Attitudes and Practices: Direct Current Transit Systems and Stray Current Corrosion

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In 1984, the Transportation Research Board, National Research Council, recognized the need for better control of stray current corrosion problems attributed to direct current powered transit systems. Described in this paper is the work performed as a direct result of that recognition in which the stray current corrosion problem is considered in its entirety. The study is based on information from numerous sources that addresses the technical aspects of system and structure design, construction and maintenance, occupational and public safety, and the institutional concerns of economics and liabilities. The work had three major phases: a literature review, site and mail surveys, and a workshop. Published literature, personal interviews, mail questionnaires, and group evaluations were used to identify the issues, evaluate engineering practices, and suggest a research plan to develop the information needed to control stray current corrosion practically and effectively.

For nearly a century, direct current (DC) powered transit systems have been a boon to urban culture. They have afforded safe, reliable, and efficient mass transportation and have come to be relied on as an integral part of city life. In light of the density and congestion in our cities today, it is not likely that the demand for rapid rail transit will decrease. It is more likely that the need for all types of mass transit, DC rail transit included, will increase in the coming years.

In addition to their obvious benefits, DC transit systems contribute something originally unanticipated to our cities: stray earth currents. These currents are generated by differences in electric potential normally occurring along transit system routes. In their traverse of the earth, from an area of high to low potential, stray currents encounter buried metallic structures. Among others, buried utility pipes and cables, underground storage vessels, and reinforced concrete structures are the most significant and most often noted. Structures are afforded some protection from naturally occurring corrosion where stray current flows from the earth onto them. However, where current flows from high potential structures to the lower potential earth, an electrochemical reaction produces and accelerates corrosion. Although stray current can be considered beneficial, as in instances where it hampers corrosion, it is normally and nearly universally considered a problem.

Stray current induced corrosion, or electrolytic corrosion, like any other type of corrosion, can be the source of severe safety and economic problems if not controlled. Pressurized pipeline rupture, storage vessel leaks, and degradation of structural integrity are possible results. To avoid these possibilities, utility companies and other owners of buried structures must maintain constant vigilance, often spending large sums to locate and replace damaged property. Likewise, transit systems often have to modify their facilities to control the generation of stray currents. Not uncommonly, transit systems bear a large part of the direct and indirect costs of protecting buried structures, even when evidence is questionable that stray currents are destructive in an area.

Historically, stray currents and associated corrosion have been controlled through the cooperative efforts of transit agencies and affected parties. Using a variety of engineering approaches, some aimed at controlling the generation of stray currents, some at controlling the way in which stray currents flow, stray current corrosion problems generally have been managed after the fact. Measures are often implemented only after corrosion problems have been discovered. Resolving corrosion problems at this point is often expensive, with insufficient time to investigate problems thoroughly. Remedies that are "quick fixes" of one problem often cause problems in other areas. Transit agencies and owners of buried structures in those areas are then forced into a game of catch-up; continuously monitoring, modifying, and replacing corrosion controls to maintain a safe and reliable environment.

The reasons for this situation are many: a lack of information on the real costs of corrosion control and corrosion damage, the difficulty of monitoring buried structures and measuring their corrosion rates, the complexities in predicting results of a given corrosion control method in a given situation, and the difficulty of determining the true causes of corrosion. The results, however, are evident. Buried metallic structures in high-density urban areas are at risk. The integrity and longevity expected by their owners are not guaranteed. The safety and reliability expected by and due to the public are inconstant. The ability of transit agencies and owners of buried structures to control problems efficiently and economically are severely hampered. If there is to be improvement, a more complete and widespread

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understanding of DC transit system generated stray currents and their effects is required.

OBJECTIVES AND SCOPE

In 1984, the Transportation Research Board, National Research Council, recognized the need for better control of stray current corrosion problems attributed to DC powered transit systems. The work described here is a direct result of that recognition (*1*). The work, because it is fundamental and intended to encompass all aspects of the stray current corrosion problem, has many objectives. However, all have one of two principal focuses: education or development.

A primary objective of this work was to collect, organize, and make available what is presently known of the effects and the control of stray current corrosion. Although key management personnel may not always be familiar with the significance of the problem, another objective was documenting the severity of the problem and quantifying the economic, legal, and engineering issues in nontechnical terms. As a result, it is hoped that attention will be drawn to the problem and coordination stimulated within and between affected institutions.

