (Carbon Dioxide)	Thermal Recovery	
		Surfactant	Alkaline		Steam	In-Situ Combustion
Oil Gravity	°API	--	<30	≥25	--	--
Insitu Oil Viscosity (μ)	cp	<100	<100	--	--	≤5,000
Depth	Feet	--	--	--	≤5,000	--
Pay Zone Thickness (h)	Feet	--	--	--	≥15	≥10
Reservoir Temperature (TR)	°F	<250	<200	--	--	--
Porosity (ϕ)	Fraction	--	--	--	≥0.15***	≥0.15***
Permeability Average (k)	md	>10	>10	--	≥10	≥10
Transmissibility (kh/μ)	md-ft/cp	--	--	--	--	--
Reservoir Pressure (PR)	psi	--	--	≥MMP**	≤2,000	≤4,000
Minimum Oil Content at Start of Process ($S_oX\phi$)	Fraction	--	--	--	≥0.08	≥0.08
Salinity of Formation Brine (TDS)	ppm	<200,000	<200,000	--	--	--
Rock Type	--	Sandstone or Carbonate	Sandstone	Sandstone or Carbonate	Sandstone or Carbonate	Sandstone or Carbonate

* Other criteria of a geological and depositional nature were also considered. Generally, reservoirs with extensive faulting, lateral discontinuities, or overlying gas caps are not prime candidates for field-wide EOR application. These factors were considered during the manual screening step when they could be identified.

** MMP denotes minimum miscibility pressure, which depends on temperature and crude oil composition.

*** Ignored if oil saturation (S_o) X porosity (ϕ) criteria are satisfied.

Source: NPC, 1984.

recovery equal to current practices utilizing more costly surfactants.

Miscible Flooding. Miscible displacement of oil works by the extraction of lighter weight hydrocarbons from the reservoir and by the dissolving of the miscible gas into the oil. The gas sweep efficiency depends on the viscosity ratio between the oil and the solvent; as the ratio increases, there is a greater tendency for the gas to finger through the reservoir, thereby limiting its contact with the post-waterflood oil. Technical advances in the area of miscible flooding, particularly CO_2 miscible flooding, will improve sweep efficiency and expand the applicability of this process to a wider range of reservoir environments. In moderately heterogeneous reservoirs, the use of larger CO_2 slugs could increase oil recovery. More heterogeneous reservoirs require further research on decreasing CO_2 mobility, most notably in terms of "foam" technology (the injection of chemicals to control CO_2 sweep efficiency by diverting the gas from more permeable to less permeable rock strata) and in the direct addition of polymers in conjunction with CO_2. Specific research is being directed towards obtaining a better understanding of reservoir geology, fluid and rock system characteristics, and the precipitation of asphaltene following application of the CO_2 slug. The miscible flooding process will also benefit from the reduction in operating costs resulting from the recent and future technical advances in gas separation/processing technology.

Thermal Recovery: As oil is heated by continuous steam injection into the reservoir, its viscosity is reduced, thus making it possible for both the steam and condensed water phases to displace the oil towards a production well. Although there have been few recent breakthroughs in thermal recovery technology, there still remains sizable potential for improvements in the sweep efficiency of the process and for extending its application, particularly to deeper, thinner reservoirs. Table C-1 lists the various technical advances in thermal recovery that are assumed in the advanced technology case. In the mid-term, it is likely that foams and other chemicals will be increasingly used in conjunction with steam injection to reduce gravity segregation (the separation of steam into steam vapor and condensed water zones due to their different densities), thereby increasing sweep efficiency and oil recovery. Development of more efficient steam injection equipment will also continue the refinement of the thermal process including improved tubing insulation and downhole steam generation. As for the latter, the placement of steam generation further underground will require improved corrosion resistant materials. Such needs will be addressed by metallurgy research. Further technical advances in cogeneration will also have the effect of enhancing thermal project economics. In-situ combustion, the other major process of thermal recovery, will likely depend on the increased application of oxygen-enriched air for technology advances. It has been shown that enriched air helps reduce excess nitrogen, which is responsible for well sanding and slowed oil production. In addition, improvements in the in-situ process should allow its application in deeper, poorer quality, higher pressure reservoirs as shown in Table C-1. Further research is still needed to transfer this technology, even in the current state, successfully to the field.

Advanced Secondary Recovery

UMO extraction will be influenced by technical advances in polymer flooding, profile modification, and infill drilling.[23] Polymers are used to improve mobility control and vertical sweep efficiency; cross-linked or gelled polymers are injected into the reservoir to form, in-situ, highly viscous fluids that divert subsequent injection fluids. However, currently used polymers are unstable at high temperatures and under mechanical stress, ineffective in high salinity environments, and excessively costly in high viscosity or low

permeability environments. The advanced technology case assumes that research will successfully address each of these technical constraints, thus expanding the range of reservoir environments in which the chemicals can be applied. Polymers are available which can perform in the higher temperature or higher salinity conditions assumed under the advanced technology case. However, the challenge for future research efforts is to develop polymers that meet all the technical improvements assumed at an acceptable cost. A similar increase in the temperature and salinity thresholds is also projected for profile modification treatments. Table C-2 displays the screening criteria used in assessing reservoirs for polymer flooding and profile modification treatments under both current and advanced technology scenarios.

Another critical advanced technology assumption is the development of improved reservoir characterization techniques that would allow drilling programs to target the most promising areas of a reservoir while bypassing already contacted areas with little potential. Such geologically targeted infill drilling holds great promise in heterogeneous reservoirs which contain, at current well spacings, a number of uncontacted or bypassed zones at high oil saturation. Development of the capability to geologically target wells will require integrated research including new tool development, improved geological and geophysical interpretation, and enhanced reservoir simulation capabilities. The advanced case results assume an aggressive, interdisciplinary research effort to rapidly improve reservoir characterization capabilities.

Summary

The development of advanced recovery techniques through integrated, interdisciplinary research holds significant promise for increasing domestic oil production. The advances assumed achievable in the next five to ten years are realistic goals given a RD&D effort focused on the critical problems that limit current EOR and UMO extraction operations. All of the advanced technology case process assumptions have been demonstrated in the laboratory or under highly controlled field conditions. Additional field testing and transfer of technology to operators should allow wide-scale application of these recovery methods within the time-frame assumed in the analyses. Additional work will need to focus on field demonstrations to limit associated risk and on decreasing costs to improve project economics, particularly at low to moderate oil prices.

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Table C-2

Screening Criteria for Advanced Secondary Processes

	Polymer*		Profile Modification	
	Current	Advanced	Current	Advanced
Reservoir Temperature (^{O}F)	<200	<250	<180	<250
Formation Brine Salinity (ppm)	<100,000	<200,000	<100,000	<200,000
Permeability (md)	>20	>10	>20	>10
Oil Viscosity (cp)	<100	<150	<100	<150

* Source: NPC, 1984

Appendix D
AN EXAMPLE PROGRAM
DEFINITION OF INITIAL RD&D ACTIVITIES

INTRODUCTION AND OBJECTIVES

The Oil Research Program Implementation Plan is based on the notion that in-depth research in a manageable number of carefully chosen reservoirs can result in increased national producibility because the selected reservoirs represent broad classes of reservoirs with high nationwide potential. This appendix reports an example of reservoir selection and initial RD&D planning to illustrate the use of the planned prioritization scheme. This example uses data obtained in early portions of Phase I of the Analysis and Planning effort, covering only the resource in Texas, Oklahoma, and New Mexico. A revised reservoir classification system is currently under development and will be applied in the actual selection and prioritization, and will reflect the complete domestic resource. This work has been initiated but is not yet complete, and will include additional states as they are completed until all other oil-producing states are incorporated in the prioritization. The example is meant to be representative only, to illustrate the technical issues, timing, and costs of activities developed for specific sites rather than in the abstract as described in the plan.

Recovery techniques that are currently available or can be developed and transferred to operators with focused RD&D include enhanced oil recovery (EOR) and unrecovered mobile oil (UMO) extraction processes. EOR operations rely on the injection of miscible gases, chemicals, or heat to contact, displace, and mobilize mainly the immobile resource left after successful secondary recovery, usually waterflooding, has produced the mobile oil from that portion of the reservoir. UMO extraction operations are designed to improve the recovery of the mobile oil that remains in other reservoir segments after conventional primary and secondary recovery is complete. These recovery processes include infill drilling, polymer flooding, permeability profile modification treatments, and selected combinations of these processes.

Focusing of research activities of this plan relies on the use of a geologic classification system. Previous evaluations have demonstrated that the geologic history of a reservoir significantly influences its internal structure and flow paths and, hence, its production response[1]. In addition, reservoirs can be identified and classified into larger groups, with common geologic histories, known as *plays*. Recent analyses have demonstrated that geologically similar reservoirs within a play have similar internal architecture and respond similarly to advanced oil recovery processes[2]. Individual plays can also be further categorized into larger families known as *geologic classes*. These larger groups of geologically similar reservoirs provide a means of focusing research efforts on the highest payoff targets. Because similar reservoirs have similar internal structure and production potential under selected advanced recovery operations, Federal oil research can be highly focused on the specific problems of key reservoirs and yield a high payback in terms of increased future oil production.

The purpose of this example is to demonstrate that a rational, mission-oriented program can be developed from an understanding of specific problems in reservoir

classes. The example is based upon detailed analysis already completed in Texas, Oklahoma, and New Mexico, and includes the use of reservoir classification, prioritization, and problem definition. It is illustrative of the approach that will be used on a National basis.

The example starts by assuming the classification system represented in Figure 5 (page 18), and the decline curve or urgency analysis of Figure 6 (page 19). With that information, four reservoirs in each of two high priority classes were identified to form the basis for establishing a focused research program. The reservoirs were selected on the basis of their size, with the largest being selected, their future production potential, again with the greatest being selected, and their urgency, with those in greatest danger of abandonment being selected. However, as planned for the actual work, other criteria were also considered, including: geographic dispersion (represent as many states as possible), the existence of ongoing secondary and tertiary projects, and potential industry interest.

As the example will show, eight reservoirs in four separate plays representing two distinct geological types were identified. The geologic types match the largest reservoir classes identified in the three states that were evaluated, a factor that will also be important when the actual selection process is applied to a more complete National example.

For this example, the specific reservoirs selected include:

1. Open Shelf Platforms, with Extensive Diagenetic Geologic Class
   A. South Central Basin Platform (SCBP) Play
      1) Grayburg reservoir, Cowden, North field in West Texas
      2) Grayburg-San Andres reservoir, McElroy field in West Texas

   B. San Andres/Grayburg Carbonate (NCBP) Play
      1) Grayburg-San Andres reservoir, Eunice Monument field in Southeast New Mexico
      2) Grayburg-San Andres reservoir, Hobbs field in Southeast New Mexico

2. Fluvial-Dominated Delta Geologic Class
   A. Northeast Oklahoma Desmonian Sandstone Play
      1) Earlsboro reservoir, Earlsboro field in Northeast Oklahoma
      2) Burbank reservoir, Burbank field in Northeast Oklahoma

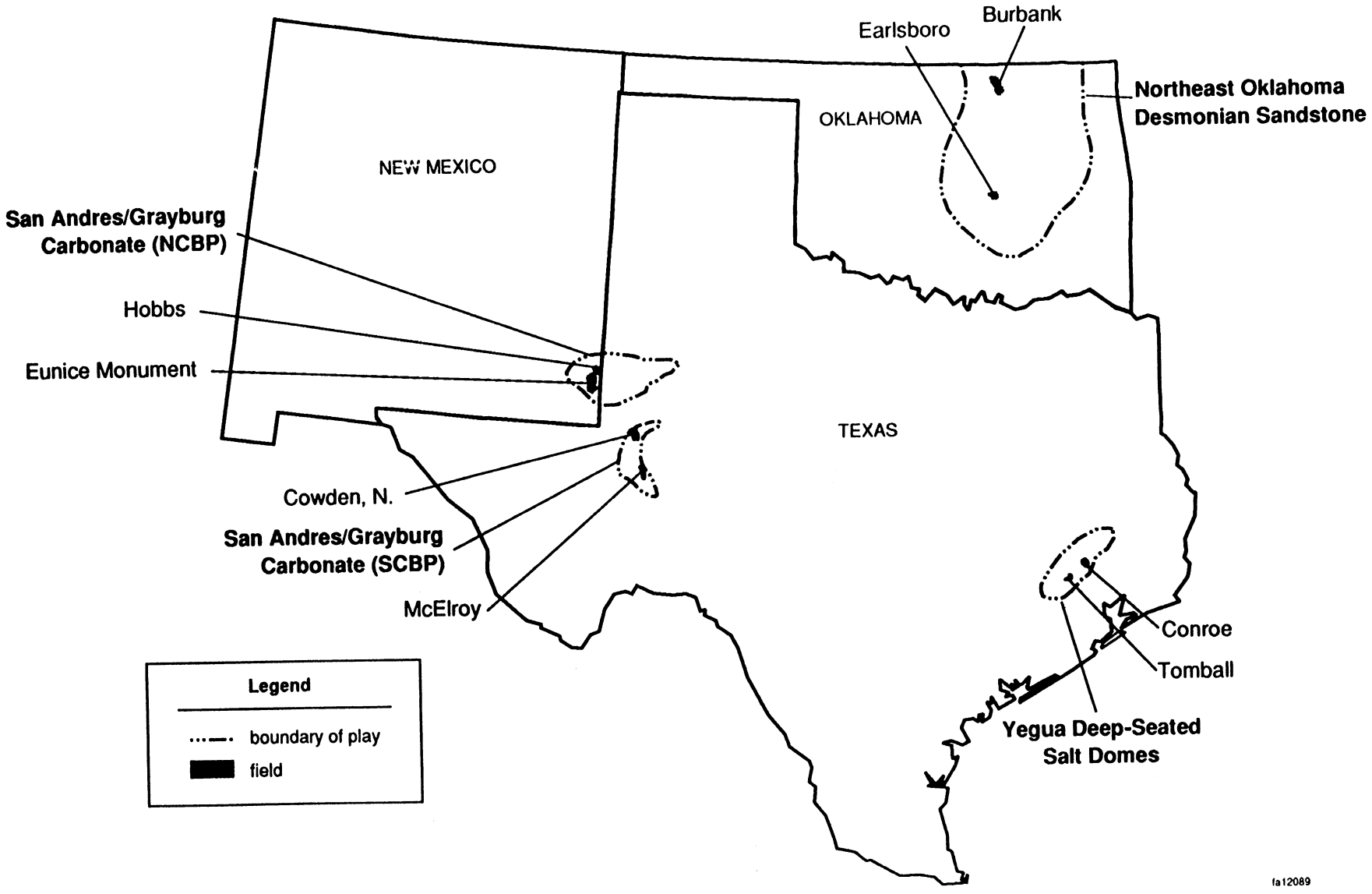
   B. Yegua Deep-Seated Salt Domes Play
      1) Conroe Main reservoir, Conroe field in Southeast Texas
      2) Cock Field reservoir, Tomball field in Southeast Texas.

The locations of these reservoirs and plays are shown in Figure D-1.

Based on data supporting this example, in the carbonate reservoirs of the Open Shelf Platforms, the initial near-term research focus should be on transferring infill drilling techniques and selected miscible flooding process requirements to field operators. Additional supporting research on temporary plugging of potentially corrosive carbonate zones would also be initiated as a near-term research activity. Initial mid-term focus would be on improving the application, sweep-efficiency, and project economics of carbon dioxide (CO_2) miscible flooding. Additional geologic descriptive work to allow targeted infill drilling and polymer injection applications to displace UMO would probably also be initiated. The combined application of CO_2 miscible flooding and infill drilling with improved operation of secondary recovery projects has significant potential for substantially increasing oil recovery in complex carbonates of this type.

Figure D-1

An Example of Reservoir Selection: Location of Candidate Reservoirs



The sandstone reservoirs of the Fluvial-Dominated Delta geologic class, as identified in this example, would require significant research on effective polymer and profile modification applications in complex sand bodies. Additional near-term research would probably focus on environmentally safe, temporary plugging procedures in shallow reservoirs. The mid-term research would focus heavily on effective use of geologically targeted infill drilling to exploit selected facies identified by improved reservoir characterization. Infill drilling, combined with profile modification treatments, may be required to fully exploit the UMO extraction potential in these plays. EOR research would need to focus primarily on methods to develop and test the application of cost-effective surfactant injection methods in these moderate temperature reservoirs. Additional supporting research on CO_2 miscible recovery may also be warranted for deeper reservoirs in this geologic class.

Focusing the initial research in the example reservoirs as described above would have the greatest overall impact. If the results in these reservoirs can be readily applied in a significant portion of the other reservoirs within the same geologic classes, the efforts will have far-reaching effects over a large number of highly productive zones. Even if the research results can only be applied to a smaller subset of reservoirs, at the play or subplay level, the impact of the oil program will be substantial since the selected reservoirs are in highly productive plays, near other major EOR or UMO extraction target reservoirs. Regardless of the scale at which the research can be applied, the selection process illustrated in the example demonstrates the use of a problem orientation and suggests how this approach maximizes impact.

BACKGROUND AND APPROACH

Several recent reports have investigated the potential for additional oil recovery from the known oil resource in three of the most significant oil producing states in the U.S.: New Mexico, Oklahoma, and Texas.[3] The amounts of the remaining oil resources extractable using EOR processes and UMO methods were estimated using DOE's Tertiary Oil Recovery Information System (TORIS). TORIS analyzed each of the reservoirs in the three-state area and determined, from the perspective of the operator, whether implementation of an advanced oil recovery project would be economic under selected oil prices and assumed technology levels. Future recovery for each project was estimated based on the reservoir-specific properties contained in the data base and regional costs for the processes analyzed. Two technology scenarios, implemented and advanced, were assumed. Implemented technology assumes oil recovery using presently available methods; advanced technology assumes the use of methods presently undergoing laboratory and/or field testing, but not yet widely available for commercial applications.

The future reserve potential was estimated for the entire known, remaining oil resource, both oil mobile to water and oil immobile to water, in each reservoir fully described in TORIS for those states. The unrecovered mobile oil (UMO) resource requires advanced primary and secondary operations to produce, while recovery of the immobile oil requires enhanced oil recovery (EOR), or tertiary processes. UMO extraction involves improving oil production through modification of existing conventional recovery methods. In the case of implemented technology, blanket infill drilling, polymer flooding, and profile modification would be the methods employed. The UMO advanced technology scenario assumed geologically targeted infill drilling and advances in polymer flooding and profile

modification techniques that would widen their applicability to more hostile reservoir environments. EOR processes produce immobile oil by reducing or eliminating adverse rock and fluid forces through the use of heat or chemical and miscible-gas injectants. The implemented EOR technology case evaluated potential recovery for nitrogen, carbon dioxide, and surfactant injection operations, and steam flooding and in-situ combustion thermal processes. The advanced technology EOR scenario assumed improvements in chemical flooding, primarily the surfactant/polymer techniques, including a reduction in the cost of the injected chemicals. The evaluation of advanced technology miscible flooding assumed the use of diverting foams and larger injection slugs in order to improve miscible sweep efficiency.

The individual reservoirs were grouped into geologic plays and finally specific geologic classes. A total of 37 geologic classes were defined in the three state region. These were based principally on the manner in which the reservoir rocks were deposited. The geologic classes broadly define groups of reservoirs that were created by similar geologic forces. For example, the geologic class Fluvial-Dominated Delta contains all reservoirs whose pay zones were deposited at the mouths of rivers and consist primarily of particles carried downstream by the river (as opposed to the portion of the delta that is influenced by geologic processing occurring in the basin or body of water into which the river is flowing).

Each geologic class contains a number of geologic plays. These plays contain groups of geologically similar reservoirs with the same source, reservoir rock, fluid properties, and trap characteristics.[4] In the three-state area, plays are usually defined by their original depositional setting and less commonly by regional erosional surfaces or diagenetic facies. The TORIS data base currently contains reservoirs in 90 separate plays: 48 in Texas, 33 in Oklahoma, and 9 in New Mexico.

The selection process for potential pilot EOR and UMO projects concentrated on the geologic types with the greatest estimated reserves producible using advanced recovery methods, the mid-term research target in the proposed oil program plan. Within each class, two plays with substantial future estimated reserve volumes for both EOR and UMO extraction were selected. Finally, two reservoirs within each play were selected, primarily based on how much of their reserves were estimated as recoverable by EOR processes and UMO methods. Ideally, the selected reservoirs had some reserves economic at the assumed oil prices of $20/B (near-term) and $32/B (mid-term), potential for recovery under both the implemented technology and advanced technology scenarios, and some secondary or tertiary projects currently underway or recently completed. In most cases, the reservoirs selected had both EOR and UMO potential in the mid-term case.

In the *actual* selection of reservoirs for field-testing, four in each geologic class is considered an absolute minimum. With two reservoirs in each of two classes, direct testing of the similarity theory is possible at the reservoir-to-play level (in each play) and the play-to-class level (cross-play comparisons). In many classes, more than this minimum number of tests may be required due to more complex geology. Further, even if the minimum number of four is to be used, it is anticipated that a substantially larger number of reservoirs would be initially selected and subjected to at least preliminary reservoir description to assure the suitability of each to the specific RD&D objectives for its class. Based on these early findings, the appropriate number of reservoirs, and specific sites within them, would be chosen well before the high cost of extraction technology pilots is incurred.

SELECTED RESERVOIRS AND RESEARCH REQUIREMENTS

In this example, eight reservoirs were selected as potential candidates for initial pilot projects within the focused RD&D program. They were chosen from the more prolific plays of the selected geologic classes, the two with the largest volume of reserves estimated as extractable using advanced technology recovery methods. Table D-1 summarizes the selected reservoirs and their estimated reserves under the near-and mid-term cases considered. Table D-2 shows the applicable recovery processes for these reservoirs.

The selected reservoirs are representative of two geologic classes and four plays, two from each geologic class. Two of the selected plays were located in Texas, one each in New Mexico and Oklahoma. The two geologic classes were the two with the greatest volume of reserves. Figure D-2 shows that the Open Shelves, Platforms and Ramps with Extensive Diagenetic Overprint geologic class has an estimated recovery potential of around 3.0 billion barrels of oil of EOR and UMO reserves, and that the Fluvial-Dominated Deltaic geologic class has an estimated maximum potential of 2.6 billion barrels. These two classes represent over 40% of the total reserves estimated as recoverable in the mid-term time-frame from analyzed reservoirs in the entire three-state region.

The two plays selected from the Open Shelf Platform class were the San Andres/Grayburg Carbonate (SCBP) play of the Texas Permian Basin and the San Andres/Grayburg Carbonate (NCBP) play of Southeast New Mexico and Texas (also part of the Permian Basin). The reservoirs selected from these plays were in the Cowden, North and McElroy fields of Texas and in the Eunice Monument and Hobbs fields of New Mexico. These four reservoirs represent 1.4 of the 3.0 billion barrels of oil estimated as recoverable under mid-term conditions from all reservoirs in their geologic class.

In the Fluvial-Dominated Delta geologic class, reservoir selections were made from the Northeast Oklahoma Desmonian Sandstone play of Oklahoma and the Yegua Deep-Seated Salt Domes play of the Texas gulf coast. Fields from the Oklahoma play included the Earlsboro and Burbank fields. Reservoirs selected from the Yegua Deep-Seated Salt Domes are in the Conroe and Tomball fields. Collectively, these reservoirs represent nearly 0.9 billion barrels of the 2.6 billion barrels of potential EOR and UMO reserves in this geologic class in the three-state region under mid-term assumptions.

Open Shelves, Platforms and Ramps with Extensive Diagenetic Overprint

This geologic class encompasses reservoirs and plays whose producing zones were formed as the result of deposition of carbonate sequences in shallow, warm mid-continental seas. The porosity and permeability of these rocks were formed by diagenetic processes which created dissolved pockets in these carbonates. The diagenetic processes also helped in maturation of the oil, which is then trapped by permeability barriers or gentle, post-depositional warping of the strata into simple anticlinal structures.

Four of the seven plays in this geologic class are located in the Permian Basin of West Texas, including two that cross the state boundary. One is in southeast New Mexico which is also considered part of the Permian Basin. The remaining two are in the Anadarko Basin of Oklahoma. The two plays used as an example in the reservoir selection were the most prolific of this geologic class. They were the San Andres/Grayburg Carbonate (SCBP) in the West Texas and the San Andres/Grayburg Carbonate (NCBP) in New Mexico and Texas.

Table D-1

Selection Criteria for Candidate Reservoirs

Estimated Reserves (MMSTB)

Fields	Reservoirs	Near-Term*		Mid-Term**	
		EOR	UMO	EOR	UMO
Cowden, North	Grayburg	--	90	119	311
McElroy	Grayburg/San Andres	--	188	--	276
Eunice Monument	Grayburg/San Andres	--	111	189	242
Hobbs	Grayburg/San Andres	--	33	98	117
Earlsboro	Earlsboro	--	--	70	56
Burbank	Burbank	--	13	87	98
Conroe	Conroe Main	--	77	217	300
Tomball	Cock Field	--	8	--	23

* Near-Term reserves are estimated at $20/Bbl oil price with Implemented Technology.