Because of the multitude of approaches toward stray current corrosion control and the variability of their usefulness depending on local situations, an objective of the work was to catalog current engineering practices and make recommendations on their effectiveness. There also is a need to clarify aspects of the problem beyond what can be accomplished in this work, and a need to develop more effective means of corrosion control than those that presently exist. Therefore, perhaps the most significant objective of this work was to develop a long-term, all-encompassing program for future research. By this means, it is hoped that the present and future ability to control stray currents and associated corrosion will be enhanced.

METHODOLOGY

The work reported in this paper considers the stray current corrosion problem in its entirety. It draws from numerous sources to address the technical aspects of systems and structures design, construction and maintenance, occupational and public safety, and the institutional concerns of economics and liabilities. The work has three major phases: (a) a literature review, (b) site and mail surveys, and (c) a workshop, as illustrated in Figure 1. Each is described more fully in the following paragraphs, as is a brochure, published following the work on these phases. Detailed descriptions of each phase are contained in the project reports (*1–8*).

An exhaustive search was made of all foreign and domestic literature pertaining to stray current corrosion published since 1900. Abstracts and original papers were obtained for as much of the identified literature as possible. The resulting body of literature was organized and reviewed, and a comprehensive, indexed bibliography created (*2*). Significant issues were identified, and preliminary research priorities were developed. Practices reported in the literature for preventing or reducing structural stray current corrosion were identified and evaluated.

Firsthand information on the present state of the stray current corrosion problem was obtained by visiting five transit agencies. These were: San Francisco Bay Area Rapid Transit District, Toronto Transit Commission, Chicago Transit Authority, Washington Metropolitan Area Transit Authority, and Massachusetts Bay Transportation Authority. Engineers and managers at the transit agencies, local utilities, and other concerned parties were interviewed. The severity of the stray current corrosion problem, key issues and related engineering practices, and research needs were discussed at each agency (*3*).

Questionnaires were distributed to over 300 transit agencies, public utilities, municipalities, and others with an interest in stray current corrosion to augment the information obtained during site visits. Questionnaires covered the same areas addressed in site visits and solicited views on research needs and priorities. Responses were categorized by respondents' affiliation and geographic area (*3*).

A 2-day workshop was conducted in November 1986 to review and evaluate results of these efforts (*4*). Thirty-five participants attended, representing transit agencies, public

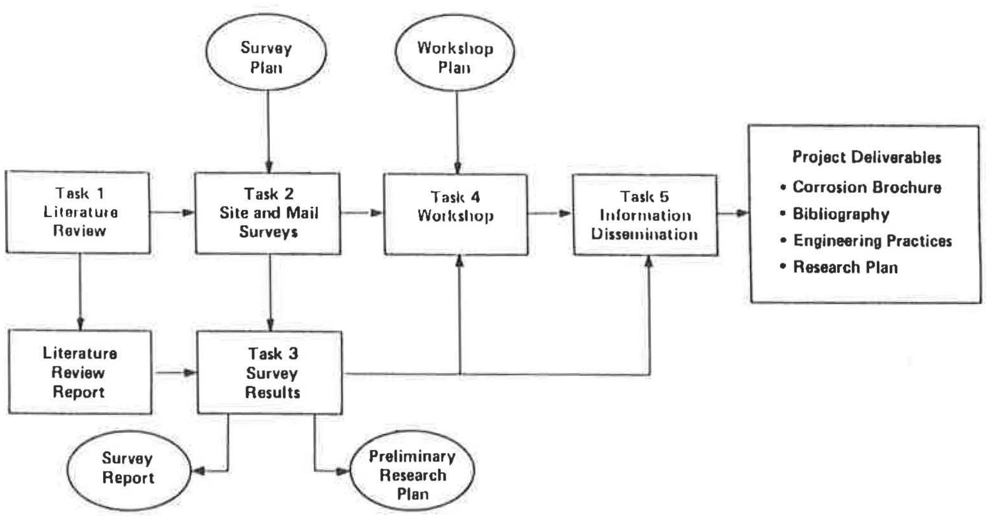

FIGURE 1 Relationship among required plans, tasks, and deliverables for NCTRP Project 48-1.

utilities, municipalities, and corrosion engineering consultants from the United States and Canada. The literature review and site and mail survey results were distributed and reviewed by the entire group. Each member was requested to individually evaluate and make recommendations concerning previously identified engineering practices. Research needs were clarified and documented in working groups. Finally, all members were asked to estimate a 5-yr research budget and to list in order of priority research areas and composite research projects developed by the working groups. The recommendations of the attendees are the basis for the report on engineering practices (*5*) and the development of the research plan (*6*).

Literature Review Findings

Approximately 1,100 potentially relevant references were obtained by searching the foreign and domestic literature. After deleting duplicate and inappropriate references, the total number was reduced to 549, of which 197 are in a foreign language. For many of the latter, English language abstracts are available.

Displayed in Figure 2 is a historical profile of publishing activity. Each bar represents the average number of papers identified for a 3-yr period to better visualize trends. Averages consist of the year at which the bar is displayed and the years immediately preceding and following.

A relatively large number of papers were published at the turn of the century. This probably indicates that the stray current corrosion problem was initially recognized at that time. Many of those reports remain relevant today. Later publications tend to refine the earlier issues and offer a few new techniques. However, the state of the art of stray current corrosion control is substantially the same today as it was in the early 1900s.

Engineering practices addressed in the literature included both the protection of buried structures from the corrosive effects of stray currents and the control of the generation of stray currents. Engineering practices are also discussed in terms of their applicability to existing and future facilities, including both transit systems and buried structures. Corrosion protection is addressed more often as applying to existing facilities. Control of stray current generation is addressed more often as applying to planned facilities.

Drainage is predominant among the engineering practices addressed (i.e., electrical connections between buried structures and the transit system's traction circuit to afford low resistance return paths for stray currents). Cathodic protection systems are less frequently discussed. There are very few citations covering protective coatings for buried structures, soil conditioning to alter electrolytic environments, or electrical connections between buried structures to control the flow of stray currents. Numerous methods for controlling stray current generation, such as storage and maintenance yard isolation and rail bonds, are described in considerable detail. Maintenance practices for corrosion control methods are addressed at a low level throughout the search period.

Also addressed in the literature are nontechnical aspects of stray current corrosion and, to some extent, effects of stray currents indirectly related to corrosion. Information on training and education, regulations and standards, and stray current