**Mid-Term reserves are estimated at $32/Bbl oil price with Advanced Technology.

Table D-2

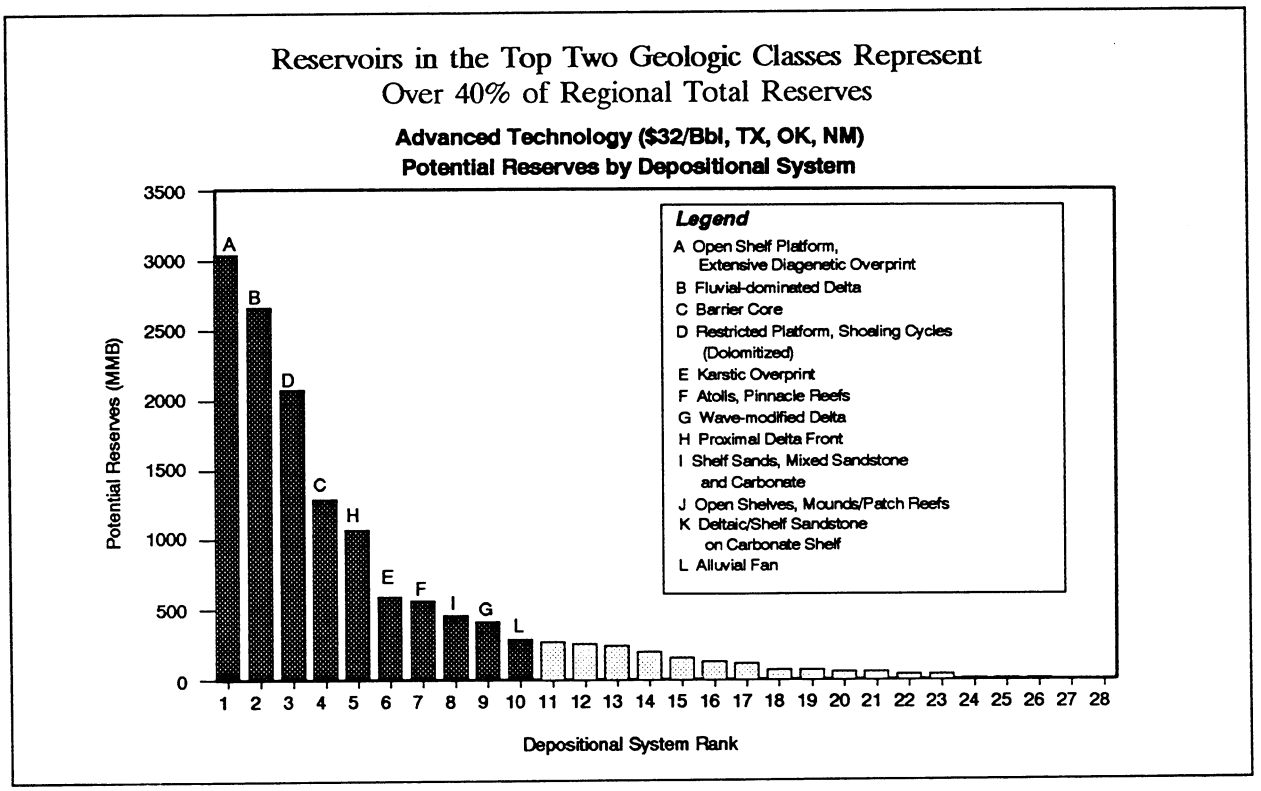
Recovery Methods for Candidate Reservoirs
Assumed Oil Prices and Technology Levels

Geologic Class	Play	Field	Reservoir	EOR Near/ Mid-Term	UMO Recovery Methods Near-Term	UMO Recovery Methods Mid-Term
Open Shelv. Plat. Ext.	San Andres/Grayburg Carbonate (SCBP)	Cowden North	Grayburg	CO_2	Infill	Infill
		McElroy	Grayburg/San Andres	--	Infill	Infill
	San Andres/Grayburg Carbonate (NCBP)	Eunice Monument	Grayburg/San Andres	CO_2	Infill	Infill
		Hobbs	Grayburg/San Andres	--	Infill/poly	Infill/poly
Fluvial-Dominated Delta	Northeast Oklahoma Desmonian Sandstone	Earlsboro	Earlsboro	CO_2	--	Infill/poly
		Burbank	Burbank	Chem	Poly	Infill
	Yegua Deep Seated Salt Domes	Conroe	Conroe Main	Chem	Infill/prf	Infill/prf
		Tomball	Cock Field	--	Prf	Infill/prf

CO_2 = CO_2 Miscible Flooding
Chem = Surfactant/Micellar Polymer Flooding
Infill = Infill Drilling (Geologically Targeted in the Advanced Case)
Poly = Polymer Flooding
Prf = Profile Modification Treatments
Infill/poly = Combined Infill Drilling with Polymer Flooding (Geologically Targeted in the Advanced Case)
Infill/prf = Combined Infill Drilling with Profile Modification Treatments (Geologically Targeted in the Advanced Case)

*Near-Term Time Frame = evaluated at $20/B oil price with Implemented Technology
Mid-Term = evaluated at $32/B oil price with Advanced Technology

Figure D-2



Description of Selected Plays and Reservoirs

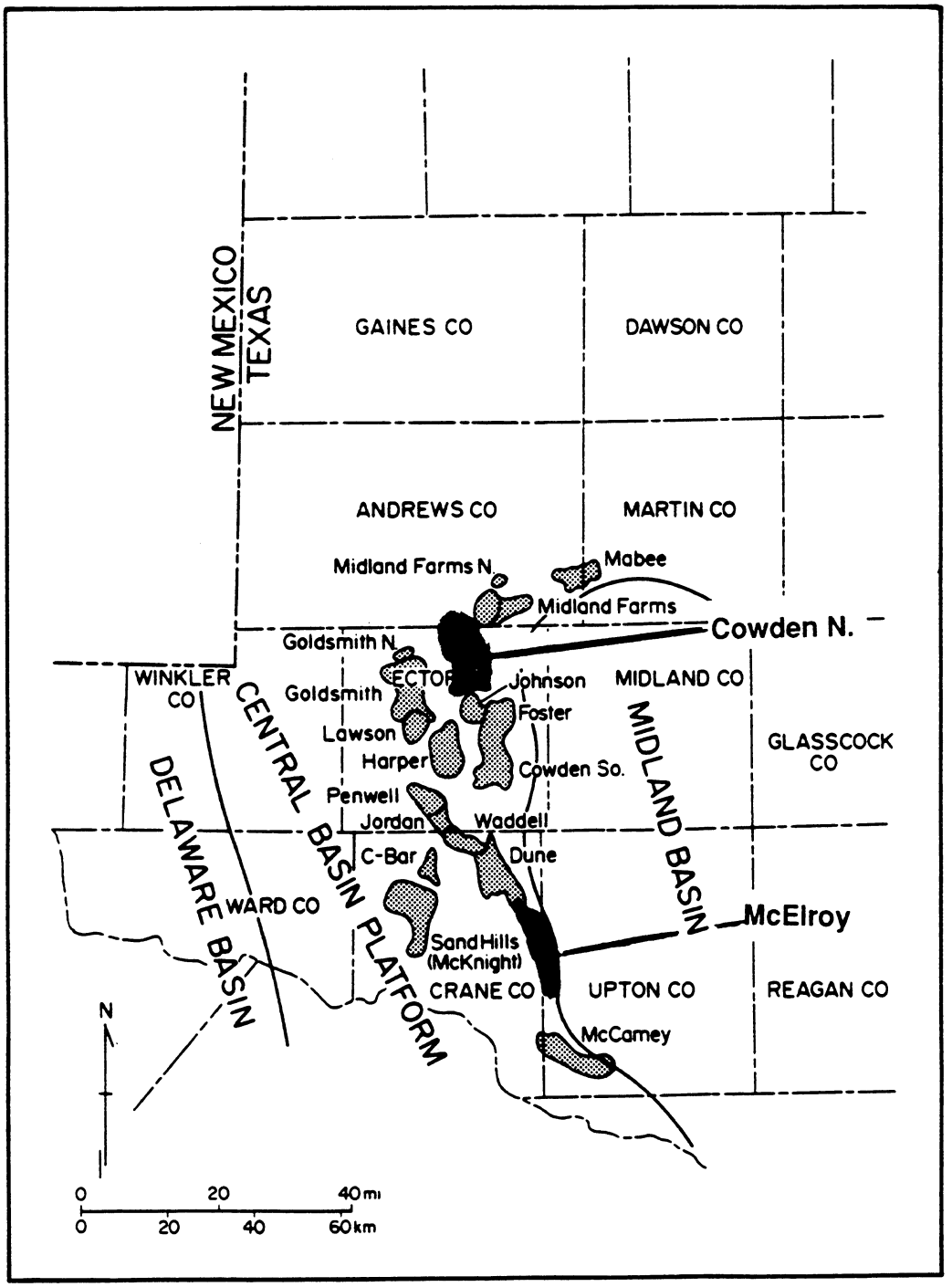
The San Andres/Grayburg Carbonate (SCBP) play is part of the group of fields located in the Central Basin Platform of the Permian Basin (Figure D-3). Reservoirs in this play are located in the limestones, dolomites, and sandstones of the San Andres and Grayburg formations. The principal reservoir rocks are dolomitized carbonates where secondary porosity has been created from leaching of skeletal grains during cyclical deposition and subareal exposure of the carbonates. This resulted in heterogeneous reservoir zones with abrupt changes in permeability. Almost all of the reservoirs have stratigraphic trapping mechanisms with occasional structural influences. Of the 19 large fields (greater than 10 million barrels of cumulative recovery) in the play, only three are not stratigraphic traps. The three exceptions (Jordan, Penwell and Waddell) have simple anticlinal traps.

The primary drive mechanism in the San Andres/Grayburg Carbonate play is solution gas, sometimes augmented with gas cap expansion or partial water drive. All major producing fields have been unitized for waterflooding and secondary recovery projects. Production from these fields is now very mature and is rapidly approaching the economic limits based on normal operating costs. Most of the waterflooding and pressure maintenance programs were initiated in the 1950's and 1960's.

The reservoirs selected from the play are in two of the larger fields. The Grayburg reservoir, Cowden, North field has projected potential of over 300 million barrels of oil recoverable in the future using miscible EOR

Figure D-3

Major Reservoirs in the San Andres/Grayburg Carbonate (SCBP) Play



Source: Bureau of Economic Geology, 1983

processes and around 120 million barrels of UMO reserves through infill drilling, assuming a $32/B oil price and availability of advanced technology. This field was discovered in 1930. It has stratigraphic trapping and a combination of solution gas and gas cap expansion drive. Well spacing is around 35 acres per well and the field was unitized in 1966. Annual production peaked in 1975 (9.4 MMB/yr.) and has been declining since. Secondary recovery is in the latter stages with both waterflooding and pressure maintenance through water and gas injection currently in use. Tests have been performed investigating the potential for tertiary recovery by using CO_2 slugs pushed by nitrogen.[5]

The second reservoir selected from the San Andres/Grayburg Carbonate Play is the McElroy field's Grayburg-San Andres reservoir. The McElroy field is a large West Texas field with a long production history. The zones in the field are characterized by stratigraphic trap and solution gas primary drive. Well spacing is at 10 acres and the field was partially unitized in 1966. A CO_2 flooding project was initiated in this reservoir by Southland in 1981.[6] During the same period, Getty Oil Co. also initiated work on a second polymer augmented waterflood.[7] The Getty project was technically and economically successful, while no such evaluation was reported for the Southland project. Besides these two advanced recovery projects, waterflooding is the commonly used secondary recovery project in the field. Production peaked at an annual rate of 13.7 million barrels of oil in 1977 and has declined since. Gas has been produced from the field since 1981, at the rate of about 2 trillion cubic feet (Tcf) per year. This reservoir was projected by TORIS to have up to 276 million barrels of oil reserves of UMO recovery with infill drilling and, on a reservoir-wide basis, no EOR potential.

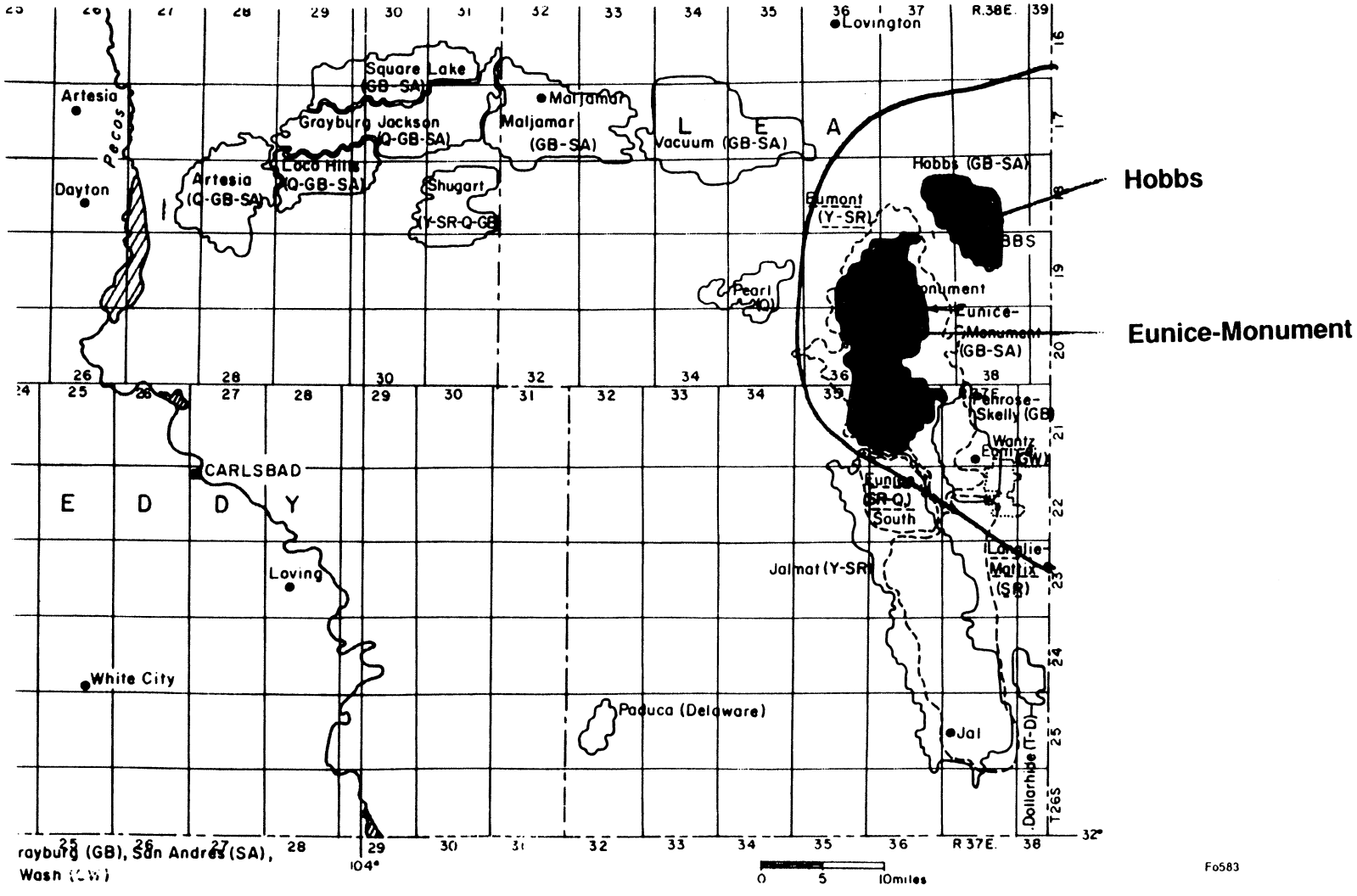
The second play in the Open Shelves, Platforms, and Ramps with Extensive Diagenetic Overprint geologic class is the San Andres/Grayburg Carbonate (NCBP) play of the Permian Basin in New Mexico and Texas. Major New Mexico reservoirs of this play are shown in Figure D-4. The depositional environment of the play's reservoirs is similar to that of the San Andres/Grayburg Carbonate (SCBP) play. In fact, the producing horizons are from the same formation. However, the reservoir characteristics of these two plays are somewhat different. The San Andres/Grayburg Carbonate (NCBP) play reservoirs have generally poorer quality rock, exhibiting a combination of structural and stratigraphic traps. The reservoirs in this play also produce under a mix of water drive, gas cap expansion, and solution gas primary drives.

The two reservoirs selected from this field are the Grayburg-San Andres reservoir of the Eunice Monument field and the Grayburg-San Andres reservoir of the Hobbs field. The Grayburg-San Andres reservoir in the Eunice Monument field was projected by TORIS to contain 242 million barrels of oil potentially producible remaining oil resource using EOR miscible flooding methods and 190 million barrels potential UMO reserves again through infill drilling. The Eunice Monument field was discovered in 1929. Production peaked in 1943 at 13.7 million barrels per year. A limited waterflood project was initiated by Gulf Oil Corp. in 1985 just after the field was unitized.[8] The 179 injection wells on an 80 acre 5 spot pattern were planned. The well spacing in the field was previously at 40 acres. The reservoir is structurally trapped (anticline) and is predominantly water driven augmented by gas solution drive.

The other reservoir selected is the Grayburg-San Andres reservoir of the Hobbs field. The Hobbs field was discovered in 1928. Initially, production ran near 13 million barrels per year and averaged about 3.5 million barrels per year from 1940 to 1965. Production then rose to nearly 5 million barrels per year in 1970 and secondary

Figure D-4

Major New Mexico Reservoirs in the San Andres/Grayburg Carbonate (NCBP) Play



Source: N.M. Bureau of Mines & Mineral Resources, 1978

recovery projects were initiated in 1971 and 1975. These limited injection programs maintained production through the late 1970's, but production has since fallen. Ultimate recovery from the zone is projected at over 150 million barrels using current operating methods. The well spacing in the field is 40 acres. TORIS projects recoverable oil reserves with UMO extraction from the reservoir of up to 117 million barrels. EOR potential reservoir-wide could total nearly 100 million barrels under mid-term oil price and technology conditions.

Initial Research Activities

The initial research activities in the Open Shelf Platform with Extensive Diagenetic Overprint geologic class would be designed to focus on transferring information on infill drilling potential to field operators. Infill drilling is economically viable in many reservoirs in this complex reservoir system even if it proceeds on a reservoir-wide, blanket drilling basis. Additional research should probably include evaluation of previous, successful and unsuccessful infill drilling programs. Special consideration would be given to ongoing projects using unique or recently altered waterflood patterns. The focus of the near-term research should be to extend the very successful water injection programs that are rapidly approaching their economic limits. Additional research on temporary well plugging in corrosive carbonate systems should also be considered in order to assure continued economic access to the remaining resource. In selected, high-quality segments of the two West Texas reservoirs, CO_2 miscible flooding pilots would probably be initiated to demonstrate the recognized potential of this EOR process in similar carbonate zones.

The initial mid-term research focus would include the development and implementation of procedures to allow infill wells to be geologically targeted. Additional research on reservoir description would support pilot tests in the selected reservoirs. The complex carbonate structures and multiple facies provide important opportunities to extract UMO if productive reservoir segments can be identified and drilled to very close (5 acres per pattern) spacing. Several pilot projects would probably be required in discrete segments of each of the four reservoirs to fully evaluate and demonstrate the economic advantages and recovery potential from closely spaced, geologically targeted infill wells. Each pilot project should include a total of at least 10 producer and 10 injection wells to assure adequate data collection and correct interpretation.

Advanced technology EOR potential in this geologic class would be predominately CO_2 miscible flooding. Key research needs in this area would focus on the improved sweep efficiency possible with foam additives, larger miscible slugs, and combined CO_2 flooding with injection profile modification treatments. Each of these improved processes would be designed to increase miscible sweep efficiency and oil recovery. All of these processes should be tested, with the most promising techniques identified more widely evaluated in all four selected reservoirs of the geologic class. Information collected and analyzed in developing geologically targeted drilling procedures should also be evaluated for use in targeting reservoir segments for improved miscible flooding.

In all, the near- and mid-term research activities in the selected example reservoirs of the Open Shelf Platform geologic class would require some ten to twenty pilot, demonstration projects. These projects would be distributed among the four selected reservoirs, and would verify results by providing data for multiple access points at each reservoir. Annual operating costs for each pilot should total around $350,000 excluding EOR injectant costs and supporting research requirements. New infill wells could

be expected to cost around $200,000 per well, slightly higher for producers than injectors. These projects should be carefully designed to assure accurate and adequate data collection and analysis of results.

Total cost, including operator cost share, for the field specific work in these four reservoirs should total between $3 to $10 million per year depending on timing of research activities. Total costs should be under $30 million over a five-to-seven year RD&D program. Full publication of all results, both successes and failures, would enhance the credibility and effectiveness of the research. Technology transfer activities would need to focus on ensuring that all operators in the defined region, particularly large unit operators, are effectively contacted concerning the research activities and their impacts. The previous success of waterflood technology in this region should enhance the operators' reception of the newly developed and demonstrated practices.

Fluvial-Dominated Deltaic

The Fluvial-Dominated Deltaic geologic class consists of plays with reservoirs resulting from the deposition of river-borne sediments near the landward side of river deltas. Nine plays make up this geologic class; three in Oklahoma and six in Texas. The two plays from which potential reservoirs for pilot projects were selected were the Northeast Oklahoma Desmonian Sandstone play and the Yegua Deep-Seated Salt Domes play, which is located along the north flank of the Houston Salt Basin in Southeast Texas.

Description of Selected Plays and Reservoirs

The Northeast Oklahoman Desmonian Sandstone play is the largest in the Fluvial-Dominated Deltaic geologic class. The reservoirs are lenticular sand-bodies deposited as channel sandstones in a deltaic complex. The traps are stratigraphic. The two reservoirs selected from this play were the Burbank reservoir of the Burbank field and the Earlsboro reservoir of the Earlsboro field. The location of these reservoirs is shown in Figure D-5.

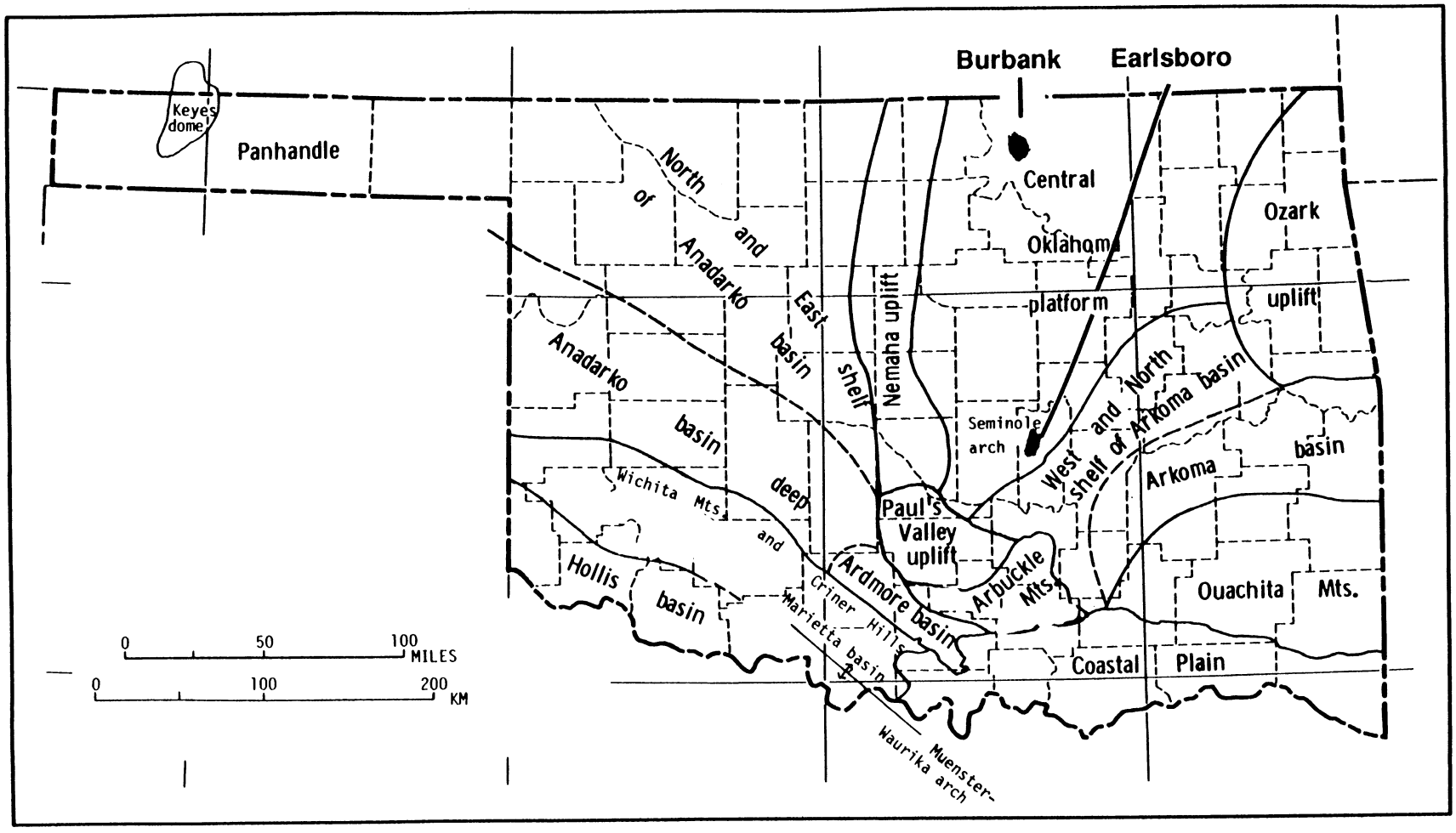
The Burbank reservoir has already been the site of an EOR pilot project operated by Phillips Petroleum Co. for 12 working-interest groups and supported by DOE. The test project was initiated in 1975 and involved surfactant-polymer flooding of a 90-acre pilot.[9] Previous to this test, gas injection to repressurize the reservoir was attempted in 1935 and steam flooding (an EOR method) was attempted in 1965. However, both EOR projects ultimately proved unsuccessful. Waterflooding was successfully introduced in the northern Burbank unit in 1950 and expanded in 1954. The Burbank reservoir is composed of lenticular sandstones which are typically heterogenous. The reservoir has a stratigraphic trap and a solution gas drive. It presently produces about 2 million barrels of oil per year, with a well spacing of around 35 acres per well. The Burbank reservoir is projected by TORIS to be capable of producing nearly 100 million barrels of unrecovered mobile oil and over 85 million barrels of oil through chemical EOR methods under mid-term price and technology assumptions.