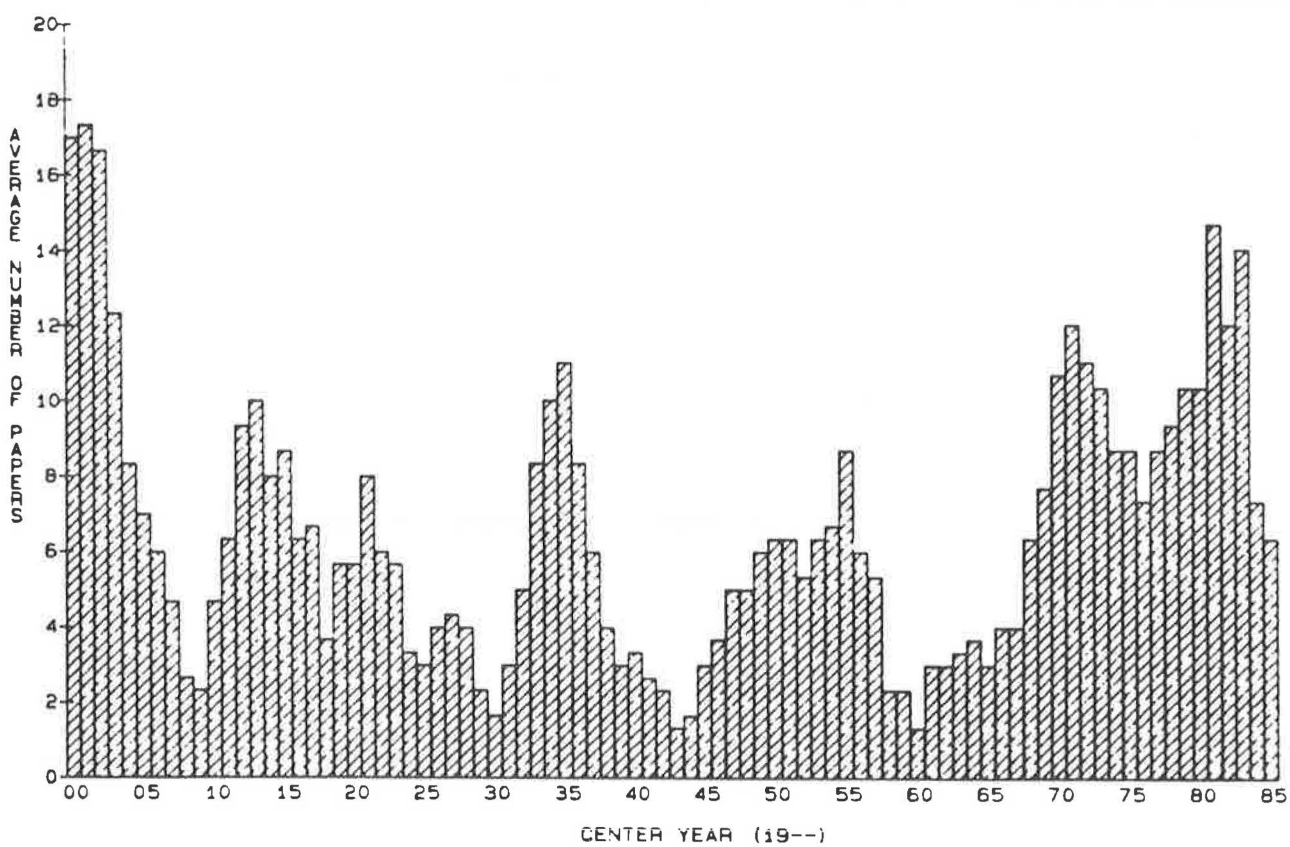

FIGURE 2 Three-yr average historical profile of total publishing activity.

coordinating efforts is included in the literature, but there is little discussion or substantial verification on economic and legal issues. Likewise, electric safety issues related to stray currents and their control are discussed infrequently, although more so in recent years.

The literature search revealed great diversity among the references in the areas and depth of coverage. However, a large number of the references dealt only with one or a few subjects within the broader area of stray current corrosion. As a result, there is no body of literature available that addresses the stray current corrosion problem in all its detail or that addresses sufficiently the options available to engineer and manage stray currents and their effects. The comprehensive bibliography and subject index compiled and included in the literature review report for this project fulfill this need in part (*2*).

Survey Results

The site and mail surveys contributed significantly to this investigation of stray current and its effects. The direct experience of the transit agencies, public utilities, municipalities, and others in dealing with stray currents were critical in determining the severity of corrosion, clarifying the issues, and developing specific research recommendations.

The mail survey distribution list was developed using the American Public Transit Association's membership index with additional contacts obtained from site surveys, corrosion control memberships, and the National Association of Corrosion Engineers (NACE). Forty-one responses were received from parties affiliated with gas, oil, power, telephone, water, transit, research, public works, and consultant groups.

The site and mail surveys indicated that transit agencies are perceived to be moderate sources of stray current corrosion. There was more concern regarding transit systems in close contact with earth than with transit systems electrically isolated from earth over most of their extent. Isolated transit agencies, however, tend to have higher capital and maintenance expenses. Institutions using pipelines (i.e., gas, oil, and water) perceived themselves as more severely affected by stray current corrosion problems than others. Consistently, gas companies tend to have larger budgets and more people involved with corrosion control (possibly in response to federal influence).

Generally, safety is not perceived as a significant problem and precautions are felt to be adequate. Nevertheless, safety was ranked among the most critical research needs. This reflects a commonly perceived climate of litigiousness. Other top research priorities were information dissemination and engineering practices pertaining to transit agencies.

In almost all instances, concerned parties are involved in corrosion coordinating committees. These committees are more interested in interorganizational relations and the solution of local problems than in generic concerns.

One of the most significant findings of the site and mail surveys was the indication that the main factor inhibiting resolution of stray current corrosion problems is low transit management priority. This was the case even when respondents provided evidence of moderate self-corrosion of transit system facilities. It was attributed to a lack of sufficient economic data, and, to a lesser extent, uncertainty concerning liability. It might be concluded from these results that there are some unresolved technical issues, but the state of the art is sufficiently mature to allow stray current problems to be resolved. The principal missing element is reliable economic data for which to choose cost-effective technical measures.

Workshop Results

The diversity and expertise of the workshop participants provided a unique opportunity for a cross-fertilization of views regarding research needs and priorities of stray current research. Through reviewing, evaluating, and building on the previous findings of the literature review and surveys, the workshop participants were the final source for the engineering practice descriptions and recommendations, priorities for research needs, research budget estimates, and specific research projects. In almost all cases, the comments and recommendations of the participants were found to be independent of their affiliations (i.e., gas, telephone, transit, and so on). This was felt to be a good indication that the results described below are universally applicable.

Brochure

As a result of the literature review, site and mail surveys, and the workshop, it was found that managers of both transit systems and affected agencies are hampered by a lack of sufficient information, primarily in the areas of the true costs of stray current corrosion and its control. Therefore, a brochure (*7*) was published to address these needs.