The Earlsboro reservoir of the Earlsboro field also produces from a lenticular sandstone demonstrating stratigraphic trapping and solution gas drive. Well spacing is at 10 acre intervals. TORIS projects the Earlsboro reservoir to produce up to 55 million barrels of UMO and as much as 70 million barrels through EOR, with either CO_2 miscible or chemical recovery methods.

The last play from which reservoirs were selected was the Yegua Deep-Seated Salt Domes play of the Texas gulf coast (Figure D-6). This play is located on the northern flank of the Houston Salt Basin. The fluvial

Figure D-5

Major Reservoirs in the Northeast Oklahoma Desmonian Sandstone Play

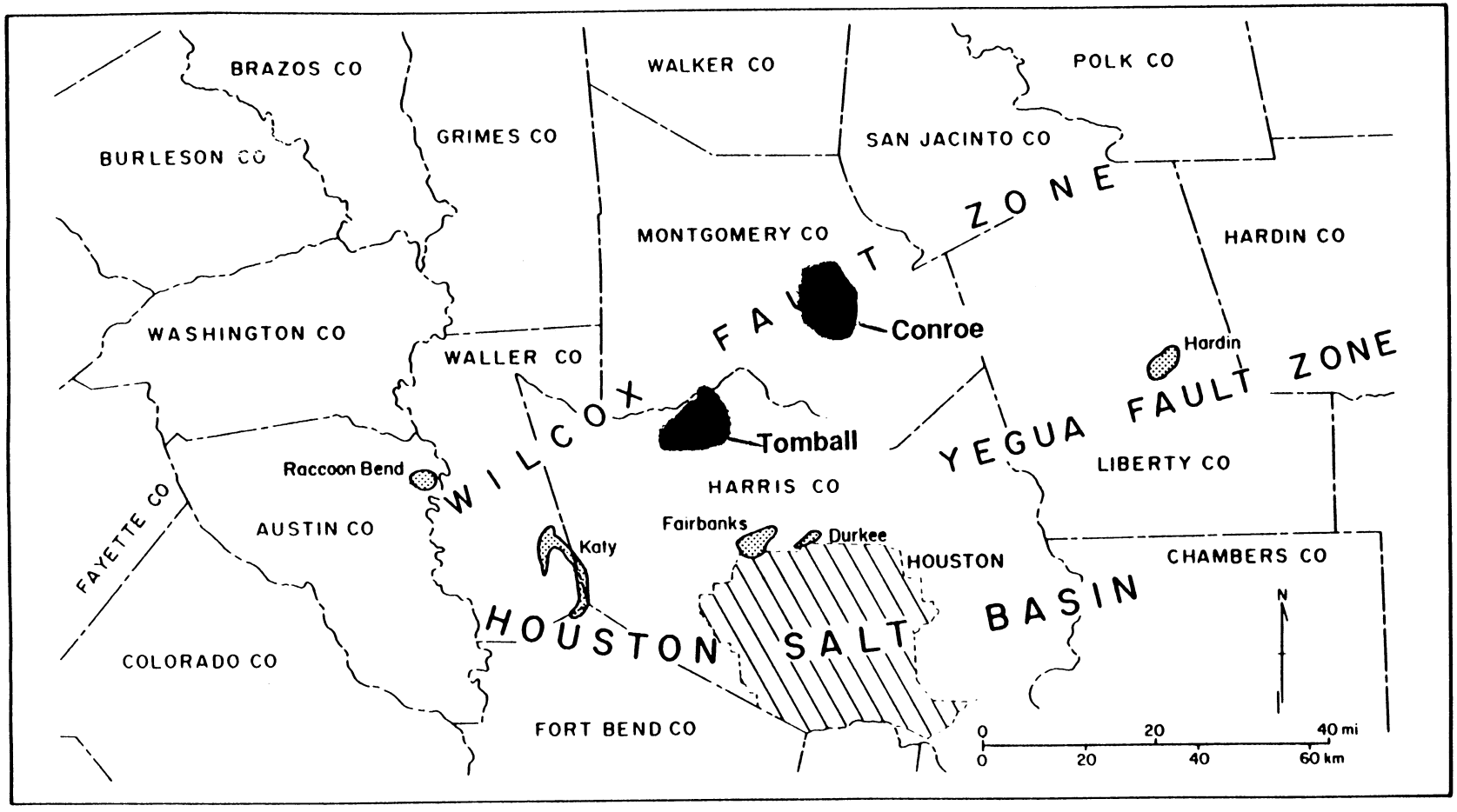


Fo58-5

Source: Landes, 1970

Figure D-6

Major Reservoirs in the Yegua Deep-Seated Salt-Dome Play



Fo58-4

Source: Bureau of Economic Geology, 1983

sandstones which make up the reservoirs of this play were deposited over the low density evaporates (slats etc.) characteristic of the Gulf coastal provinces. Diapiric movement of the slats created the structural traps characteristic of the reservoirs in this play. These traps are typically domal or near-domal anticlines. They range from unfaulted to highly faulted. The reservoir rocks are heterogenous composites of shale-separated sandstones partly connected by unsealed to poorly sealed faults.

Most of the reservoirs in this play are still primary recovery projects. The reservoirs generally have effective water drives, sometimes augmented with gas cap expansion. The structural and stratigraphic complexity of this play, along with the continued effective primary reservoir drive, provide significant opportunities for increased primary recovery. The two reservoirs selected from this play are among the older fields. They are the Conroe Main reservoir of the Conroe field and the Cock Field reservoir of the Tomball field. A secondary recovery project has been initiated in the Conroe Main reservoir, but the Cock Field reservoir is still produced by primary means.

The Conroe Main reservoir was discovered in 1932 and is projected by TORIS to contain up to 300 million barrels of recoverable UMO reserves and up to 217 million barrels of EOR potential under mid-term economic/technology conditions. The reservoir was unitized in 1978 and a pressure maintenance program was initiated to try to control a severe gas cap shrinkage problem[10] reduction has continued to drop drastically, from about 20 million barrels a year in the late 1970's to around 6 million barrels a year recently. The trap type of the Conroe Main reservoir is a faulted anticline and the original drive mechanism is a combined water drive and gas cap expansion, now augmented by both water and gas injection. Well spacing is presently at 20 acres per well.

The Cock Field reservoir of the Tomball field was discovered in 1933. It is still in the primary recovery phase but production has declined significantly in recent years. The reservoir is now producing about 40,000 barrels of oil per year after having had an annual rate of almost 0.6 million barrels in 1970. The Cock Field reservoir is not unitized. It is structurally trapped in a faulted anticline and also produces by a combination of water drive and gas cap expansion. Although no secondary recovery has been initiated in this reservoir, other reservoirs within the Tomball field have pressure maintenance injection projects underway.

Initial Research Activities

The initial research activities in the example Fluvial-Dominated Delta geologic class would focus on transferring information on infill drilling and profile modification processes to field operators. Infill drilling is economically viable in the Conroe field if it is combined with profile modification treatments. Additional research should include documentation on methods to lower the cost of water injection projects and on supplying detailed results of these projects to service companies, consultants, and producers. Near-term research would focus on extending production from low rate stripper wells in reservoirs with and without ongoing injection programs. Supporting research on temporary well plugging in relatively shallow reservoirs with production casing cemented to the surface would be critical to maintaining economic access to the remaining resource in zones within this geologic class. EOR potential, which is not viable in the near-term, could have significant mid-term potential if existing wells could be maintained as points of future access for production and injections. In addition, detailed findings and results from the Phillips micellar-polymer project in Burbank field should be reviewed and transferred to operators in other similar reservoirs.

The mid-term research in this example geologic class could again include the development and implementation of geologically targeted infill drilling. Additional research on reservoir description should be added because it would support pilot tests in the selected reservoirs to fully develop the UMO recovery potential in these key reservoirs. Blanket infill drilling under implemented technology, the near-term potential, is not economically viable in most of the reservoirs in this geologic class. In addition, the combination of infill drilling with profile modification treatments or polymer injection programs would be critical to fully realizing the recovery potential from the UMO resource in the mid term. Several pilot projects would probably be required in each of the four reservoirs to fully evaluate and demonstrate the economic advantages and UMO extraction potential. Each pilot project should again include a total of 10 producer and 10 injection wells to assure adequate data collection and correct interpretation of research results.

Advanced technology EOR potential in this example geologic class would be predominately surfactant flooding, although miscible flooding is possible in some deeper zones. Key research needs in this area would focus on the improved sweep efficiency possible with new, more resilient chemicals that are cost-effective to apply in key reservoirs at reasonable oil prices. These improvements are designed to make surfactant flooding a prolific EOR process, economic at lower oil prices than currently possible. Information collected and analyzed in developing geologically targeted drilling procedures would also be evaluated for use in targeting reservoir segments for EOR, utilizing both chemical and miscible recovery techniques.

Once again, the near- and mid-term research activities in four example reservoirs of the Fluvial-Dominated Deltaic geologic class would require some ten to twenty pilot projects to obtain a thorough evaluation of process predictability and of the potential for extrapolating results to geologically similar reservoirs. Costs should be less than for the Open Shelf Platform RD&D activities due to the lower operating costs and relatively shallower reservoir depths in the plays. This should allow the field-specific research work to be completed for less than $25 million over a ten year program. However, cost-sharing could be more difficult given the larger number of small independent operators in these reservoirs, particularly in those located in Oklahoma.

SUMMARY AND CONCLUSIONS

As the example shows, the targeting of research on specific reservoirs, plays, and geologic classes holds significant promise for increasing domestic oil production. The eight reservoirs described and analyzed in this example are projected to be significant future sources of oil production capacity in their own right. However, more importantly, their reservoir rock, geologic conditions, and fluid characteristics should be representative of reservoirs containing some 40% of the estimated total recovery potential in the three-state region evaluated thus far. The ability to transfer information on the success and failure of research and demonstration projects in these key reservoirs could substantially increase the application and effectiveness of both EOR and UMO extraction projects in the U.S. The same expectations would hold in actual program implementation, where efforts would be focused as well even though providing broader National coverage.

The costs estimated for the example, covering both the near- and mid-term field-specific research, are expected to be representative of those for the actual classes ultimately selected. The total, estimated at between $50 and $75 million over a 5 to 10

year period for actual field projects should be partially offset by cost-sharing; the estimates in the plan assume 50% in estimating actual program costs. These estimates do not include costs for associated supporting research in reservoir description and extraction technology development.

In the actual program, specific research and pilot project activities would vary from reservoir to reservoir based on the critical needs determined as the program progresses. Based on current information applicable to this example, the initial near-term activities would focus on technology transfer of information about infill drilling and development and transfer of new methods of temporary well abandonment to operators of reservoirs in both of these diverse geologic classes. Mid-term research should focus immediately on improving reservoir descriptive techniques to allow highly targeted infill drilling in discrete segments of complex reservoir structures. EOR activities would initially focus on determining improved methods for injecting CO_2 miscible gas into reservoirs of the Open Shelf Platform geologic class and on developing and applying more effective polymers and surfactants for cost-effective chemical floods in reservoirs of the Fluvial-Dominated Deltaic geologic class. These activities would be modified over time as new data is collected and additional, more-advanced recovery processes are identified and evaluated.

The benefits of this RD&D would extend into the long-term as well, as improved geologic understanding and better descriptive methods and recovery processes could aid in producing additional oil from the still massive oil resource which would remain in these geologic classes. While long-term research would initially focus on reservoirs of these two classes that are not producible with available processes under assumed economic and technology conditions, a large volume of oil would remain in many of the reservoirs successfully developed under identified and analyzed future recovery operations. Near- and mid-term research could improve recovery in these reservoirs beyond the estimates developed under the assumed technology levels analyzed to date. Therefore, the true benefits of the program would only be apparent after completion of some of the immediate priority activities.

Overall, a research program such as that described in this example shows how site-specific problem orientation can produce results that lead to improved domestic oil recovery within reasonable resource requirements. The development of procedures and recovery processes aimed at the larger reservoirs from the more prolific geologic classes should serve to focus research on critical needs and maximize the resulting benefits. The overall approach provides a cost-effective method for assuring maximum application of research results by a large number of operators in critical regions. Cost-sharing of the required investments with these operators could provide additional benefits and focus to the overall RD&D efforts.

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FUNDING OPTIONS

These funding levels have not been approved for inclusion in the Department's or the President's budget. They are provided in response to a Congressional request in the FY 1990 appropriation. The base case (earliest start) program covers ten of the twelve highest priority reservoir classes identified. It has not been constrained by budgetary limitations; only technical constraints affect task start dates. This unconstrained base case has not been analyzed to determine the costs and benefits of the program, nor have resource trade-offs been made with other program areas within the Department. None of the funding levels identified in this report should be interpreted as representing the Department's program budgets in this area.

Two alternate funding options have been developed. Both alternatives allow the near-term field work to begin as soon as possible. These activities are designed to preserve access to the remaining resource until mid-term field work and technology transfer can be implemented. Each option delays the start of the mid-term field work. The delayed start option allows two reservoir classes to begin each fiscal year. The remaining option begins only one class per year.

Detailed funding levels for each of the funding options are shown in the following pages.

- Budget Scenarios - 10 Classes
- Major Milestones - 10 Classes
- Base Case Budget
- Delayed Start Budget
- One Class Per Year Budget

Table I-1

BUDGET SCENARIOS – 10 CLASSES

$000/Year and Completion Date of Field Demos

Numbers to the right of a column indicate that field work for those classes (excl. out-year monitoring & TT) is completed that year.

Assumptions:

	BASE CASE All tasks begin based on earliest CPM start	*Compl. Class*	DELAYED STARTS Class 1 & NT work for all classes begin ASAP. All other classes begin 2 per year.	*Compl. Class*	ONE CLASS PER YEAR Class 1 & NT work for all classes begin ASAP. All other classes begin 1 per year.	*Compl. Class*
FY 90	22,473		22,473		22,473	
FY 91	22,469		22,469		22,469	
FY 92	27,390		26,690		25,690	
FY 93	39,875		35,075		25,075	
FY 94	44,480		39,880		30,830	
FY 95	105,280		68,580		43,530	
FY 96	92,780		66,580		42,280	
FY 97	55,830	1,2	58,130	1,2	42,780	1
FY 98	21,130	3-8	54,230	3,4	41,080	2
FY 99	22,480		53,180	5,6	42,030	3
FY 00	19,730	9,10	19,930	7,8	41,980	4
FY 01	17,880		20,780	9,10	42,080	5
FY 02	17,130		18,830		37,330	6
FY 03	16,380		17,080		35,380	7
FY 04	14,980		15,680		34,230	8
FY 05			14,980		17,530	9
FY 06					17,530	10
FY 07					16,380	
FY 08					15,680	
FY 09					14,980	
FY 10					14,630	
TOTAL	**540,287**		**554,567**		**625,967**	
AVG/YR	**36,019**		**34,660**		**29,808**	

All figures exclude $500 K per year after FY 91 for other analytical work.

Note: NT stands for Near-Term. TT stands for Technology Transfer.

Table I-2

Major Milestones – 10 Classes

Comparison of Funding Alternatives

	Base Case	Delayed Start	One Class Per Year
Initial Classification Based on Best Available Data	1990	1990	1990
Classification of Onshore Resource (Excl. LA, AK, Appalachia & Heavy Oil)	1990	1990	1990
Classification of Onshore Resource Incl. Heavy Oil (Excl. AK & Appalachia)	1991	1991	1991
Classification of Full U.S. Resource	1992	1992	1992
Identification of Top 12 Reservoir Classes	1992	1992	1992
Class 1 Field Work Begins	1991	1991	1991
Class 1 Field Work Complete	1997	1997	1997
Class 2 Field Work Complete	1997	1997	1998
Class 3 Field Work Complete	1998	1998	1999
Class 4 Field Work Complete	1998	1998	2000
Class 5 Field Work Complete	1998	1999	2001
Class 6 Field Work Complete	1998	1999	2002
Class 7 Field Work Complete	1998	2000	2003
Class 8 Field Work Complete	1998	2000	2004
Class 9 Field Work Complete	2000	2001	2005
Class 10 Field Work Complete	2000	2001	2006

Table I-3

BASE CASE BUDGET
$000
All tasks begin based on their earliest CPM date.
No budgetary constraints.

	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	TOTAL
DATA ANALYSIS	1,170	2,275	250	595												4,290
MON, EVAL & PLANNING	480	480	480	880	880	880	880	880	880	880	880	880	880	880	880	12,000
SUPPORTING RESEARCH	20,823	9,474	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	204,497
SUBTOTAL	22,473	12,229	14,130	14,875	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	220,787
NEAR-TERM WORK (PRESERVE ACCESS THROUGH TECHNOLOGY TRANSFER OF PROVEN TECHNOLOGY)																
CLASS 1		1,900*	250	650	700	200	200									3,900
CLASS 2		1,900*	250	650	700	200	200									3,900
CLASS 3		50	1,750	350	800	550	200	200								3,900
CLASS 4		50	1,750	350	800	550	200	200								3,900
CLASS 5		50	1,750	350	800	550	200	200								3,900
CLASS 6		50	1,750	350	800	550	200	200								3,900
CLASS 7		40	360	1,750	650	700	200	200								3,900
CLASS 8			400	1,750	650	700	200	200								3,900
CLASS 9				50	1,750	350	800	550	200	200						3,900
CLASS 10				50	1,750	350	800	550	200	200						3,900
SUBTOTAL	0	4,040	8,260	6,300	9,400	4,700	3,200	2,300	400	400	0	0	0	0	0	39,000
FIELD WORK (DESIGN AND FIELD TEST OF ADVANCED TECHNOLOGY)																
CLASS 1		3,100*	1,900	1,950	1,150	16,700	0	550	500	500						26,350
CLASS 2		3,100*	1,900	1,950	1,150	16,700	0	550	500	500						26,350
CLASS 3			300	4,700	1,950	17,850	0	550	500	500						26,350
CLASS 4			300	4,700	1,950	17,850	0	550	500	500						26,350
CLASS 5			300	2,400	2,300	1,950	17,850	0	550	500	500					26,350
CLASS 6			300	2,400	2,300	1,950	17,850	0	550	500	500					26,350
CLASS 7				300	4,700	1,950	17,850	0	550	500	500					26,350
CLASS 8				300	4,700	1,950	17,850	0	550	500	500					26,350
CLASS 9					300	4,700	1,950	17,850	0	550	500	500				26,350
CLASS 10					300	4,700	1,950	17,850	0	550	500	500				26,350
SUBTOTAL	0	6,200	5,000	18,700	20,800	86,300	75,300	37,900	4,200	5,100	3,000	1,000	0	0	0	263,500
TECHNOLOGY TRANSFER OF FIELD TEST RESULTS																
CLASS 1								600	200	200	350	350				1,700
CLASS 2								250	350	200	200	350	350			1,700
CLASS 3								250	350	200	200	350	350			1,700
CLASS 4								250	350	200	200	350	350			1,700
CLASS 5									250	350	200	200	350	350		1,700
CLASS 6									250	350	200	200	350	350		1,700
CLASS 7									250	350	200	200	350	350		1,700
CLASS 8										250	350	200	200	350	350	1,700
CLASS 9										250	350	200	200	350	350	1,700
CLASS 10																
SUBTOTAL	0	0	0	0	0	0	0	1,350	2,250	2,700	2,450	2,600	2,850	2,100	700	17,000
TOTAL	22,473**	22,469	27,390	39,875	44,480	105,280	92,780	55,830	21,130	22,480	19,730	17,880	17,130	16,380	14,980	540,287
OTHER ANALYTICAL WORK	0***	0***	500	500	500	500	500	500	500	500	500	500	500	500	500	6,000
HEAVY OIL	4,014	4,636	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	62,650

* The sum of these items is equivalent to the $5 million per class requested in FY91 to begin field work in classes 1 & 2

** This is equal to the total for light oil in FY90. Much of this amount supports mortgages developed under previous implementation plans.

*** Included in the total above

Table I-4

DELAYED START
$000
Class 1 starts ASAP. All NT work starts ASAP.
Other classes FW begin 2 per year.

	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	TOTAL
DATA ANALYSIS	1,170	2,275	250	595													4,290
MON, EVAL & PLANNING	480	480	480	880	880	880	880	880	880	880	880	880	880	880	880	880	12,880
SUPPORTING RESEARCH	20,823	9,474	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	217,897
SUBTOTAL	22,473	12,229	14,130	14,875	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	235,067
NEAR-TERM WORK (PRESERVE ACCESS THROUGH TECHNOLOGY TRANSFER OF PROVEN TECHNOLOGY)																	
CLASS 1		1,900*	250	650	700	200	200										3,900
CLASS 2		1,900*	250	650	700	200	200										3,900
CLASS 3		50	1,750	350	800	550	200	200									3,900
CLASS 4		50	1,750	350	800	550	200	200									3,900
CLASS 5		50	1,750	350	800	550	200	200									3,900
CLASS 6		50	1,750	350	800	550	200	200									3,900
CLASS 7		40	360	1,750	650	700	200	200									3,900
CLASS 8			400	1,750	650	700	200	200									3,900
CLASS 9				50	1,750	350	800	550	200	200							3,900
CLASS 10				50	1,750	350	800	550	200	200							3,900
SUBTOTAL	0	4,040	8,260	6,300	9,400	4,700	3,200	2,300	400	400	0	0	0	0	0	0	39,000
FIELD WORK (DESIGN AND FIELD TEST OF ADVANCED TECHNOLOGY)																	
CLASS 1		3,100*	1,900	1,950	1,150	16,700	0	550	500	500							26,350
CLASS 2		3,100*	1,900	1,950	1,150	16,700	0	550	500	500							26,350
CLASS 3			250	4,750	1,950	1,150	16,700	0	550	500	500						26,350
CLASS 4			250	4,750	1,950	1,150	16,700	0	550	500	500						26,350
CLASS 5				250	4,750	1,950	1,150	16,700	0	550	500	500					26,350
CLASS 6				250	4,750	1,950	1,150	16,700	0	550	500	500					26,350
CLASS 7					250	4,750	1,950	1,150	16,700	0	550	500	500				26,350
CLASS 8					250	4,750	1,950	1,150	16,700	0	550	500	500				26,350
CLASS 9						250	4,750	1,950	1,150	16,700	0	550	500	500			26,350
CLASS 10						250	4,750	1,950	1,150	16,700	0	550	500	500			26,350
SUBTOTAL	0	6,200	4,300	13,900	16,200	49,600	49,100	40,700	37,800	36,500	3,100	3,100	2,000	1,000	0	0	263,500
TECHNOLOGY TRANSFER OF FIELD TEST RESULTS																	
CLASS 1								600	200	200	350	350					1,700
CLASS 2								250	350	200	200	350	350				1,700
CLASS 3									600	200	200	350	350				1,700
CLASS 4									600	200	200	350	350				1,700
CLASS 5										600	200	200	350	350			1,700
CLASS 6										600	200	200	350	350			1,700
CLASS 7											600	200	200	350	350		1,700
CLASS 8											600	200	200	350	350		1,700
CLASS 9												600	200	200	350	350	1,700
CLASS 10												600	200	200	350	350	1,700
SUBTOTAL	0	0	0	0	0	0	0	850	1,750	2,000	2,550	3,400	2,550	1,800	1,400	700	17,000
TOTAL	22,473**	22,469	26,690	35,075	39,880	68,580	66,580	58,130	54,230	53,180	19,930	20,780	18,830	17,080	15,680	14,980	554,567
OTHER ANALYTICAL WORK	0***	0***	500	500	500	500	500	500	500	500	500	500	500	500	500	500	7,000
HEAVY OIL	4,014	4,636	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	71,650

* The sum of these items is equivalent to the $5 million per class requested in FY91 to begin field work in classes 1 & 2.
** This is equal to the total for light oil in FY90. Much of this amount supports mortgages developed under previous implementation plans.
*** Included in the total above

Table I-5

ONE CLASS PER YEAR
$000
Class 1 starts ASAP. All NT work starts ASAP.
Other classes FW begin 1 per year.

	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY 07	FY08	FY09	FY10	TOTAL
																						4,290
DATA ANALYSIS	1,170	2,275	250	595																		17,280
MON, EVAL & PLANNING	480	480	480	880	880	880	880	880	880	880	880	880	880	880	880	880	880	880	880	880	880	284,897
SUPPORTING RESEARCH	20,823	9,474	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	
SUBTOTAL	22,473	12,229	14,130	14,875	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	14,280	306,467
NEAR-TERM WORK (PRESERVE ACCESS THROUGH TECHNOLOGY TRANSFER OF PROVEN TECHNOLOGY)																						3,900
CLASS 1		1,900*	250	650	700	200	200															3,900
CLASS 2		1,900*	250	650	700	200	200															3,900
CLASS 3		50	1,750	350	800	550	200	200														3,900
CLASS 4		50	1,750	350	800	550	200	200														3,900
CLASS 5		50	1,750	350	800	550	200	200														3,900
CLASS 6		50	1,750	350	800	550	200	200														3,900
CLASS 7		40	360	1,750	650	700	200	200														3,900
CLASS 8			400	1,750	650	700	200	200														3,900
CLASS 9				50	1,750	350	800	550	200	200												3,900
CLASS 10				50	1,750	350	800	550	200	200												
SUBTOTAL	0	4,040	8,260	6,300	9,400	4,700	3,200	2,300	400	400	0	0	0	0	0	0	0	0	0	0	0	39,000
FIELD WORK (DESIGN AND FIELD TEST OF ADVANCED TECHNOLOGY)																						26,350
CLASS 1		3,100*	1,900	1,950	1,150	16,700	0	550	500	500												26,350
CLASS 2		3,100*	1,400	1,700	1,000	900	16,700	0	550	500	500											26,350
CLASS 3				250	4,750	1,950	1,150	16,700	0	550	500	500										26,350
CLASS 4					250	4,750	1,950	1,150	16,700	0	550	500	500									26,350
CLASS 5						250	4,750	1,950	1,150	16,700	0	550	500	500								26,350
CLASS 6							250	4,750	1,950	1,150	16,700	0	550	500	500							26,350
CLASS 7								250	4,750	1,950	1,150	16,700	0	550	500	500						26,350
CLASS 8									250	4,750	1,950	1,150	16,700	0	550	500	500					26,350
CLASS 9										250	4,750	1,950	1,150	16,700	0	550	500	500				26,350
CLASS 10											250	4,750	1,950	1,150	16,700	0	550	500	500			
SUBTOTAL	0	6,200	3,300	3,900	7,150	24,550	24,800	25,350	25,850	26,350	26,350	26,100	21,350	19,400	18,250	1,550	1,550	1,000	500	0	0	263,500
TECHNOLOGY TRANSFER OF FIELD TEST RESULTS								600	200	200	350	350										1,700
CLASS 1								250	350	200	200	350	350									1,700
CLASS 2										600	200	200	350	350								1,700
CLASS 3											600	200	200	350	350							1,700
CLASS 4												600	200	200	350	350						1,700
CLASS 5													600	200	200	350	350					1,700
CLASS 6														600	200	200	350	350				1,700
CLASS 7															600	200	200	350	350			1,700
CLASS 8																600	200	200	350	350		1,700
CLASS 9																	600	200	200	350	350	1,700
CLASS 10																						
SUBTOTAL	0	0	0	0	0	0	0	850	550	1,000	1,350	1,700	1,700	1,700	1,700	1,700	1,700	1,100	900	700	350	17,000
TOTAL	22,473**	22,469	25,690	25,075	30,830	43,530	42,280	42,780	41,080	42,030	41,980	42,080	37,330	35,380	34,230	17,530	17,530	16,380	15,680	14,980	14,630	625,967
OTHER ANALYTICAL WORK	0***	0***	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	9,500
HEAVY OIL	4,014	4,636	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	94,150

* The sum of these items is equivalent to the $5 million per class requested in FY91 to begin field work in classes 1 & 2.
** This is equal to the total for light oil in FY90. Much of this amount supports mortgages developed under previous implementation plans.
*** Included in the total above.

ANALYSIS & PLANNING

The program includes three primary functions: analysis and planning; field demonstrations; and supporting research. Analysis and planning includes the data collection and analysis functions to analyze, classify and prioritize the domestic resource base. These analytical tasks will define the field work and supporting research needs. Also incorporated in this function are the on-going program management tasks, including monitoring and evaluation of program activities, maintenance and updating of the database and models which support program activities, and other analytical work.

The data analysis function has been divided into four phases. The first phase, which begins immediately, uses the best available data to rank reservoir classes for beginning field work. An analysis of mobile and immobile oil in New Mexico, Oklahoma, and Texas characterized over 40% of the oil remaining in the U.S. The top reservoir classes identified in these states represent such a large potential resource, with high risk of abandonment, that they provide the first two classes where field work will begin. The second phase of data analysis incorporates the data collected under the IOCC Multi-state Study. The Multi-state Study was funded in FY 1989, with funding released the end of September 1989. States will classify their large reservoirs already in the TORIS data base system to correspond with the classification system adopted. This will provide comparable data for nearly the entire onshore resource base. A second assessment and ranking of the resource will be performed when this classification is complete. The third phase of the data analysis function will incorporate data from states where large reservoirs are currently missing from the TORIS data base, such as Louisiana. Other states will also be providing, under the IOCC study, data for additional reservoirs not previously considered. Also completed during this third phase is an assessment of the nation's heavy oil resources and their incorporation into the data base. When these data analyses are complete, a third ranking of the U.S. onshore resource will be performed to identify additional high priority reservoir classes. The final phase of data analysis supplies data for the rest of the U.S., including offshore. From this phase, a ranking of the complete domestic resource base is undertaken, defining the top twelve reservoir classes and launching the field work necessary to complete the top ten classes.

The total cost of the analysis and planning segment of the program is $16.3 million over the next 15 years, for an average cost of $1.08 million per year. The data analysis phase covers only the years FY 1990 through FY 1993, with peak expenditures of $2.3 million in FY 1991. These expenditures are covered in the FY 1991 budget already submitted. The evaluation, management and planning function budget increases in FY 1993 from $480,000 per year to $880,000 per year to incorporate to on-going maintenance and update of the data bases and models which form the analytical base for the program and which have been extensively developed through the data analysis phase.

Other analytical work, such as the use of TORIS in support of NES development, has been increasing in the past few years. This analytical work has been budgeted at $500,000 per year. It has not been included in the total since it does not represent a program requirement to achieve the stated goal of

increasing domestic producibility, but it represents an important function which should be included in the final budget.

The milestones for the data analysis phase demonstrate the timing of the four classifications shown above. The initial classification based on the analyses of New Mexico, Oklahoma, and Texas will be completed in June 1990. Data on other reservoirs in the data base are classified and analyzed in October 1990. After incorporating the data from the additional states and data on heavy oil, the full onshore resource, excluding Alaska and Appalachia, is completed April 1991. The full U.S. resource classification will be complete October 1992. At that point the top twelve reservoir classes will also have been identified and prioritized. Class requirements documents for all twelve classes will be published by March 1993.

The data analysis phase is presented in more detail in the following pages:

- Base Case Budget for Analysis & Planning
- Major Milestones for Analysis & Planning
- Data Analysis Logic Flow
- Work Breakdown Structure for Analysis & Planning
- Logic Flow for Data Analysis Phase I
- Logic Flow for Data Analysis Phase II
- Logic Flow for Data Analysis Phase III
- Logic Flow for Data Analysis Phase IV
- Fold-out Diagrams Showing Timing of All Data Analysis Tasks
- Task Listing for Data Analysis

Table II-1

BASE CASE BUDGET

$000

Analysis & Planning

	Data Analysis Phase I	Data Analysis Phase II	Data Analysis Phase III	Data Analysis Phase IV	Total Data Analysis	Evaluation, Management & Planning	Total	Other Analytical Work (1)
FY 90	320	100	550	200	1,170	480	1,650	0*
FY 91	100	800	475	900	2,275	480	2,755	0*
FY 92				250	250	480	730	500
FY 93				595	595	880	1,475	500
FY 94						880	880	500
FY 95						880	880	500
FY 96						880	880	500
FY 97						880	880	500
FY 98						880	880	500
FY 99						880	880	500
FY 00						880	880	500
FY 01						880	880	500
FY 02						880	880	500
FY 03						880	880	500
FY 04						880	880	500
Total	420	900	1,025	1,945	4,290	12,000	16,290	6,500

Average Cost Per Year = $1,086

(1) Funds cover use of TORIS is support of activities not directly related to the plan, such as NES development.

* Included in the total light oil budget.

Table II-2

MAJOR MILESTONES

Analysis & Planning

	Date
Initial Classification Based on Best Available Data	June 1990
Release Report on Class 1 & Supporting Research Requirements	August 1990
Release Report on Class 2 & Supporting Research Requirements	September 1990
Classification of Onshore Resource (Excl. LA, AK & Appalachia & Heavy Oil)	October 1990
Release Report on Class 3 & Supporting Research Requirements	December 1990
Release Report on Class 4 & Supporting Research Requirements	January 1991
Release Report on Class 5 & Supporting Research Requirements	February 1991
Release Report on Class 6 & Supporting Research Requirements	March 1991
Classification of Onshore Resource Incl. Heavy Oil (Excl. AK & Appalachia)	April 1991
Release Report on Class 7 & Supporting Research Requirements	May 1991
Release Report on Class 8 & Supporting Research Requirements	June 1991
Classification of Full U.S. Resource (Incl. Offshore)	October 1992
Identification of Top 12 Reservoir Classes	October 1992
Release Report on Class 9 & Supporting Research Requirements	December 1992
Release Report on Class 10 & Supporting Research Requirements	January 1993
Release Report on Class 11 & Supporting Research Requirements	February 1993
Release Report on Class 12 & Supporting Research Requirements	March 1993

Figure II-1

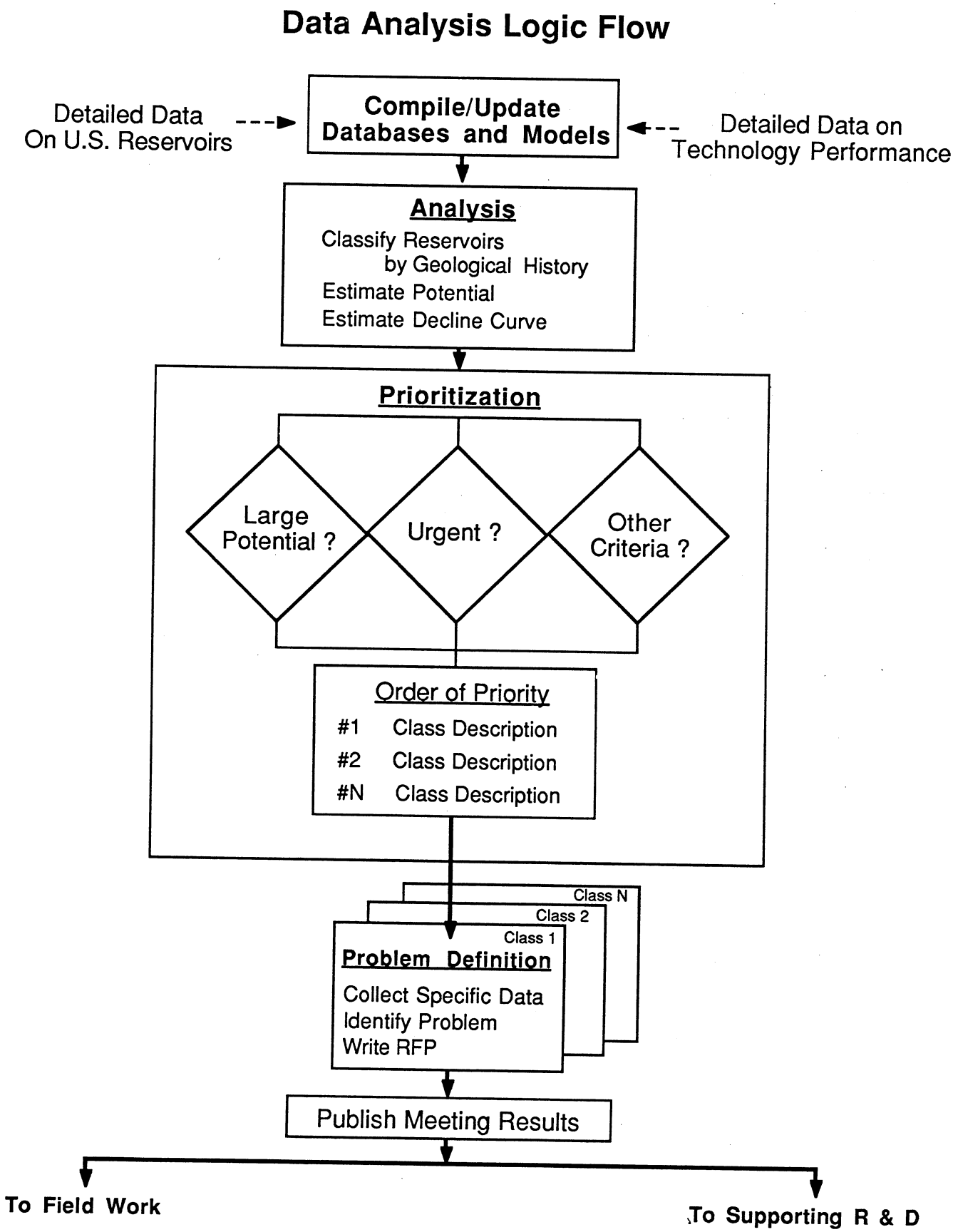

Data Analysis Logic Flow
Detailed Data On U.S. Reservoirs
Compile/Update Databases and Models
Detailed Data on Technology Performance
Analysis
Classify Reservoirs by Geological History
Estimate Potential
Estimate Decline Curve
Prioritization
Large Potential ?
Urgent ?
Other Criteria ?
Order of Priority
#1 Class Description
#2 Class Description
#N Class Description
Class N
Class 2
Class 1
Problem Definition
Collect Specific Data
Identify Problem
Write RFP
Publish Meeting Results
To Field Work
To Supporting R & D

Figure II-2

Work Breakdown Structure For Analysis and Planning

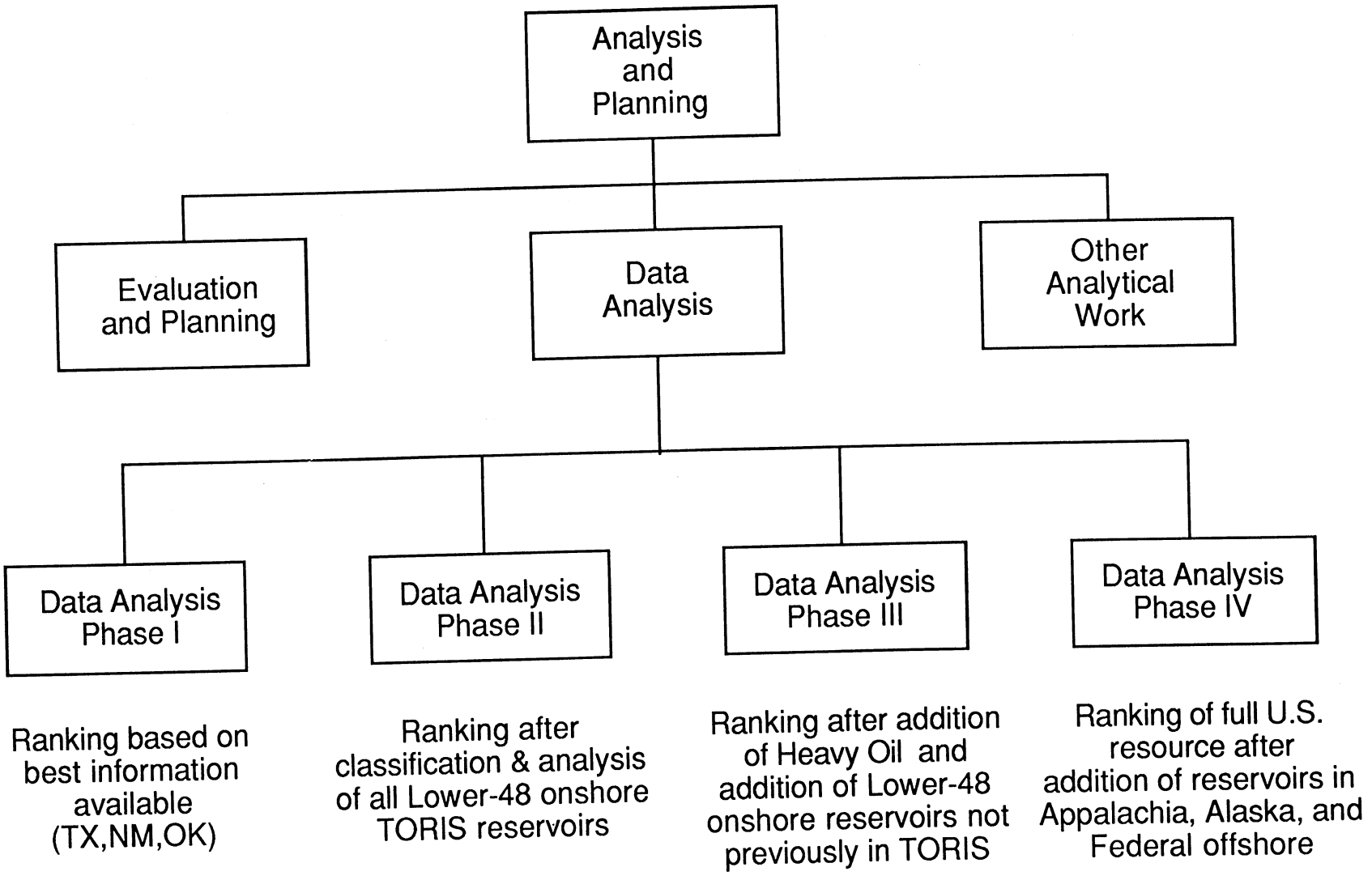


Figure II-3

Data Analysis Phase I

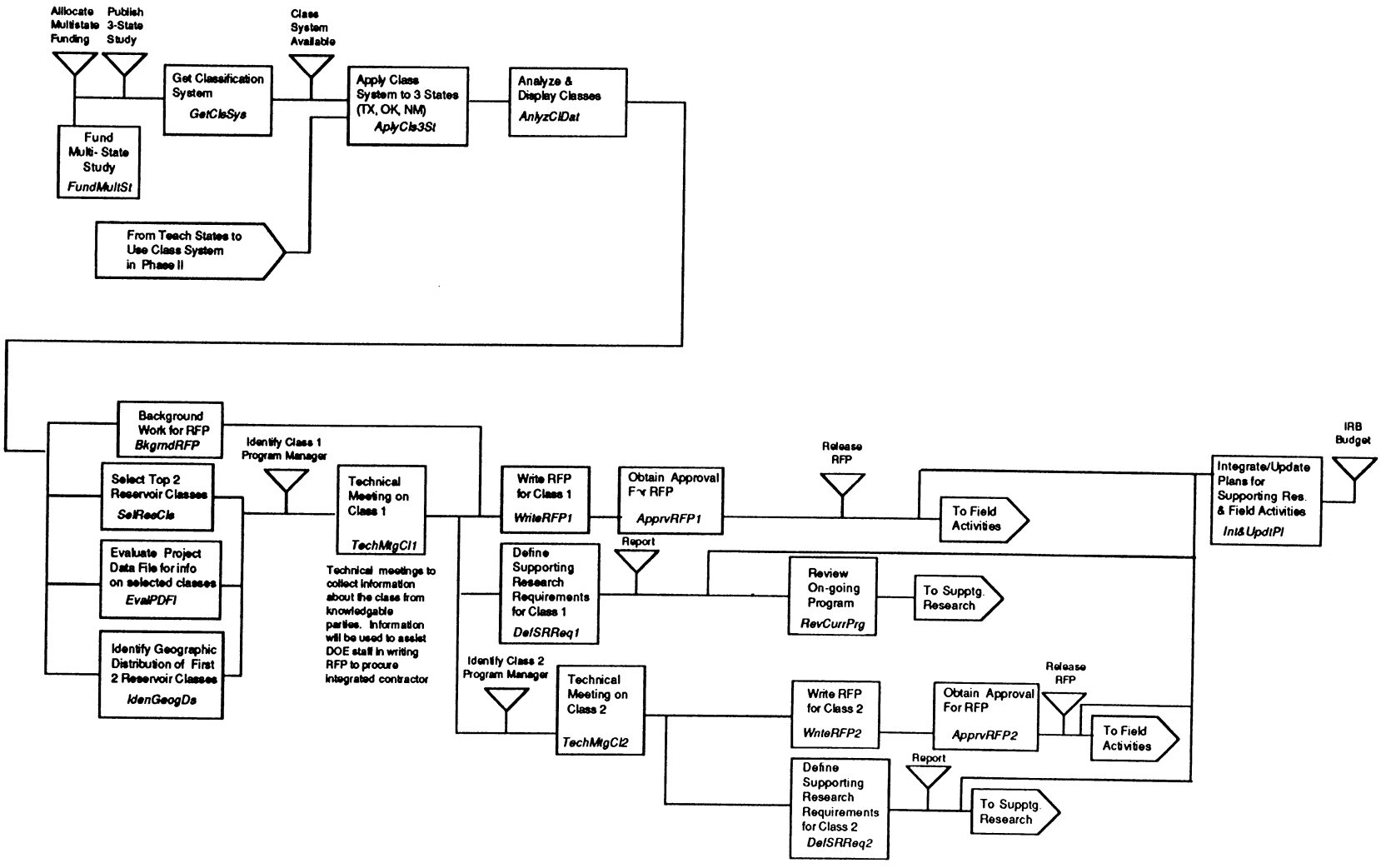


Figure II-4

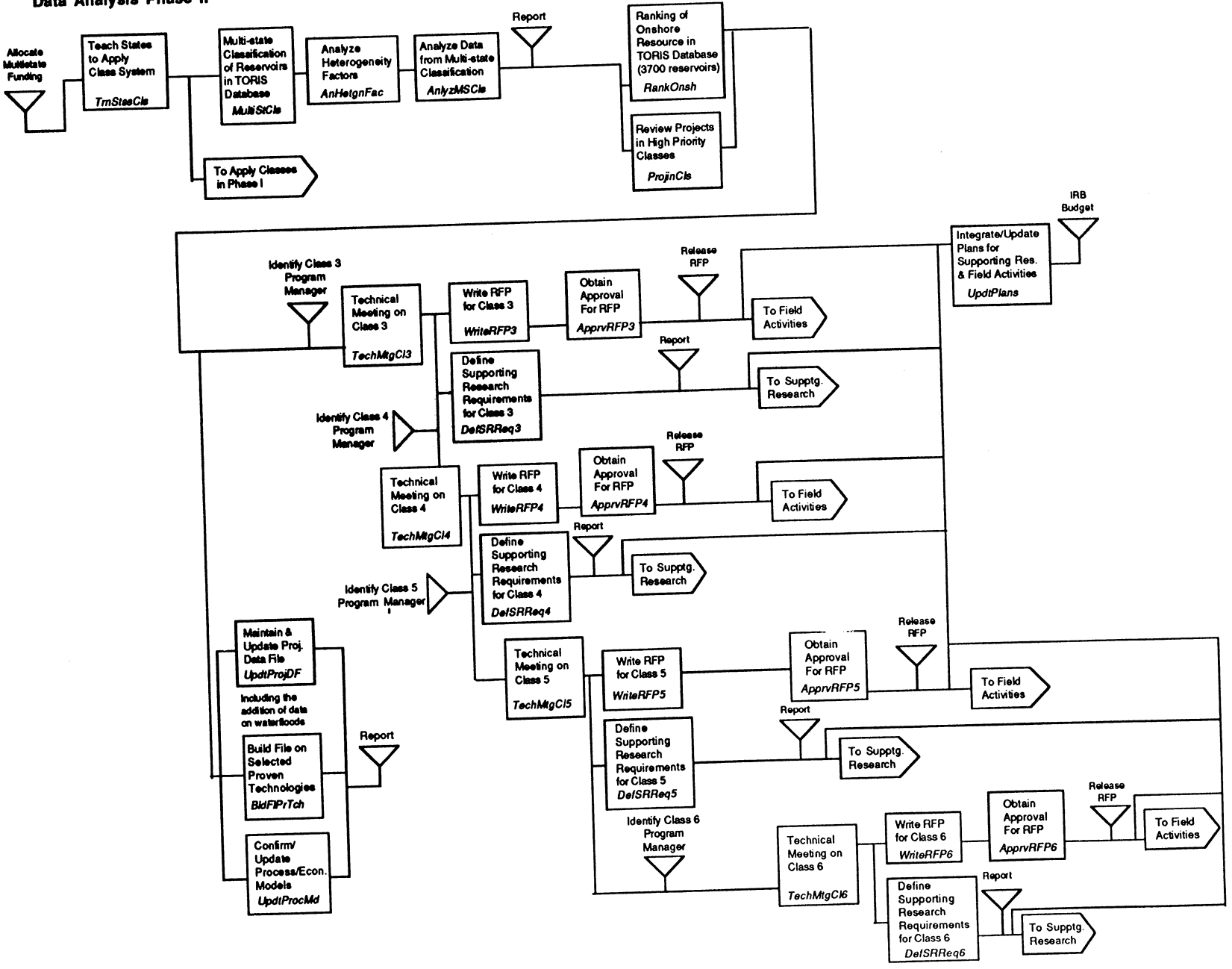

Data Analysis Phase II
Allocate Multistate Funding
Teach States to Apply Class System
TrnStesCls
Multi-state Classification of Reservoirs in TORIS Database
MultiStCls
Analyze Heterogeneity Factors
AnHetgnFac
Analyze Data from Multi-state Classification
AnlyzMSCls
Report
Ranking of Onshore Resource in TORIS Database (3700 reservoirs)
RankOnsh
Review Projects in High Priority Classes
ProjinCls
To Apply Classes in Phase I
IRB Budget
Integrate/Update Plans for Supporting Res. & Field Activities
UpdtPlans
Identify Class 3 Program Manager
Technical Meeting on Class 3
TechMtgCl3
Write RFP for Class 3
WriteRFP3
Obtain Approval For RFP
ApprvRFP3
Release RFP
To Field Activities
Report
Define Supporting Research Requirements for Class 3
DefSRReq3
To Supptg. Research
Identify Class 4 Program Manager
Technical Meeting on Class 4
TechMtgCl4
Write RFP for Class 4
WriteRFP4
Obtain Approval For RFP
ApprvRFP4
Release RFP
To Field Activities
Report
Define Supporting Research Requirements for Class 4
DefSRReq4
To Supptg. Research
Identify Class 5 Program Manager
Technical Meeting on Class 5
TechMtgCl5
Write RFP for Class 5
WriteRFP5
Obtain Approval For RFP
ApprvRFP5
Release RFP
To Field Activities
Report
Define Supporting Research Requirements for Class 5
DefSRReq5
To Supptg. Research
Identify Class 6 Program Manager
Technical Meeting on Class 6
TechMtgCl6
Write RFP for Class 6
WriteRFP6
Obtain Approval For RFP
ApprvRFP6
Release RFP
To Field Activities
Report
Define Supporting Research Requirements for Class 6
DefSRReq6
To Supptg. Research
Maintain & Update Proj. Data File
UpdtProjDF
Including the addition of data on waterfloods
Build File on Selected Proven Technologies
BldFlPrTch
Confirm/ Update Process/Econ. Models
UpdtProcMd
Report

Figure II-5

Data Analysis Phase III

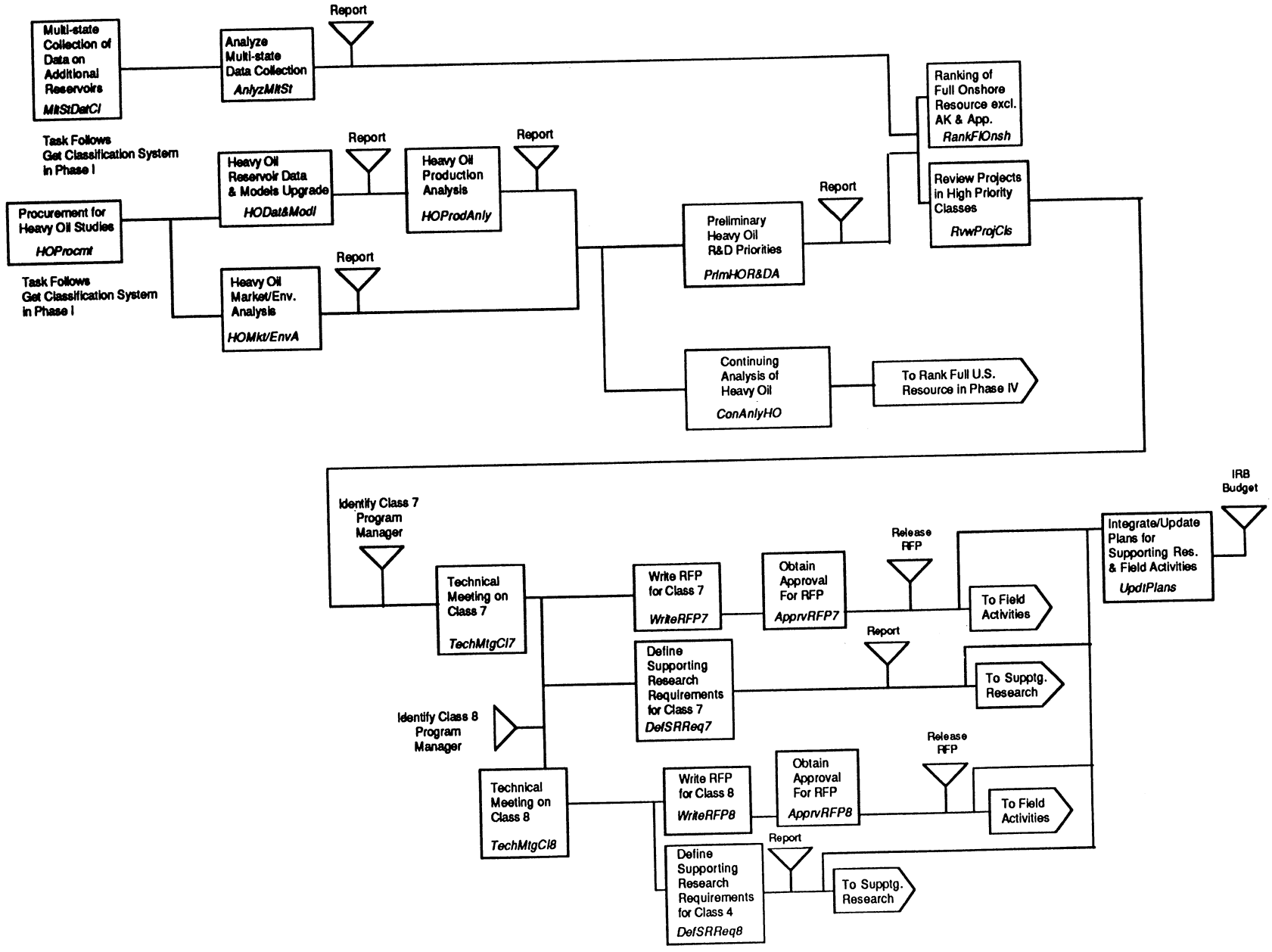


Figure II-6

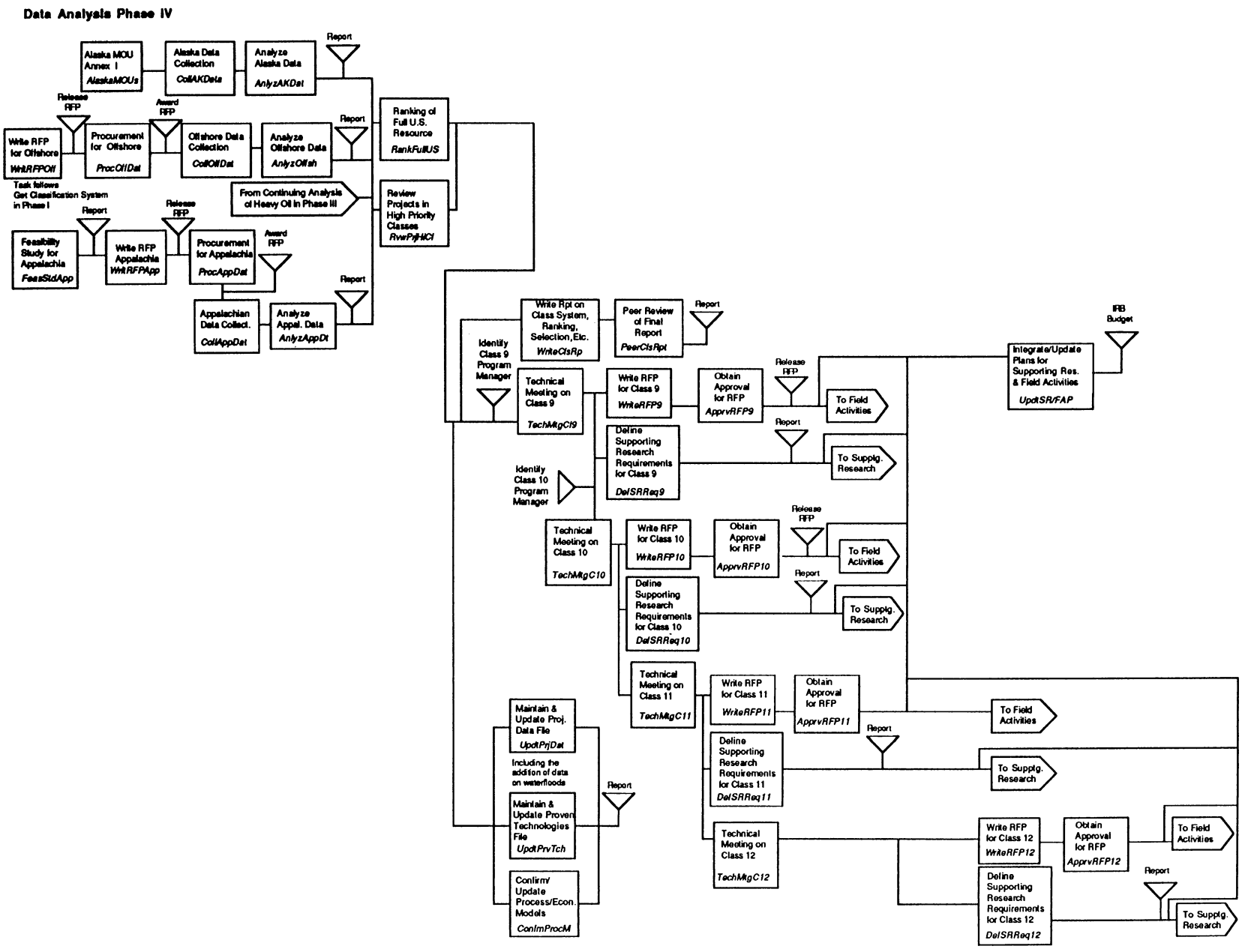

Data Analysis Phase IV
Alaska MOU Annex I
AlaskaMOUs
Alaska Data Collection
CollAKData
Analyze Alaska Data
AnlyzAKDat
Report
Release RFP
Award RFP
Write RFP for Offshore
WrtRFPOff
Procurement for Offshore
ProcOffDat
Offshore Data Collection
CollOffDat
Analyze Offshore Data
AnlyzOffsh
Report
Ranking of Full U.S. Resource
RankFullUS
Task follows Get Classification System in Phase I
From Continuing Analysis of Heavy Oil in Phase III
Review Projects in High Priority Classes
RvwPrjHiCl
Report
Release RFP
Award RFP
Feasibility Study for Appalachia
FeasStdApp
Write RFP Appalachia
WrtRFPApp
Procurement for Appalachia
ProcAppDat
Appalachian Data Collect.
CollAppDat
Analyze Appal. Data
AnlyzAppDt
Report
Identify Class 9 Program Manager
Write Rpt on Class System, Ranking, Selection, Etc.
WriteClsRp
Peer Review of Final Report
PeerClsRpt
Report
IRB Budget
Integrate/Update Plans for Supporting Res. & Field Activities
UpdtSR/FAP
Technical Meeting on Class 9
TechMtgCl9
Write RFP for Class 9
WriteRFP9
Obtain Approval for RFP
ApprvRFP9
Release RFP
To Field Activities
Report
Define Supporting Research Requirements for Class 9
DefSRReq9
To Supptg. Research
Identify Class 10 Program Manager
Technical Meeting on Class 10
TechMtgC10
Write RFP for Class 10
WriteRFP10
Obtain Approval for RFP
ApprvRFP10
Release RFP
To Field Activities
Report
Define Supporting Research Requirements for Class 10
DefSRReq10
To Supptg. Research
Technical Meeting on Class 11
TechMtgC11
Write RFP for Class 11
WriteRFP11
Obtain Approval for RFP
ApprvRFP11
To Field Activities
Report
Define Supporting Research Requirements for Class 11
DefSRReq11
To Supptg. Research
Maintain & Update Proj. Data File
UpdtPrjDat
Including the addition of data on waterfloods
Maintain & Update Proven Technologies File
UpdtPrvTch
Confirm/ Update Process/Econ. Models
ConfmProcM
Report
Technical Meeting on Class 12
TechMtgC12
Write RFP for Class 12
WriteRFP12
Obtain Approval for RFP
ApprvRFP12
To Field Activities
Report
Define Supporting Research Requirements for Class 12
DefSRReq12
To Supptg. Research

Table II-3

DATA ANALYSIS

Task Listing

WBS Code	Activity ID	Activity Description	Duration (Weeks)	Early Start	Early Finish
01	ANAL.SUPPT	ANALYTICAL SUPPORT & PLANNING	45.55	25-Sep-89	21-Sep-93
01.1	DATA.ANLY1	DATA ANALYSIS PHASE I	13.50	25-Sep-89	30-Nov-90
01.1.001	FundMultSt	Provide Funding for IOCC Multistate Study	1.00	25-Sep-89	29-Sep-89
01.1.010	AlcFundMlt	Allocate Funding for Multistate Study	0.00	01-Oct-89	01-Oct-89
01.1.020	Pub3-state	Publish 3-state report	0.00	01-Oct-89	01-Oct-89
01.1.022	GetClsSys	Get Classification System Completed	8.00	15-Feb-90	12-Apr-90
01.1.023	ClsSysAvl	Class System Available	0.00	12-Apr-90	12-Apr-90
01.1.025	AplyCls3St	Apply New Classification System to 3 States	4.00	20-Apr-90	17-May-90
01.1.026	AnlyzClDat	Analyze Database & Display By Classes for Select	3.00	18-May-90	08-Jun-90
01.1.030	SelResCls	Select Top 2 Reservoir Classes Based on Avail Da	2.00	11-Jun-90	22-Jun-90
01.1.040	EvalPDFl	Eval Project Data File for Info on Sel. Classes	4.00	11-Jun-90	09-Jul-90
01.1.050	IdenGeogDs	Identify Geographic Distribution on Top 2 Class	2.00	11-Jun-90	22-Jun-90
01.1.070	BkgrndRFP	Background Work for Preparation of RFP's	8.00	11-Jun-90	06-Aug-90
01.1.099	IdntCl1Mgr	Identify Class 1 Program Manager	0.00	22-Jun-90	22-Jun-90
01.1.100	TechMtgCl1	Technical Meeting on Class 1	4.00	10-Jul-90	06-Aug-90
01.1.110	WriteRFP1	Write RFP for Class 1	4.00	19-Sep-90	17-Oct-90
01.1.115	ApprvRFP1	Obtain Approval for RFP for Class 1	6.00	07-Aug-90	18-Sep-90
01.1.120	Rel.RFP.1	Release RFP on Class 1	0.00	17-Oct-90	17-Oct-90
01.1.130	DefSRReq1	Define Supporting Research Requirements Class 1	2.00	07-Aug-90	20-Aug-90
01.1.140	RptSRReq1	Report on Supporting Research Req. for Class 1	0.00	20-Aug-90	20-Aug-90
01.1.150	RevCurrPrg	Review Current Program for Fit & Refocusing	6.00	21-Aug-90	02-Oct-90
01.1.199	IdntCl2Mgr	Identify Class 2 Program Manager	0.00	06-Aug-90	06-Aug-90
01.1.200	TechMtgCl2	Technical Meeting on Class 2	4.00	07-Aug-90	04-Sep-90
01.1.210	WriteRFP2	Write RFP for Class 2	4.00	05-Sep-90	02-Oct-90
01.1.215	ApprvRFP2	Obtain Approval for Rfp for Class 2	6.00	03-Oct-90	15-Nov-90
01.1.220	Rel.RFP.2	Release RFP Class 2	0.00	15-Nov-90	15-Nov-90
01.1.230	DefSRReq2	Define Supporting Research Req. for Class 2	2.00	05-Sep-90	18-Sep-90
01.1.240	RptSRReq2	Report on Supporting Research Req. Class 2	0.00	18-Sep-90	18-Sep-90
01.1.400	Int&UpdtPl	Integrate & Update Plans for Supptg Res & Field	8.00	03-Oct-90	30-Nov-90
01.1.410	FY93IRBBdg	FY 93 IRB Budgets	0.00	30-Nov-90	30-Nov-90

Table II-3 (Continued)

WBS Code	Activity ID	Activity Description	Duration (Weeks)	Early Start	Early Finish
01.2	DATA.ANLY2	DATA ANALYSIS PHASE II	70.00	13-Apr-90	03-Sep-91
01.2.100	TrnStssCls	Train States to Apply Classification System	1.00	13-Apr-90	19-Apr-90
01.2.130	MultStCls	Multi State Classification of Reservoirs	8.00	20-Apr-90	15-Jun-90
01.2.140	AnHetgnFac	Analyze Heterogeneity Factors in Multi State	6.00	18-Jun-90	30-Jul-90
01.2.160	AnlyzMSCls	Analyze Multi State Reservoir Classification	6.00	31-Jul-90	11-Sep-90
01.2.170	RptMSCls	Report Results of Multi State Classification	0.00	11-Sep-90	11-Sep-90
01.2.400	UpdtProjDF	Update Project Data File	45.00	10-Oct-90	03-Sep-91
01.2.410	BldFlPrTch	Build File on Selected Proven Technologies	45.00	10-Oct-90	03-Sep-91
01.2.420	UpdtProcMd	Update Process/Economic Models	8.00	09-Jul-91	03-Sep-91
01.2.440	RptDFl&Mod	Report on Proj Data File, New Tech File & Models	0.00	03-Sep-91	03-Sep-91
01.2.500	RankOnsh	Rank Onshore Resource (ex. LA, AK & Appalachia)	4.00	12-Sep-90	09-Oct-90
01.2.510	ProjinCls	Review Projects in High Priority Reservoir Class	4.00	10-Oct-90	07-Nov-90
01.2.699	IdntCl3Mgr	Identify Class 3 Program Manager	0.00	09-Oct-90	09-Oct-90
01.2.700	TechMtgCl3	Technical Meeting for Class 3	4.00	08-Nov-90	07-Dec-90
01.2.710	WriteRFP3	Write RFP for Class 3	4.00	10-Dec-90	08-Jan-91
01.2.715	ApprvRFP3	Obtain Approval for Class 3 RFP	6.00	09-Jan-91	21-Feb-91
01.2.720	Rel.RFP.3	Release RFP for Class 3	0.00	21-Feb-91	21-Feb-91
01.2.730	DefSRReq3	Define Supporting Research Req. Class 3	2.00	10-Dec-90	21-Dec-90
01.2.740	RptSRReq3	Report on Supporting Research Req. Class 3	0.00	21-Dec-90	21-Dec-90
01.2.749	IdntCl4Mgr	Identify Class 4 Program Manager	0.00	07-Dec-90	07-Dec-90
01.2.750	TechMtgCl4	Technical Meeting on Class 4	4.00	10-Dec-90	08-Jan-91
01.2.760	WriteRFP4	Write RFP for Class 4	4.00	09-Jan-91	06-Feb-91
01.2.765	ApprvRFP4	Obtain Approval for Class 4 RFP	6.00	07-Feb-91	21-Mar-91
01.2.770	Rel.RFP.4	Release RFP for Class 4	0.00	21-Mar-91	21-Mar-91
01.2.780	DefSRReq4	Define Supporting Research Requirements Class 4	2.00	09-Jan-91	23-Jan-91
01.2.790	RptSRReq4	Report Supporting Research Requirements Class 4	0.00	23-Jan-91	23-Jan-91
01.2.799	IdntCl5Mgr	Identify Class 5 Program Manager	0.00	08-Jan-91	08-Jan-91
01.2.800	TechMtgCl5	Technical Meeting on Class 5	4.00	09-Jan-91	06-Feb-91
01.2.810	WriteRFP5	Write RFP for Class 5	4.00	07-Feb-91	07-Mar-91
01.2.811	ApprvRFP5	Obtain Approval for Class 5 RFP	6.00	08-Mar-91	18-Apr-91
01.2.812	Rel.RFP.5	Release RFP for Class 5	0.00	18-Apr-91	18-Apr-91
01.2.820	DefSRReq5	Define Supporting Research Req. for Class 5	2.00	07-Feb-91	21-Feb-91
01.2.830	RptSRReq5	Report on Supporting Research Req. for Class 5	0.00	21-Feb-91	21-Feb-91
01.2.839	IdntCl6Mgr	Identify Class 6 Program Manager	0.00	06-Feb-91	06-Feb-91

Table II-3 (Continued)

WBS Code	Activity ID	Activity Description	Duration (Weeks)	Early Start	Early Finish
01.2.840	TechMtgCl6	Technical Meeting on Class 6	4.00	07-Feb-91	07-Mar-91
01.2.850	WriteRFP6	Write RFP for Class 6	4.00	08-Mar-91	04-Apr-91
01.2.851	ApprvRFP6	Obtain Approval for Class 6 RFP	6.00	05-Apr-91	16-May-91
01.2.852	Rel.RFP.6	Release RFP for Class 6	0.00	16-May-91	16-May-91
01.2.860	DefSRReq6	Define Supporting Research Req. for Class 6	2.00	08-Mar-91	21-Mar-91
01.2.870	RptSRReq6	Report on Supporting Research Req. for Class 6	0.00	21-Mar-91	21-Mar-91
01.2.900	IntUpdtPl	Integrate & Update Plans for Supptg Res & FW	8.00	22-Mar-91	16-May-91
01.2.910	IRBBudget	Completion of IRB Budget Plans	0.00	16-May-91	16-May-91
01.3	DATA.ANAL3	DATA ANALYSIS PHASE III	81.00	15-Feb-90	24-Sep-91
01.3.100	MltStDatCl	Multi State Data Collection - LA & Others	30.00	20-Apr-90	23-Nov-90
01.3.110	AnlyzMltSt	Analyze Data from Multi State Data Collection	10.00	26-Nov-90	06-Feb-91
01.3.115	RptMulti2	Report Results of Multistate Data Coll Phase 2	0.00	06-Feb-91	06-Feb-91
01.3.200	HOProcmt	Procurement of Heavy Oil Study	13.00	15-Feb-90	17-May-90
01.3.210	HODat&Modl	Heavy Oil Data & Models Upgrade	26.00	18-May-90	23-Nov-90
01.3.220	HODataBase	Heavy Oil Data Base Available	0.00	23-Nov-90	23-Nov-90
01.3.230	HOProdAnly	Heavy Oil Production Analysis	12.00	26-Nov-90	21-Feb-91
01.3.235	RptHOProd	Report on Heavy Oil Production Constraints	0.00	21-Feb-91	21-Feb-91
01.3.240	HOMkt/EnvA	Heavy Oil Market/Environmental Analysis	34.00	18-May-90	23-Jan-91
01.3.245	RptHOMktEn	Report on Heavy Oil Market/Environmental Cnstrnt	0.00	23-Jan-91	23-Jan-91
01.3.250	PrlmHOR&DA	Prelim Heavy Oil R&D Leverage & Priorities Anlys	4.00	22-Feb-91	21-Mar-91
01.3.260	RptHOR&DPr	Report Heavy Oil R&D Priorities	0.00	21-Mar-91	21-Mar-91
01.3.270	ContAnlyHO	Continuing Analysis of HO Production Constraints	30.00	22-Feb-91	24-Sep-91
01.3.280	FnlRptHOCn	Final Report on Heavy Oil Production Constraints	0.00	24-Sep-91	24-Sep-91
01.3.400	RankFlOnsh	Rank Full Onshore, Incl HO (excl. App & AK)	4.00	22-Mar-91	18-Apr-91
01.3.410	RvwProjCls	Review Projects in High Priority Reservoir Class	4.00	22-Mar-91	18-Apr-91
01.3.599	IdntCl7Mgr	Identify Class 7 Program Manager	0.00	18-Apr-91	18-Apr-91
01.3.600	TechMtgCl7	Technical Meeting on Class 7	4.00	19-Apr-91	16-May-91
01.3.610	WriteRFP7	Write RFP for Class 7	4.00	17-May-91	14-Jun-91
01.3.615	ApprvRFP7	Obtain Approval for RFP for Class 7	6.00	17-Jun-91	29-Jul-91
01.3.620	Rel.RFP.7	Release RFP for Class 7	0.00	29-Jul-91	29-Jul-91
01.3.630	DefSRReq7	Define Supporting Research Req. for Class 7	2.00	17-May-91	31-May-91
01.3.640	RptSRReq7	Report on Supporting Research Req. for Class7	0.00	31-May-91	31-May-91
01.3.699	IdntCl8Mgr	Identify Class 8 Program Manager	0.00	16-May-91	16-May-91
01.3.700	TechMtgCl8	Technical Meeting for Class 8	4.00	17-May-91	14-Jun-91

Table II-3 (Continued)

WBS Code	Activity ID	Activity Description	Duration (Weeks)	Early Start	Early Finish
01.3.710	WriteRFP8	Write RFP for Class 8	4.00	17-Jun-91	15-Jul-91
01.3.715	ApprvRFP8	Obtain Approval for RFP for Class 8	6.00	16-Jul-91	26-Aug-91
01.3.720	Rel.RFP.8	Release RFP for Class 8	0.00	26-Aug-91	26-Aug-91
01.3.730	DefSRReq8	Define Supporting Research Req. for Class 8	2.00	17-Jun-91	28-Jun-91
01.3.740	RptSRReq8	Report on Supporting Research Req for Class 8	0.00	28-Jun-91	28-Jun-91
01.3.800	UpdtPlans	Integrate & Update Plans for Supptg Res & Field	8.00	01-Jul-91	26-Aug-91
01.3.810	FY94IRBBdg	FY94 IRB Budget Call	0.00	26-Aug-91	26-Aug-91
01.4	DATA.ANLY4	DATA ANALYSIS PHASE IV	181.00	15-Feb-90	21-Sep-93
01.4.010	WritRFPOff	Write RFP for Offshore Data Collection	4.00	13-Apr-90	10-May-90
01.4.020	RelRFPOff	Release RFP for Offshore Data Collection	0.00	10-May-90	10-May-90
01.4.030	ProcOffDat	Procurement for Offshore Data Collection	50.00	11-May-90	09-May-91
01.4.040	AwdRFPOff	Award RFP for Offshore Data Collection	0.00	09-May-91	09-May-91
01.4.050	CollOffDat	Collect Offshore Data	50.00	10-May-91	07-May-92
01.4.060	AnlyzOffsh	Analyze Offshore Data Collected	20.00	08-May-92	29-Sep-92
01.4.070	RptOffData	Report on Offshore Data	0.00	29-Sep-92	29-Sep-92
01.4.100	AlaskaMOUs	Refocus Alaska MOU's to Collect Needed AK Data	4.00	13-Apr-90	10-May-90
01.4.110	CollAKData	Collect Alaska Data	52.00	11-May-90	23-May-91
01.4.120	AnlyzAKDat	Analyze Alaskan Data	16.00	24-May-91	17-Sep-91
01.4.130	RptAKData	Report on Alaskan Data	0.00	17-Sep-91	17-Sep-91
01.4.200	FeasStdApp	Feasibility Study for Data Coll on Appalachia	25.00	15-Feb-90	13-Aug-90
01.4.210	RptonAppal	Report on Appalachia Feasibility Study	0.00	13-Aug-90	13-Aug-90
01.4.220	WritRFPApp	Write RFP for Appalachian Data Collection	4.00	14-Aug-90	11-Sep-90
01.4.222	RelRFPApp	Release RFP for Appalachian Data Collection	0.00	11-Sep-90	11-Sep-90
01.4.240	ProcAppDat	Procurement for Appalachian Data	40.00	12-Sep-90	28-Jun-91
01.4.250	AwdAppRFP	Award RFP for Appalachian Data	0.00	28-Jun-91	28-Jun-91
01.4.260	CollAppDat	Collect Appalachian Data	50.00	01-Jul-91	26-Jun-92
01.4.270	AnlyzAppDt	Analyze Appalachian Data	12.00	29-Jun-92	22-Sep-92
01.4.280	RptAppDat	Report on Appalachian Data Collection	0.00	22-Sep-92	22-Sep-92
01.4.300	UpdtPrjDat	Maintain & Update Project Data File	45.00	29-Oct-92	21-Sep-93
01.4.310	ConfmProcM	Confirm/Update Process/Economic Models	8.00	27-Jul-93	21-Sep-93
01.4.320	UpdtPrvTch	Maintain & Update Proven Technologies File	45.00	29-Oct-92	21-Sep-93
01.4.330	RptDatF&Md	Report on Proj Data File, Prvn Tech Fl & Proc Md	0.00	21-Sep-93	21-Sep-93
01.4.400	RankFullUS	Ranking of Full U.S. Resource Base by Class	4.00	30-Sep-92	28-Oct-92
01.4.410	RvwPrjHiCl	Review Projects in High Priority Classes	4.00	30-Sep-92	28-Oct-92

Table II-3 (Continued)

WBS Code	Activity ID	Activity Description	Duration (Weeks)	Early Start	Early Finish
01.4.499	IndtCl9Mgr	Identify Class 9 Program Manager	0.00	28-Oct-92	28-Oct-92
01.4.500	TechMtgCl9	Technical Meeting on Class 9	4.00	29-Oct-92	27-Nov-92
01.4.510	WriteRFP9	Write RFP for Class 9	4.00	30-Nov-92	28-Dec-92
01.4.511	ApprvRFP9	Obtain Approval for RFP for Class 9	6.00	29-Dec-92	10-Feb-93
01.4.512	Rel.RFP.9	Release RFP for Class 9	0.00	10-Feb-93	10-Feb-93
01.4.520	DefSRReq9	Define Supporting Research Req. for Class 9	2.00	30-Nov-92	11-Dec-92
01.4.530	RptSRReq9	Report on Supporting Research Req. for Class 9	0.00	11-Dec-92	11-Dec-92
01.4.539	IndtC10Mgr	Identify Class 10 Program Manager	0.00	27-Nov-92	27-Nov-92
01.4.540	TechMtgC10	Technical Meeting on Class 10	4.00	30-Nov-92	28-Dec-92
01.4.550	WriteRFP10	Write RFP for Class 10	4.00	29-Dec-92	27-Jan-93
01.4.551	ApprvRFP10	Obtain Approval for RFP for Class 10	6.00	28-Jan-93	11-Mar-93
01.4.552	Rel.RFP.10	Release RFP for Class 10	0.00	11-Mar-93	11-Mar-93
01.4.560	DefSRReq10	Define Supporting Research Req. for Class 10	2.00	29-Dec-92	13-Jan-93
01.4.570	RptSRReq10	Report on Supporting Research Req. for Class 10	0.00	13-Jan-93	13-Jan-93
01.4.579	IndtC11Mgr	Identify Class 11 Program Manager	0.00	28-Dec-92	28-Dec-92
01.4.580	TechMtgC11	Technical Meeting on Class 11	4.00	29-Dec-92	27-Jan-93
01.4.600	WriteRFP11	Write RFP for Class 11	4.00	28-Jan-93	25-Feb-93
01.4.601	ApprvRFP11	Obtain Approval for RFP for Class 11	6.00	26-Feb-93	08-Apr-93
01.4.602	Rel.RFP.11	Release RFP for Class 11	0.00	08-Apr-93	08-Apr-93
01.4.610	DefSRReq11	Define Supporting Research Req. for Class 11	2.00	28-Jan-93	10-Feb-93
01.4.620	RptSRReq11	Report on Supporting Research Req. for Class 11	0.00	10-Feb-93	10-Feb-93
01.4.629	IndtC12Mgr	Identify Class 12 Program Manager	0.00	27-Jan-93	27-Jan-93
01.4.630	TechMtgC12	Technical Meeting on Class 12	4.00	28-Jan-93	25-Feb-93
01.4.640	WriteRFP12	Write RFP for Class 12	4.00	26-Feb-93	25-Mar-93
01.4.641	ApprvRFP12	Obtain Approval for RFP for Class 12	6.00	26-Mar-93	06-May-93
01.4.642	Rel.RFP.12	Release RFP for Class 12	0.00	06-May-93	06-May-93
01.4.650	DefSRReq12	Define Supporting Research Req for Class 12	2.00	26-Feb-93	11-Mar-93
01.4.660	RptSRReq12	Report on Supporting Research Req for Class 12	0.00	11-Mar-93	11-Mar-93
01.4.700	UpdtSR/FAP	Integrate/Update Plans for Supptg Res & FieldAct	8.00	12-Mar-93	06-May-93
01.4.710	FY95IRBBdg	FY95 IRB Budget Call	0.00	06-May-93	06-May-93
01.4.715	WriteClsRp	Write Rpt on Class System,Ranking,Selection,etc.	8.00	07-May-93	02-Jul-93
01.4.720	PeerClsRpt	Peer Review of Final Report on Class Selection	8.00	06-Jul-93	30-Aug-93
01.4.730	FinalClsRp	Final Report on Class System, Selection, Etc.	0.00	30-Aug-93	30-Aug-93

FIELD DEMONSTRATIONS

The program includes three primary functions: analysis and planning; field demonstrations; and supporting research. The field research, development, and demonstration function includes the transfer of existing technologies to field operators who can employ these technologies to increase production, thereby preserving access to the resource. In conjunction, cost-shared field demonstrations of advanced technologies will be conducted to prove the applicability of these technologies in specific reservoir classes. The results of these demonstrations will be disseminated widely through an aggressive program of technology transfer.

Because much of the remaining resource base is at risk of abandonment, waiting until the full U.S. resource can be classified and prioritized in October 1992 would result in losing access to resources which could be preserved with immediate action. Therefore, the plan calls for initiating the most urgent field work as soon as it is practical. The terms Class 1 through Class 10, as used, represent the order in which field work is begun, not their prioritization. It should also be noted that the specific tasks outlined for Class 1 represent an example only. The specifics for a class cannot be spelled out until the problem definition phase is completed. Classes 2-10 are merely replicates of the Class 1 example timed to begin based on completion of the problem definition for each class. Specific activities required for each class will be defined at that time.

The field work for each class falls into three categories: near-term, including preservation of access through technology transfer; mid-term, with emphasis on solving technical barriers to the application of advanced extraction processes; and follow-through with technology transfer, after the field tests have been completed and success verified. Near-term field work is designed to preserve access to the reservoirs. Near-term activities concentrate on the transfer of existing technology to increase the application of these proven technologies in the field. The near-term field work may also include small, cost-shared verification tests to "prove" the applicability of current technology in a high priority reservoir class. Mid-term work incorporates cost-shared field tests of advanced technology to demonstrate its effectiveness in increasing producibility of a reservoir. Since the generalizability of field work results to other reservoirs within a play, or to other plays within a class is an important component of maximizing results, field work incorporates tests at four sites — two reservoirs in each of two plays within each class. This selection will allow the similarity to be evaluated so that generalizability can be inferred. While technology transfer is an integral part of the mid-term field work, post-field demonstration technology transfer has been identified separately due to its importance in successfully increasing producibility. Dissemination of mid-term results will be made throughout the process as progress is made.

For budgeting purposes, reservoir classes have been assumed to be generic. In reality, the amount of information already available, and the size of the field tests required will vary by reservoir class. For many classes, some of the work outlined will already have been completed by an operator and the data will be available. As such, total costs for some reservoir classes may be overstated.

The cost of near-term field work to preserve access is budgeted at $3.2 million per class. Reservoir classes which are not at great risk of abandonment or which do not require a verification test of current technology will not incur expenditures this high. Mid-term field work is budgeted at a cost of $24.7 million per class. Again, savings are possible where a participating operator has already done some of the necessary work or can bear more of the cost. Technology transfer is budgeted at $1.4 million per class.

Total cost of the field RD&D is estimated to be $319.5 million or $31.9 million per class. Over the 15 years of the base case program, field work costs average $21.3 million per year. FY 1995 and FY 1996 are the peak expenditure years at $75 $91 million and $78.5 million, respectively. Costs are highest in these years since field work is being conducted in all ten reservoir classes. Costs fall dramatically and after FY 1998 are less than $10 million per year.

Major milestones associated with the field RD&D demonstrate the timing of each phase. Near-term field work begins in the first class in July 1991. The mid-term field work for the first class begins in August 1991 and is completed in September 1997. Following the mid-term field work are on-going technology transfer activities. The mid-term field work for all ten reservoir classes is completed in January 2000.

The field RD&D function is presented in more detail in the following pages. Since all classes of field work have been assumed to incorporate the same tasks, logic flow diagrams and task listings are presented for Class 1 only.

- Base Case Budget for Field RD&D
- Major Milestones for Field RD&D
- Field Work Logic Flow
- Work Breakdown Structure for Field Work
- Logic Flow for Near-Term Field Work for Class 1
- Logic Flow for Mid-Term Field Work for Class 1
- Logic Flow for Technology Transfer for Class 1
- Task Listing for Class 1 Field Work

Table III-1

BASE CASE BUDGET

$000

Field RD&D

	Class 1 Near-Term (1)	Class 1 Mid-Term (2)	Class 1 Technology Transfer (3)	Total Class 1	Total Classes 2-10	Total
FY 90				0		0
FY 91	1,900			1,900	8,340	10,240
FY 92	250	3,100		3,350	9,910	13,260
FY 93	650	1,900		2,550	22,450	25,000
FY 94	700	1,950		2,650	27,550	30,200
FY 95	200	1,150		1,350	89,650	91,000
FY 96	200	16,700		16,900	61,600	78,500
FY 97		0	600	600	40,950	41,550
FY 98		550	200	750	6,100	6,850
FY 99		500	200	700	7,500	8,200
FY 00		500	350	850	4,600	5,450
FY 01			350	350	3,250	3,600
FY 02					2,850	2,850
FY 03					2,100	2,100
FY 04					700	700
Total	3,900	26,350	1,700	31,950	287,550	319,500

Average Cost Per Year = $21,300

Note: Class 1 is an example of the tasks and costs which may be required. When the problem definition phase is complete, these tasks and associated costs can be specified. Classes 2-10 are replicates of the Class 1 example, timed to reflect their possible technical start dates.

(1) Preserve access through technology transfer of proven technology.
(2) Design and field test of advanced technology.
(3) Technology transfer of field test results.

Table III-2

MAJOR MILESTONES

Field RD&D

	Date
Class 1 Near-Term Field Work Begins	July 1991
Class 1 Mid-Term Field Work Begins	August 1991
Class 1 Mid-Term Field Work Complete	September 1997
Class 2 Near-Term Field Work Begins	July 1991
Class 2 Mid-Term Field Work Begins	August 1991
Class 2 Mid-Term Field Work Complete	September 1997
Class 3 Near-Term Field Work Begins	December 1991
Class 3 Mid-Term Field Work Begins	August 1992
Class 3 Mid-Term Field Work Complete	January 1998
Class 4 Near-Term Field Work Begins	January 1991
Class 4 Mid-Term Field Work Begins	September 1992
Class 4 Mid-Term Field Work Complete	February 1998
Class 5 Near-Term Field Work Begins	February 1992
Class 5 Mid-Term Field Work Begins	October 1992
Class 5 Mid-Term Field Work Complete	March 1998
Class 6 Near-Term Field Work Begins	March 1992
Class 6 Mid-Term Field Work Begins	November 1992
Class 6 Mid-Term Field Work Complete	April 1998
Class 7 Near-Term Field Work Begins	May 1992
Class 7 Mid-Term Field Work Begins	January 1993
Class 7 Mid-Term Field Work Complete	June 1998
Class 8 Near-Term Field Work Begins	June 1992
Class 8 Mid-Term Field Work Begins	February 1993
Class 8 Mid-Term Field Work Complete	July 1998
Class 9 Near-Term Field Work Begins	November 1993
Class 9 Mid-Term Field Work Begins	August 1994
Class 9 Mid-Term Field Work Complete	January 2000
Class 10 Near-Term Field Work Begins	December 1993
Class 10 Mid-Term Field Work Begins	September 1994
Class 10 Mid-Term Field Work Complete	January 2000

Figure III-1

Field RD&D Logic Flow

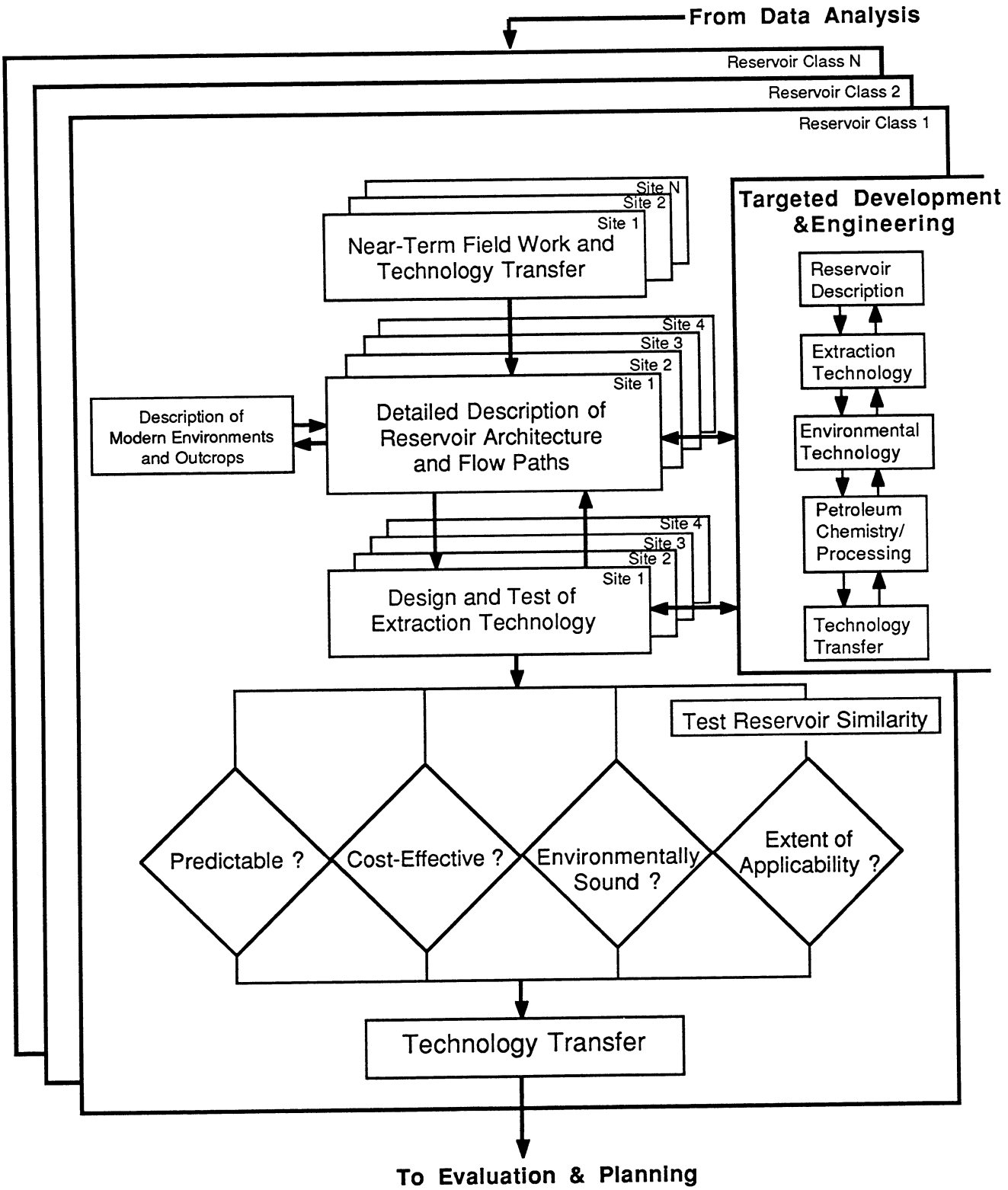


Figure III-2

Work Breakdown Structure For Field RD&D

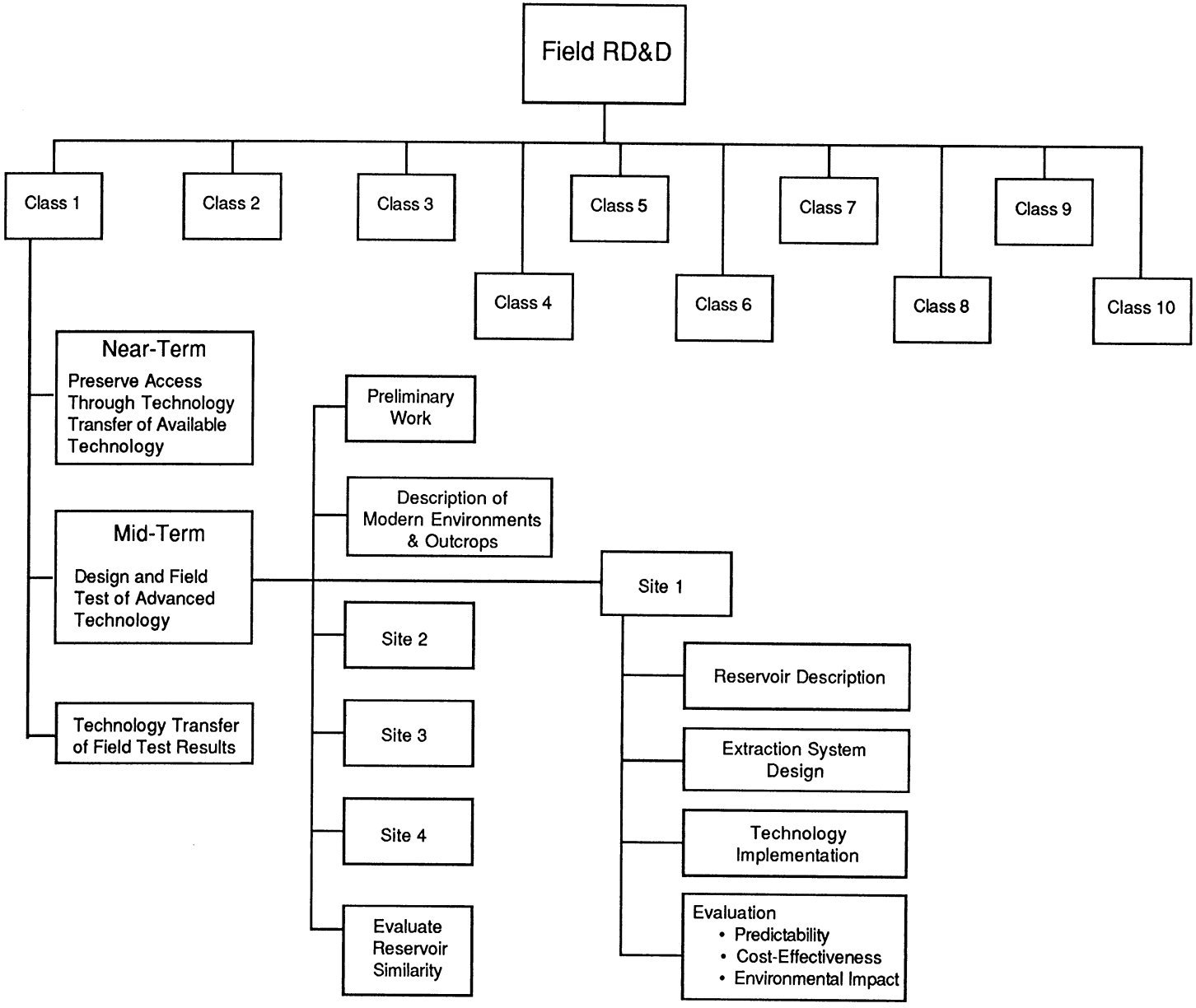


Figure III-3

Class 1 - Field Work

Near-Term (Preserve Access Through Technology Transfer of Proven Technology)

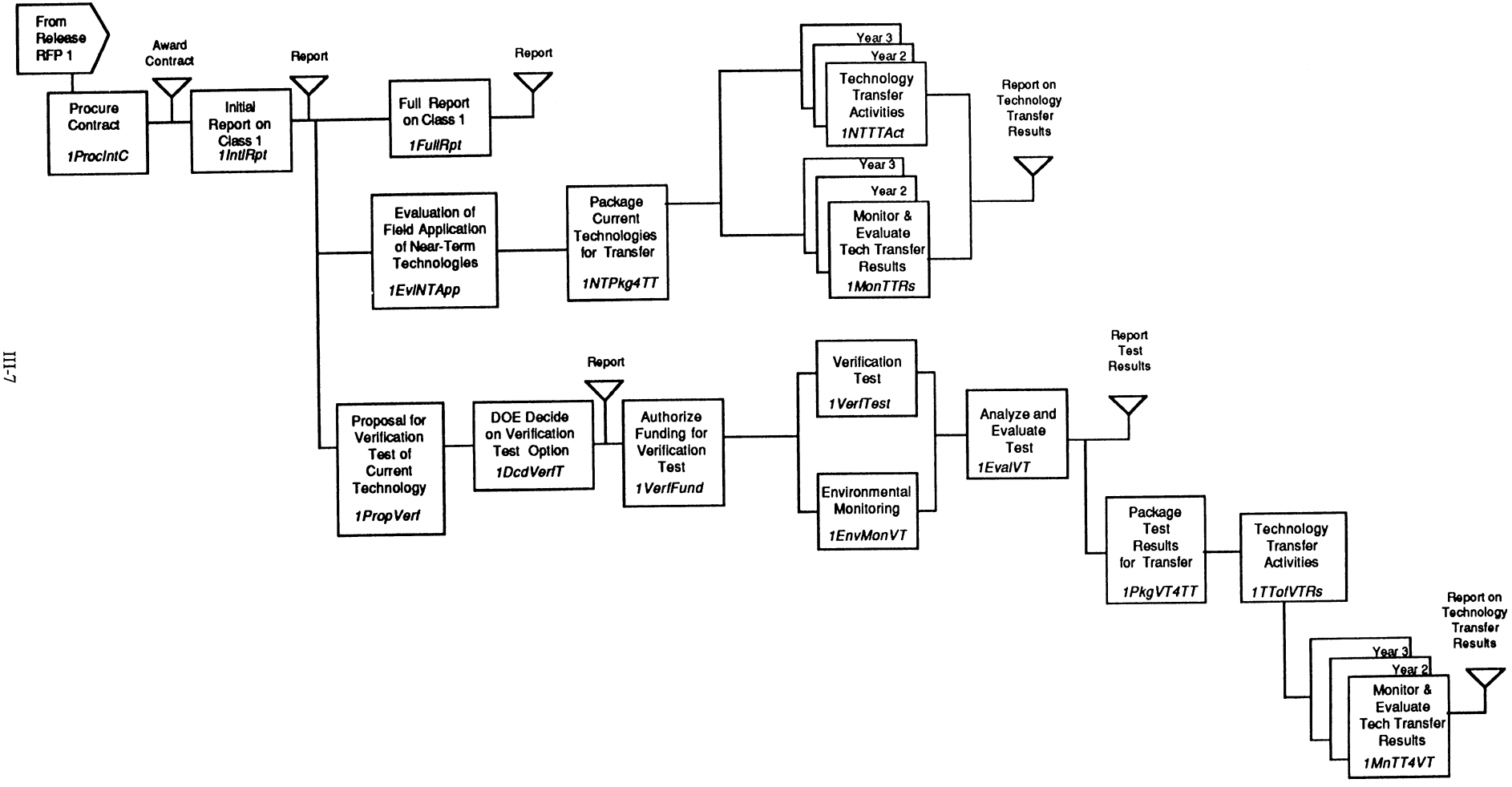


Figure III-4

Class 1 Field Work

Mid-Term (Design and Field Tests of Advanced Technology)

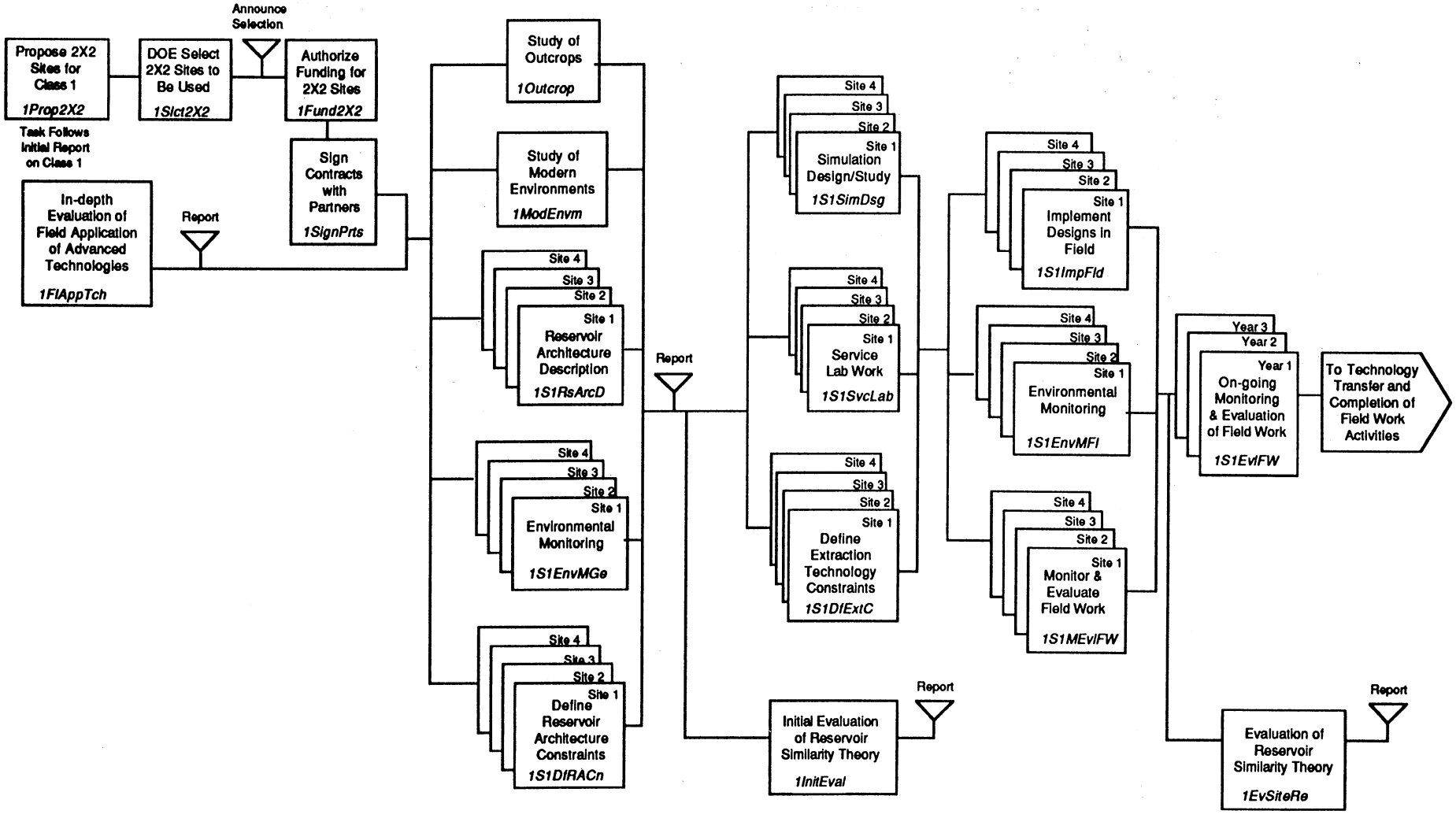


Figure III-5

Class 1 Field Work
Technology Transfer of Field Test Results

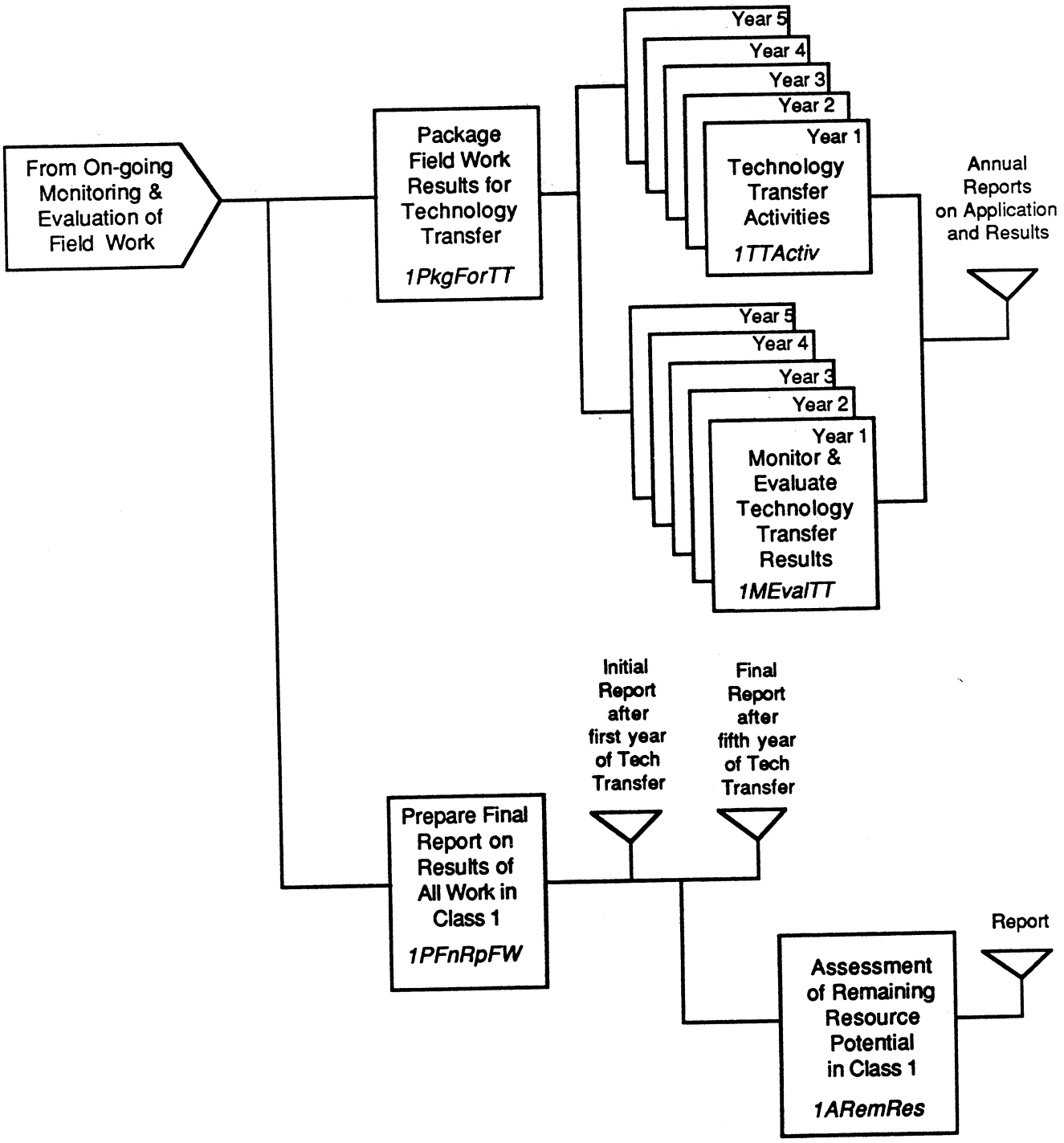


Table III-3

CLASS 1 FIELD WORK

Task Listing

WBS Code	Activity ID	Activity Description	Duration (Weeks)	Early Start	Early Finish
03	CL1FLDWRK	CLASS 1 FIELD WORK	599.00	17-Oct-90	30-Aug-2002
03.1	CL1NTFLD	CLASS 1 NEAR-TERM FIELD WORK	351.60	17-Oct-90	18-Oct-97
03.1.010	1ProcIntC	Procure Contract for Class 1	40.00	17-Oct-90	02-Aug-91
03.1.020	1AwardCnt	Award Contract for Class 1	0.00	02-Aug-91	02-Aug-91
03.1.030	1IndpEvlF	Class 1 - In-depth Evaluation of Field Projects	5.00	17-Oct-90	21-Nov-90
03.1.040	1IntlRpt	Initial Report on Class 1 from Contractor	9.00	05-Aug-91	07-Oct-91
03.1.050	1PrlmRptD	Preliminary Report on Class 1 Delivered	0.00	07-Oct-91	07-Oct-91
03.1.100	1FullRpt	Full Report on Class 1 from Contractor	26.00	08-Oct-91	15-Apr-92
03.1.110	1FullRptD	Delivery of Full Report on Class 1	0.00	15-Apr-92	15-Apr-92
03.1.200	1EvlNTApp	Class 1 -Eval of NT Technology Field Application	13.00	08-Oct-91	14-Jan-92
03.1.210	1NTPkg4TT	Class 1 NT - Package Existing Tech for TT	26.00	15-Jan-92	17-Jul-92
03.1.230	1NTTTAct	Class 1 Near-Term Tech Transfer Activities	52.00	17-Jul-92	16-Jul-93
03.1.240	1MonTTRs1	Class 1-Mon & Eval Tech Transfer Results- Year 1	52.00	17-Jul-92	16-Jul-93
03.1.250	1NTTTRpt1	Cl 1-Interim Rpt on NT Tech Transfer Results	0.00	16-Jul-93	16-Jul-93
03.1.255	1NTTTAct2	Cl 1-NT Tech Transfer Activities - Year 2	52.00	16-Jul-93	15-Jul-94
03.1.260	1MonTTRs2	Cl 1- Mon & Eval NT Tech Transfer Results-Yr 2	52.00	16-Jul-93	15-Jul-94
03.1.265	1NTTTRpt2	Cl 1-Interim Report on NT Tech Transfer Results	0.00	15-Jul-94	15-Jul-94
03.1.268	1NTTTAct3	Cl 1-NT Tech Transfer Activities - Year 3	52.00	15-Jul-94	14-Jul-95
03.1.270	1MonTTRs3	Cl 1- Mon & Eval NT Tech Transfer Results-Yr 3	52.00	15-Jul-94	14-Jul-95
03.1.275	1NTFinTTR	Cl 1-Final Report on NT Tech Transfer Results	0.00	14-Jul-95	14-Jul-95
03.1.300	1PropVerf	Cl 1-Proposal for Verification Test of Curr Tch	8.00	08-Oct-91	05-Dec-91
03.1.310	1DcdVerfT	Cl 1-DOE Decide on Verification Test Option	4.00	06-Dec-91	06-Jan-92
03.1.315	1RptVerSl	Cl 1-Report on Verification Test Selection	0.00	06-Jan-92	06-Jan-92
03.1.320	1VerfFund	Cl 1-Authorize Funding for Verification Test	6.00	07-Jan-92	18-Feb-92
03.1.330	1RelFVerf	Cl 1-Release Funding for Verification Test	0.00	18-Feb-92	18-Feb-92
03.1.350	1VerfTest	Class 1-Field Verification Test of Current Tech	78.00	19-Feb-92	03-Sep-93
03.1.360	1EnvMonVT	Class 1-Environmental Mon. of Verification Test	78.00	19-Feb-92	03-Sep-93
03.1.370	1EvalVT	Class 1- Analyze & Evaluation Verification Test	4.00	07-Sep-93	04-Oct-93
03.1.380	1RptVTRsl	Class 1-Report on Verification Test Results	0.00	04-Oct-93	04-Oct-93
03.1.400	1PkgVT4TT	Class 1-Package Verif.Test Results for TT	12.00	05-Oct-93	31-Dec-93
03.1.410	1TTofVTRs	Class 1- Tech Transfer Act from Verification Tst	40.00	04-Jan-94	18-Oct-94
03.1.420	1MnTT4VT1	Cl 1-Monitor & Eval TT Results from Ver Test	52.50	18-Oct-94	21-Oct-95

Table III-3 (Continued)

WBS Code	Activity ID	Activity Description	Duration (Weeks)	Early Start	Early Finish
03.1.430	1VTTTRpt1	Cl 1-Interim Rpt on TT Result from Verif Test	0.00	21-Oct-95	21-Oct-95
03.1.440	1MnTT4VT2	Cl 1-Monitor & Eval TT Result from Verif Test	52.00	21-Oct-95	19-Oct-96
03.1.450	1VTTTRpt2	Cl 1-Interim Rpt on TT Result from Verif Test	0.00	19-Oct-96	19-Oct-96
03.1.460	1MnTT4VT3	Cl 1-Monitor & Eval TT Result from Verif Test	52.00	19-Oct-96	18-Oct-97
03.1.470	1VTTTFRpt	Cl 1-Final Rpt on TT Result from Verif Test	0.00	18-Oct-97	18-Oct-97
03.2	C1MIDTERM	MID-TERM FIELD WORK FOR CLASS 1	551.00	01-Oct-91	30-Aug-2002
03.2.0	C1MTPrlWrk	Class 1 Mid-Term Preliminary Work	34.00	01-Oct-91	04-Jun-92
03.2.0.010	1Prop2X2	Propose 2 X 2 Sites for Class 1 Field Work	16.00	01-Oct-91	28-Jan-92
03.2.0.020	1Slct2X2	Cl 1-DOE Select 2X2 Sites from those proposed	4.00	29-Jan-92	26-Feb-92
03.2.0.030	1Annc2X2	Cl 1-Announce Selection of 2X2 Sites	0.00	26-Feb-92	26-Feb-92
03.2.0.040	1Fund2X2	Cl 1-Authorize Funding for 2X2 Site Work	6.00	27-Feb-92	08-Apr-92
03.2.0.050	1RelFn2X2	Cl 1-Release Funding for 2X2 Site Work	0.00	08-Apr-92	08-Apr-92
03.2.0.100	1FlAppTch	Cl 1-In-depth Proj Eval of Fld App of Adv Tech	26.00	01-Oct-91	08-Apr-92
03.2.0.110	1RptFlApp	Cl 1-Rpt on Field Application of Adv. Tech.	0.00	08-Apr-92	08-Apr-92
03.2.0.200	1SignPrts	Sign Contracts with Partners for Cl 1 Site Work	8.00	09-Apr-92	04-Jun-92
03.2.1	C1Site1FW	Class 1 - Site 1 Field Work	388.00	05-Jun-92	01-Mar-2000
03.2.1.010	1S1RsArcD	Cl1, Site 1 - Reservoir Architecture Description	52.00	05-Jun-92	17-Jun-93
03.2.1.020	1S1RsArc2	Cl 1, S1-Year 2 of Res. Arch. Description Work	52.00	18-Jun-93	30-Jun-94
03.2.1.030	1S1IResRp	Cl 1, S1-Interim Rpt on Reservoir Desc. Rel Wrk	0.00	17-Jun-93	17-Jun-93
03.2.1.040	1S1FResRP	Cl 1, S1-Prep Final Rpt on Reservoir Desc. Work	4.00	01-Jul-94	29-Jul-94
03.2.1.050	1S1FResRt	Cl 1, S1-Final Report on Reservoir Work Del.	0.00	29-Jul-94	29-Jul-94
03.2.1.070	1S1EnvMGe	Cl1,Site 1-Environmental Monitoring/Geolog. Work	52.00	05-Jun-92	17-Jun-93
03.2.1.080	1S1EnvMG2	Cl 1, S1-Environmental Mon. of Geol. Work-Year2	52.00	18-Jun-93	30-Jun-94
03.2.1.100	1S1DfRACn	Cl1,Site 1-Define Res Arch Constraints	52.00	05-Jun-92	17-Jun-93
03.2.1.110	1ModEnvm1	Class 1 - Study of Modern Environments	52.00	05-Jun-92	17-Jun-93
03.2.1.120	1ModEnvm2	Class 1 - Study of Modern Environments	52.00	18-Jun-93	30-Jun-94
03.2.1.130	1Outcrop1	Class 1-Study of Outcrops	52.00	05-Jun-92	17-Jun-93
03.2.1.140	1Outcrop2	Class 1- Study of Outcrops	52.00	18-Jun-93	30-Jun-94
03.2.1.200	1S1SimDsg	Cl1,Site 1-Simulation Design/Study	26.00	01-Jul-94	09-Jan-95
03.2.1.220	1S1SvcLab	Cl1,Site 1- Service Lab Work	26.00	01-Aug-94	07-Feb-95
03.2.1.230	1S1DfExtC	Cl1,Site 1-Define Extraction Tech. Constraints	17.00	01-Aug-94	01-Dec-94
03.2.1.300	1S1ImpFld	Cl1,Site 1-Implement Designs in Field	104.00	08-Feb-95	05-Mar-97
03.2.1.350	1S1EnvMFl	Cl1, Site 1-Environmental Mon of Field Work	104.00	08-Feb-95	05-Mar-97

Table III-3 (Continued)

WBS Code	Activity ID	Activity Description	Duration (Weeks)	Early Start	Early Finish
03.2.1.400	1S1MEvlFW	Cl1,Site 1-Monitor & Evaluate Field Work	104.00	08-Feb-95	05-Mar-97
03.2.1.410	1S1EvlFW1	Cl 1, S1-Ongoing Evaluation of Field Work-Yr 1	52.00	05-Mar-97	04-Mar-98
03.2.1.420	1S1InRpFW	Cl 1, S1-Initial Rpt on Eval of Field Work	0.00	04-Mar-98	04-Mar-98
03.2.1.430	1S1EvlFW2	Cl 1, S1-Ongoing Evaluation of Field Work-Yr 2	52.00	04-Mar-98	03-Mar-99
03.2.1.440	1S1ItRpFW	Cl 1, S1-Interim Rpt on Eval of Field Work	0.00	03-Mar-99	03-Mar-99
03.2.1.450	1S1EvlFW3	Cl 1, S1-Ongoing Evaluation of Field Work-Yr 3	52.00	03-Mar-99	01-Mar-2000
03.2.1.460	1S1FnRpFW	Cl 1, S1-Final Rpt on Eval of Field Work	0.00	01-Mar-2000	01-Mar-2000
03.2.2	C1Site2FW	Class 1 - Site 2 Field Work	388.00	05-Jun-92	01-Mar-2000
03.2.2.010	1S2RsArcD	Cl1, Site 2 - Reservoir Architecture Description	52.00	05-Jun-92	17-Jun-93
03.2.2.020	1S2RsArc2	Cl 1, S2-Year 2 of Res. Arch. Description Work	52.00	18-Jun-93	30-Jun-94
03.2.2.030	1S2IResRp	Cl 1, S2-Interim Rpt on Reservoir Desc. Rel Wrk	0.00	17-Jun-93	17-Jun-93
03.2.2.040	1S2FResRP	Cl 1, S2-Prep Final Rpt on Reservoir Desc. Work	4.00	01-Jul-94	29-Jul-94
03.2.2.050	1S2FResRt	Cl 1, S2-Final Report on Reservoir Work Del.	0.00	29-Jul-94	29-Jul-94
03.2.2.070	1S2EnvMGe	Cl1,Site 2-Environmental Monitoring/Geolog. Work	52.00	05-Jun-92	17-Jun-93
03.2.2.080	1S2EnvMG2	Cl 1, S2-Environmental Mon. of Geol. Work-Year2	52.00	18-Jun-93	30-Jun-94
03.2.2.100	1S2DfRACn	Cl1,Site 2-Define Res Arch Constraints	52.00	05-Jun-92	17-Jun-93
03.2.2.115	1S2SiteP1	Cl 1, S2-Site Preparation Work	52.00	05-Jun-92	17-Jun-93
03.2.2.125	1S2SiteP2	Cl 1, S2-Site Preparation Work	52.00	18-Jun-93	30-Jun-94
03.2.2.200	1S2SimDsg	Cl1,Site 2-Simulation Design/Study	26.00	01-Jul-94	09-Jan-95
03.2.2.220	1S2SvcLab	Cl1,Site 2- Service Lab Work	26.00	01-Aug-94	07-Feb-95
03.2.2.230	1S2DfExtC	Cl1,Site 2-Define Extraction Tech. Constraints	17.00	01-Aug-94	01-Dec-94
03.2.2.300	1S2ImpFld	Cl1,Site 2-Implement Designs in Field	104.00	08-Feb-95	05-Mar-97
03.2.2.350	1S2EnvMFl	Cl1, Site 2-Environmental Mon of Field Work	104.00	08-Feb-95	05-Mar-97
03.2.2.370	1S2MEvlFW	Cl1,Site 2-Monitor & Evaluate Field Work	104.00	08-Feb-95	05-Mar-97
03.2.2.410	1S2EvlFW1	Cl 1, S2-Ongoing Evaluation of Field Work-Yr 1	52.00	05-Mar-97	04-Mar-98
03.2.2.420	1S2InRpFW	Cl 1, S2-Initial Rpt on Eval of Field Work	0.00	04-Mar-98	04-Mar-98
03.2.2.430	1S2EvlFW2	Cl 1, S2-Ongoing Evaluation of Field Work-Yr 2	52.00	04-Mar-98	03-Mar-99
03.2.2.440	1S2ItRpFW	Cl 1, S2-Interim Rpt on Eval of Field Work	0.00	03-Mar-99	03-Mar-99
03.2.2.450	1S2EvlFW3	Cl 1, S2-Ongoing Evaluation of Field Work-Yr 3	52.00	03-Mar-99	01-Mar-2000
03.2.2.460	1S2FnRpFW	Cl 1, S2-Final Rpt on Eval of Field Work	0.00	01-Mar-2000	01-Mar-2000
03.2.3	C1Site3FW	Class 1 - Site 3 Field Work	388.00	05-Jun-92	01-Mar-2000
03.2.3.010	1S3RsArcD	Cl1, Site 3 - Reservoir Architecture Description	52.00	05-Jun-92	17-Jun-93
03.2.3.020	1S3RsArc2	Cl 1, S3-Year 2 of Res. Arch. Description Work	52.00	18-Jun-93	30-Jun-94
03.2.3.030	1S3IResRp	Cl 1, S3-Interim Rpt on Reservoir Desc. Rel Wrk	0.00	17-Jun-93	17-Jun-93

Table III-3 (Continued)

WBS Code	Activity ID	Activity Description	Duration (Weeks)	Early Start	Early Finish
03.2.3.040	1S3FResRP	Cl 1, S3-Prep Final Rpt on Reservoir Desc. Work	4.00	01-Jul-94	29-Jul-94
03.2.3.050	1S3FResRt	Cl 1, S3-Final Report on Reservoir Work Del.	0.00	29-Jul-94	29-Jul-94
03.2.3.070	1S3EnvMGe	Cl1,Site 3-Environmental Monitoring/Geolog. Work	52.00	05-Jun-92	17-Jun-93
03.2.3.080	1S3EnvMG2	Cl 1, S3-Environmental Mon. of Geol. Work-Year2	52.00	18-Jun-93	30-Jun-94
03.2.3.100	1S3DfRACn	Cl1,Site 3-Define Res Arch Constraints	52.00	05-Jun-92	17-Jun-93
03.2.3.115	1S3SiteP1	Cl 1, S3-Site Preparation Work	52.00	05-Jun-92	17-Jun-93
03.2.3.125	1S3SiteP2	Cl1, S3 - Site Preparation Work	52.00	18-Jun-93	30-Jun-94
03.2.3.200	1S3SimDsg	Cl1,Site 3-Simulation Design/Study	26.00	01-Jul-94	09-Jan-95
03.2.3.220	1S3SvcLab	Cl1,Site 3- Service Lab Work	26.00	01-Aug-94	07-Feb-95
03.2.3.230	1S3DfExtC	Cl1,Site 3-Define Extraction Tech. Constraints	17.00	01-Aug-94	01-Dec-94
03.2.3.300	1S3ImpFld	Cl1,Site 3-Implement Designs in Field	104.00	08-Feb-95	05-Mar-97
03.2.3.350	1S3EnvMFl	Cl1, Site 3-Environmental Mon of Field Work	104.00	10-Jan-95	04-Feb-97
03.2.3.370	1S3MEvlFW	Cl1,Site 3-Monitor & Evaluate Field Work	104.00	08-Feb-95	05-Mar-97
03.2.3.410	1S3EvlFW1	Cl 1, S3-Ongoing Evaluation of Field Work-Yr 1	52.00	05-Mar-97	04-Mar-98
03.2.3.420	1S3InRpFW	Cl 1, S3-Initial Rpt on Eval of Field Work	0.00	04-Mar-98	04-Mar-98
03.2.3.430	1S3EvlFW2	Cl 1, S3-Ongoing Evaluation of Field Work-Yr 2	52.00	04-Mar-98	03-Mar-99
03.2.3.440	1S3ItRpFW	Cl 1, S3-Interim Rpt on Eval of Field Work	0.00	03-Mar-99	03-Mar-99
03.2.3.450	1S3EvlFW3	Cl 1, S3-Ongoing Evaluation of Field Work-Yr 3	52.00	03-Mar-99	01-Mar-2000
03.2.3.460	1S3FnRpFW	Cl 1, S3-Final Rpt on Eval of Field Work	0.00	01-Mar-2000	01-Mar-2000
03.2.4	C1Site4FW	Class 1 - Site 4 Field Work	388.00	05-Jun-92	01-Mar-2000
03.2.4.010	1S4RsArcD	Cl1, Site 4 - Reservoir Architecture Description	52.00	05-Jun-92	17-Jun-93
03.2.4.020	1S4RsArc2	Cl 1, S4-Year 2 of Res. Arch. Description Work	52.00	18-Jun-93	30-Jun-94
03.2.4.030	1S4IResRp	Cl 1, S4-Interim Rpt on Reservoir Desc. Rel Wrk	0.00	17-Jun-93	17-Jun-93
03.2.4.040	1S4FResRP	Cl 1, S4-Prep Final Rpt on Reservoir Desc. Work	4.00	01-Jul-94	29-Jul-94
03.2.4.050	1S4FResRt	Cl 1, S4-Final Report on Reservoir Work Del.	0.00	29-Jul-94	29-Jul-94
03.2.4.070	1S4EnvMGe	Cl1,Site 4-Environmental Monitoring/Geolog. Work	52.00	05-Jun-92	17-Jun-93
03.2.4.080	1S4EnvMG2	Cl 1, S4-Environmental Mon. of Geol. Work-Year2	52.00	18-Jun-93	30-Jun-94
03.2.4.100	1S4DfRACn	Cl1,Site 4-Define Res Arch Constraints	52.00	05-Jun-92	17-Jun-93
03.2.4.115	1S4SiteP1	Cl 1, S4 - Site Preparation Work	52.00	05-Jun-92	17-Jun-93
03.2.4.125	1S4SiteP2	Cl 1, S4 - Site Preparation Work	52.00	18-Jun-93	30-Jun-94
03.2.4.200	1S4SimDsg	Cl1,Site 4-Simulation Design/Study	26.00	01-Jul-94	09-Jan-95
03.2.4.220	1S4SvcLab	Cl1,Site 4- Service Lab Work	26.00	01-Aug-94	07-Feb-95
03.2.4.230	1S4DfExtC	Cl1,Site 4-Define Extraction Tech. Constraints	17.00	01-Aug-94	01-Dec-94
03.2.4.300	1S4ImpFld	Cl1,Site 4-Implement Designs in Field	104.00	08-Feb-95	05-Mar-97
03.2.4.350	1S4EnvMFl	Cl1, Site 4-Environmental Mon of Field Work	104.00	08-Feb-95	05-Mar-97

Table III-3 (Continued)

WBS Code	Activity ID	Activity Description	Duration (Weeks)	Early Start	Early Finish
03.2.4.370	1S4MEvlFW	Cl1,Site 4-Monitor & Evaluate Field Work	104.00	08-Feb-95	05-Mar-97
03.2.4.410	1S4EvlFW1	Cl 1, S4-Ongoing Evaluation of Field Work-Yr 1	52.00	05-Mar-97	04-Mar-98
03.2.4.420	1S4InRpFW	Cl 1, S4-Initial Rpt on Eval of Field Work	0.00	04-Mar-98	04-Mar-98
03.2.4.430	1S4EvlFW2	Cl 1, S4-Ongoing Evaluation of Field Work-Yr 2	52.00	04-Mar-98	03-Mar-99
03.2.4.440	1S4ItRpFW	Cl 1, S4-Interim Rpt on Eval of Field Work	0.00	03-Mar-99	03-Mar-99
03.2.4.450	1S4EvlFW3	Cl 1, S4-Ongoing Evaluation of Field Work-Yr 3	52.00	03-Mar-99	01-Mar-2000
03.2.4.460	1S4FnRpFW	Cl 1, S4-Final Rpt on Eval of Field Work	0.00	01-Mar-2000	01-Mar-2000
03.2.5	C1TECHTRN	CLASS 1-TECHNOLOGY TRANSFER	279.00	06-Mar-97	30-Aug-2002
03.2.5.010	1PkgForTT	Cl 1-Package Field Results for Tech Transfer	26.00	06-Mar-97	05-Sep-97
03.2.5.020	1TTActiv	Class 1-Technology Transfer Activities	52.00	05-Sep-97	04-Sep-98
03.2.5.030	1MEvalTT1	Class 1-Monitor & Evaluate Tech Trans Result	52.00	05-Sep-97	04-Sep-98
03.2.5.040	1InitTTRp	Class 1-Initial Rpt on Tech Transfer Results	0.00	04-Sep-98	04-Sep-98
03.2.5.045	1TTActiv2	Cl 1-Tech Transfer Activities - Year 2	52.00	04-Sep-98	03-Sep-99
03.2.5.050	1MEvalTT2	Class 1-Monitor & Evaluate Tech Transfer Results	52.00	04-Sep-98	03-Sep-99
03.2.5.060	1IntmTTR2	Cl 1-Interim Rpt on Tech Transfer Results-Yr 2	0.00	03-Sep-99	03-Sep-99
03.2.5.065	1TTActiv3	Cl 1-Tech Transfer Activities - Year 3	52.00	03-Sep-99	01-Sep-2000
03.2.5.070	1MEvalTT3	Class 1-Monitor & Evaluate Tech Transfer Results	52.00	03-Sep-99	01-Sep-2000
03.2.5.080	1IntmTTR3	Cl 1-Interim Rpt on Tech Trans Results - Year 3	0.00	01-Sep-2000	01-Sep-2000
03.2.5.090	1TTActiv4	Cl 1-Tech Transfer Activities - Year 4	52.00	01-Sep-2000	31-Aug-2001
03.2.5.100	1MEvalTT4	Cl 1-Monitor & Evaluate Tech Transfer Results	52.00	01-Sep-2000	31-Aug-2001
03.2.5.110	1IntmTTR4	Cl 1-Interim Rpt on Tech Trans Results - Year 4	0.00	31-Aug-2001	31-Aug-2001
03.2.5.120	1TTActiv5	Cl 1-Tech Transfer Activities - Year 5	52.00	31-Aug-2001	30-Aug-2002
03.2.5.130	1MEvalTT5	Cl 1-Monitor & Evaluate Tech Transfer Results	52.00	31-Aug-2001	30-Aug-2002
03.2.5.140	1FinlTTRp	Class 1-Final Rpt on Tech Transfer Results	0.00	30-Aug-2002	30-Aug-2002
03.2.6	1EvResSim	EVALUATE RESERVOIR SIMILARITY THEORY	45.00	18-Jun-93	29-May-97
03.2.6.010	1InitEval	Initial Eval of Res Sim aft Reservoir Desc	8.00	18-Jun-93	13-Aug-93
03.2.6.015	1IRpRsSim	Cl 1-Initial Rpt on Res. Similarity (aft Res)	0.00	13-Aug-93	13-Aug-93
03.2.6.020	1EvSiteRe	Eval of Res Sim After Field Work For All 4 Sites	12.00	06-Mar-97	29-May-97
03.2.6.030	1FRpRsSim	Cl 1-Final Rpt on Res. Similarity (aft FW)	0.00	29-May-97	29-May-97
03.3	1COMPLETE	ACTIVITIES TO COMPLETE FIELD WORK	203.00	08-Sep-98	30-Aug-2002
03.3.1	1FWREPORT	CLASS 1-FIELD WORK & TECH TRANSFER RPT	203.00	08-Sep-98	30-Aug-2002
03.3.1.010	1PFnRpFW	Class 1-Prepare Final Report on Results of Prog	4.00	08-Sep-98	05-Oct-98

Table III-3 (Continued)

WBS Code	Activity ID	Activity Description	Duration (Weeks)	Early Start	Early Finish
03.3.1.020	1FinalRpt	Class 1-Final Report on Field Work & Tech Trans	0.00	05-Oct-98	05-Oct-98
03.3.1.030	1UpFnlRpt	Cl 1-Update of Final Report on FW & TT	0.00	30-Aug-2002	30-Aug-2002
03.3.2	1REMRESC	CLASS 1-REMAINING RESOURCE POTENTIAL	4.00	06-Oct-98	03-Nov-98
03.3.2.010	1ARemRes	Class 1-Assessment of Remaining Resource Potnl	4.00	06-Oct-98	03-Nov-98
03.3.2.020	1RRemRes	Class 1-Report on Remaining Resource Potential	0.00	03-Nov-98	03-Nov-98

SUPPORTING RESEARCH — TARGETED AND DISCIPLINE-ORIENTED

The program includes three primary functions: analysis and planning; field demonstrations; and supporting research. Supporting research serves two important functions within the program. Targeted research designed to mitigate constraints within high priority reservoir classes is integrally linked with the field work. Discipline-oriented research serves the dual purpose of providing advances which are beneficial across a number of reservoir classes and advancing the state-of-the-art through greater understanding, increased applicability, or novel approaches. Discipline-oriented research may provide the tools to reach that portion of the U.S. resource base which cannot be produced with current advanced technologies.

The supporting research component of the program includes three primary areas of research: reservoir description R&D; extraction and engineering R&D; and environmental and related R&D and technology transfer. Each of these areas will include some activities which are targeted to specific reservoir classes and others which are discipline-oriented. Full definition of these activities can only occur after the highest priority reservoir classes have been identified. Since targeted activities are designed to mitigate problems specific to a reservoir class it is difficult to generalize about these activities prior to class identification. Milestones for the supporting research component of the program will be defined later.

The base budget for supporting research activities has been estimated at $13.4 million per year. This amount is reduced from FY 90 and FY 91 as the program is refocused from the previous emphasis on long-term basic research to a program which incorporates field work and class specific research. The $13.4 million per year budget for supporting research is divided into $8.4 million for targeted R&D projects related to the field work and $5 million for discipline-oriented R&D expected to produce benefits in the long-term.

While it is difficult to be specific about the exact research projects which will be undertaken until after the top reservoir classes have been defined, certain areas of research activities can be defined. Reservoir description R&D projects will include activities in remote sensing and logging, geostatistics and reservoir simulation, reservoir assessment and research into fundamental reservoir behavior. Much of this research will be targeted to the heterogeneities described in specific reservoir classes.

Engineering and extraction R&D will address all processes which can be used to recover the remaining mobile and immobile oil resource base, including chemical flooding, gas flooding, thermal processes, microbial EOR, and novel processes. Selected drilling research tasks will also be funded as they relate to increased producibility. Chemical flooding research activities will include chemical process modeling, development of economic surfactants, development of in-depth profile modification polymers, and developing polymers for mobility control. Gas flooding research will address mobility control and sweep improvement for CO_2, improving process simulation models, lowering miscibility pressure (MMP), and imbibition CO_2

processes. Thermal process research will address override of injected steam and steam bank in the reservoir, override of injected air or oxygen used in fore floods, and well bore heat loss. Microbial research will encompass the use of microbes in profile modification and in-situ generation of chemicals and gases by fermentation, as well as fundamental biochemistry and fundamental behavior of microbes.

Environmental R&D will incorporate the program's new mandate to address the environmental impacts of drilling and production. Oil field operations are regulated by federal and state programs under a number of federal statutes, including the Resource Conservation and Recovery Act (governing the management of drilling and production wastes), the Safe Drinking Water Act (underground injection for both enhanced recovery and subsurface disposal of produced water), the Clean Water Act (discharges to surface waters), the Clean Air Act (air emissions), the Superfund Amendments and Reauthorization Act (emergency planning and community right-to-know), and others. The myriad regulations and accompanying construction, operating, and paperwork requirements can be costly and burdensome to operators, especially the smaller independents. The costs and delays associated with environmental requirements can hasten abandonment of marginal wells and make advanced recovery projects economically unattractive.

Oil drilling and production must be carried out in an environmentally safe manner. Research is needed to help operators achieve this goal while minimizing the costs of environmental compliance. In addition, new environmental protection requirements are constantly under consideration by EPA, Congress, states, and others as laws are reauthorized or amended and programs are evaluated. DOE research and analysis can help to bring needed data on the resource, recovery processes, and oil field regulations to the regulatory debate to assure that the costs and benefits of environmental protection requirements are properly balanced. Research that can help achieve both of these purposes may include:

- Technology development for the management of drilling and production wastes, including waste minimization, resource recovery, substitution of more benign materials, waste characterization, and effects of wastes on the environment;

- Technology development for more cost-effective protection of drinking water aquifers, including logging techniques, well construction techniques, mechanical integrity testing methods, and abandonment methods;

- Analysis of the environmental risks associated with idle and temporarily abandoned wells and methods, such as fluid level monitoring, logging to detect fluid movement, well bore modeling, or retrievable bridge plugs, to delay permanent plugging of uneconomic wells that may be used in future advanced recovery projects;

- Evaluation of technologies, economics, regulatory requirements, and research options for economically reversible plugging techniques, to be used as a fallback technology where future access to a reservoir is economically important but where wells must be plugged, and where geologic, engineering, regulatory, and institutional conditions permit such reversible plugging;

- Evaluation of the environmental impacts of advanced recovery technologies, including the transport, fate, and effects of injected fluids and microbes, the characterization and disposal of production wastes, the impact on nearby abandoned wells, and

the associated risk to groundwater and surface waters;

- Evaluation and mitigation of air emissions (especially important for thermal recovery of heavy oil);

- Development of environmentally acceptable methods of drilling and production in wetlands;

- Development of data management systems to assist states and federal agencies in developing and implementing risk-based regulatory programs and to assist operators in lowering their costs of environmental compliance while providing better environmental protection;

- Research on oil field safety and health concerns such as H_2S and radioactivity;

- Developing state or area-wide plans to delineate requirements that oil operations must meet for the protection of endangered species (currently done individually by operators for every project in some areas);

- Working with and providing data and analysis to EPA, state agencies, and others who are evaluating current environmental protection programs and technologies and are considering new requirements; and

- Providing technical support to operators with regard to environmental protection and regulatory requirements.

Environmental research may be either targeted or discipline-oriented. Most of the above research topics cut across reservoir classes and, indeed, are generic to both oil and gas. Thus, cross-cutting research will be required. However, the specific environmental issues and requirements of high priority reservoir classes will have to be addressed. Once these are identified, they will help to set priorities among the above research topics, as well as define site-specific environmental projects. Close coordination of environmental research between the oil and gas programs will be required to prevent duplication and maximize the value of the work to both programs.

The supporting R&D segment of the budget also includes the funds for technology transfer of the results of all discipline oriented research in the program. Results of class specific, targeted research will be transferred to the industry as part of the field work technology transfer program. But it is important not to overlook the necessity of technology transfer for the discipline-oriented segment of supporting research as well. Technology transfer of this research will be primarily to other researchers -- at universities, private labs, and the national labs. Since these researchers often build on the research results of others in the field, or use results to confirm their own research, transfer of research results can multiply the research benefits to the state-of-the-art, and ultimately to oil recovery.

The supporting research function is presented in summary on the following pages. Detailed logic flow diagrams and task listings for supporting research cannot be produced until the research program has been further defined through the development of research requirements in support of the top reservoir classes.

- Base Case Budget for Supporting Research

- Work Breakdown Structure for Supporting R&D

- Supporting R&D Logic Flow

Table IV-1

BASE CASE BUDGET

$000

Supporting Research

	Targeted D&E	Discipline-Oriented R&D	Total Supporting R&D	Heavy Oil	Environmental R&D**
FY 90	1,500	19,323	**20,823**	4,014	0
FY 91	2,160*	7,314*	**9,474**	4,636	1,500
FY 92	8,400	5,000	**13,400**	4,500	3,000
FY 93	8,400	5,000	**13,400**	4,500	3,000
FY 94	8,400	5,000	**13,400**	4,500	3,000
FY 95	8,400	5,000	**13,400**	4,500	3,000
FY 96	8,400	5,000	**13,400**	4,500	3,000
FY 97	8,400	5,000	**13,400**	4,500	3,000
FY 98	8,400	5,000	**13,400**	4,500	3,000
FY 99	8,400	5,000	**13,400**	4,500	3,000
FY 00	8,400	5,000	**13,400**	4,500	3,000
FY 01	8,400	5,000	**13,400**	4,500	3,000
FY 02	8,400	5,000	**13,400**	4,500	3,000
FY 03	8,400	5,000	**13,400**	4,500	3,000
FY 04	8,400	5,000	**13,400**	4,500	3,000
Total	**110,700**	**84,323**	**204,497**	**67,150**	**40,500**

Average Cost Per Year = $13,633

* These are estimates. Actual program content to be determined pending problem definition phase and refit and refocusing of existing mortgages.

** Included in total supporting R&D.

MAJOR MILESTONES

Milestones for Supporting Research will be defined as class-specific research needs are defined for each reservoir class.

Figure IV-1

Work Breakdown Structure For Supporting R&D

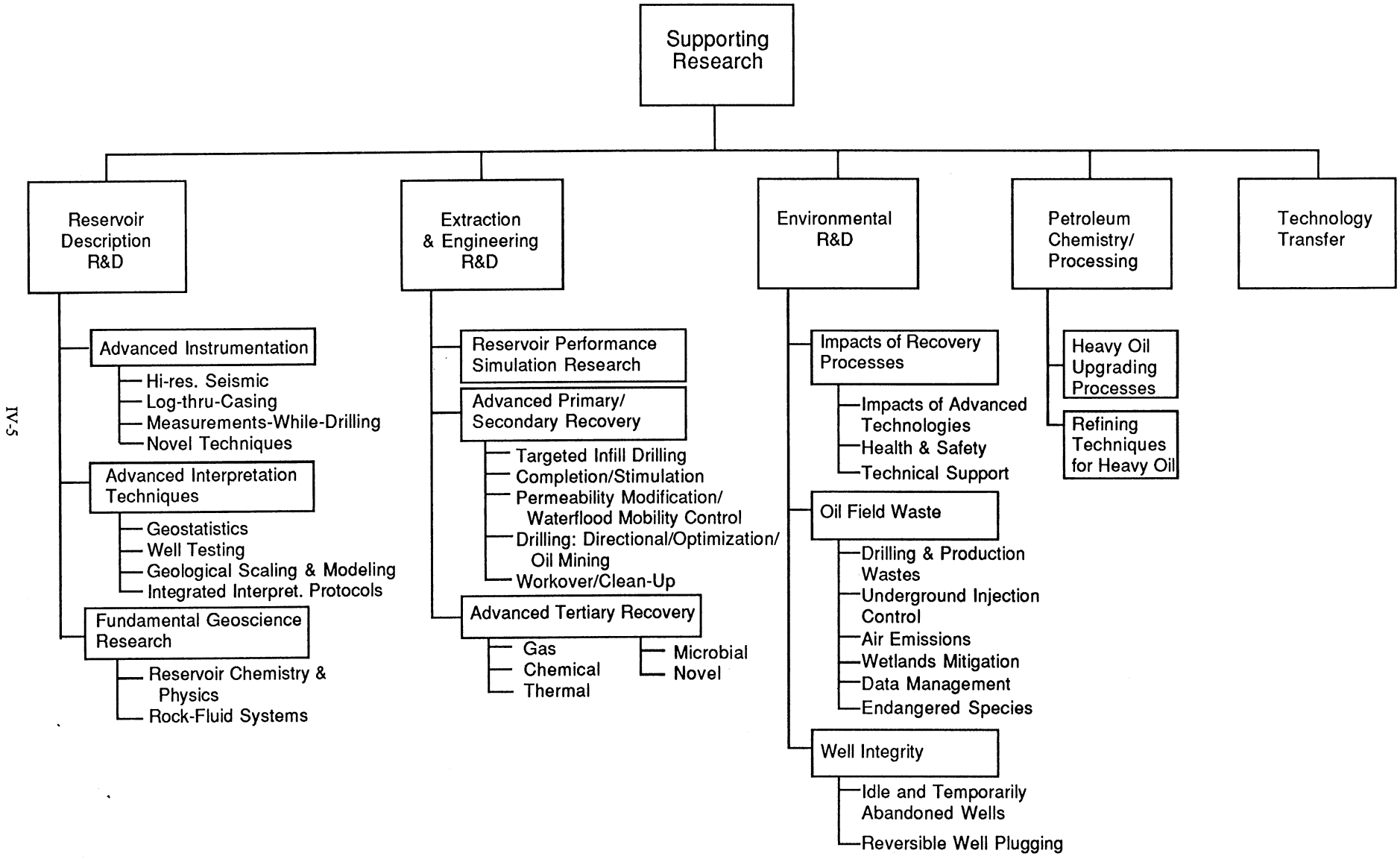
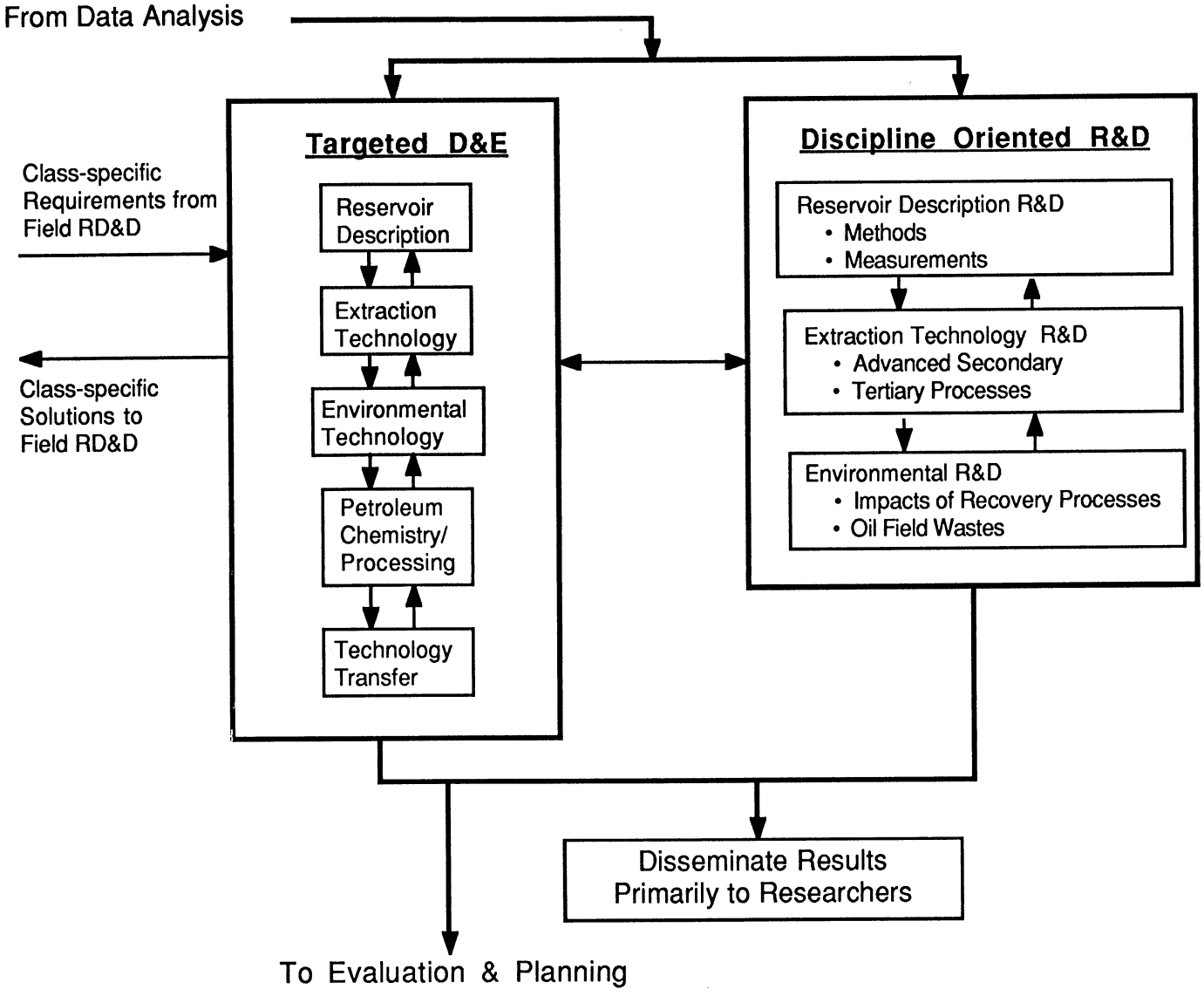


Figure IV-2

Supporting R&D Logic Flow