The objectives of the information contained in the brochure were to introduce transit and utility management to the problem of DC transit stray current corrosion, to convince management of the need for design, test, and maintenance measures to counteract stray current corrosion, and to educate engineers about the value of corrosion control measures. The brochure is intended for utilities and transit agencies, management, transit system designers, transit and utility corrosion specialists, and corrosion coordinating committees.

ENGINEERING PRACTICES

Cataloging and making recommendations on engineering practices used in controlling stray currents and associated corrosion is formidable: stray current corrosion control has been likened to a "black art," with no single method the answer for every system nor all its effects predictable. Each system must be analyzed individually to determine which method or methods will best achieve cost-effective stray current control. It was therefore decided to identify the effectiveness of engineering practices independent of specific system engineering in the hope that these efforts would become a foundation for more detailed future work. Immediately, it is hoped that this review will clarify which methods can be beneficially employed on proposed and existing systems.

Maintenance is the most essential element of a stray current corrosion control program. It must be well thought out, detailed, consistent, and routine. No matter what type of engineering practice is chosen, it can only be as effective as its maintenance routine.

Drainage refers to electrical connections between buried structures and the transit system traction circuit to control where stray currents flow off buried structures. Drainage is recommended only as a last resort. It tends to increase the geographic area in which stray currents are significant, especially for electrically isolated transit systems. Direct drainage, where simple cables connect buried structures and transit systems, is not recommended. Current flows in either direction, potentially contributing to corrosion. Diode drainage, placing rectifying semiconductor devices in series with drainage cables, is limited to currents typically less than 200 A. In addition, forward bias voltages remain during conduction. Reverse current switches (mechanical rectifying devices in series with drainage cables) are recommended when diodes do not provide the necessary characteristics. However, mechanical switches have a tendency to malfunction, especially at high current loads.

Utility interconnections, electrical connections between buried structures of collocated utilities, present problems like those associated with drainage. Each connection alters the electrical network and can thereby increase or redistribute stray currents.

Impressed current rectifiers, which actively bias underground structures to force protective current flow, are not normally effective for stray current control. Noncompensating rectifiers must be adjusted to account for worst-case stray current conditions. Adjusting to the worst-case conditions can cause nontransit stray current problems at other buried structures, and can overprotect the original structure because of excessive negative potentials and resulting hydrogen evolution. Constant potential rectifiers can be used to avoid overprotection, but they must have wide operating ranges to effectively counter stray currents.

Isolating devices for interrupting the continuity of the current path, especially in buried pipe, have high maintenance requirements that may not be cost-effective. Additionally, current can bypass isolating devices through the earth, contributing to localized corrosion. They should be used only in conjunction with other stray current control methods.

Protective coatings, not considering modern jacketing of electrical cables, can be effective in limiting stray current pickup. As with isolating devices, protective coatings should be used in conjunction with other schemes to account for the possibility of accelerated corrosion at localized flaws. The use of noncorrodible materials is extremely effective when installing new underground structures.

Frequent substation placing is effective in reducing stray currents, but is not necessarily a cost-effective approach for existing facilities. It should be a goal for proposed transit systems and routes.

Rail bonds, electrically connecting cables across rail joints, are effective in reducing traction circuit return path resistance and associated voltage gradients. However, they break easily and often and therefore require constant maintenance. Welded rails offer the same protection with considerably less maintenance.

Cross bonds, electrical connections between running rails, offer the same advantages as rail bonds and ensure equal potentials on each rail. Direct connections cannot be used if one rail is part of a signaling circuit. With proper care, low-pass impedance bonds can be used in these instances.

Voltage equalization at traction substations controls voltage differences between track sections and, therefore, stray currents. Substation performance is normally determined by operation considerations, and may not be available as a stray current control technique.

Special ballast can reduce stray currents, but must be kept as dry as possible and free of contaminants to remain effective.

Diode grounding, rectifying devices placed between substation ground and earth ground, is effective only if all other parts of the transit system are isolated from ground. Completely isolated systems are recommended.

Insulated negative feeders, insulated electric cable returning currents from distant sections of isolated track to common points, can reduce potential differences between portions of a transit system. Capital and maintenance costs are high, and large reductions in stray currents are difficult to achieve.

Electrical isolation of maintenance and storage yards from main lines can significantly reduce stray currents by increasing the total resistance of the traction circuits to earth. It should be practiced wherever feasible, especially with otherwise electrically isolated systems. Appropriate yard procedures are required. For example, train cars should not be parked where isolation devices might be bypassed inadvertently.

PRIORITIZING RESEARCH NEEDS

Beyond the development of the individual research projects described later, research needs at a more fundamental level were investigated. The 35 workshop participants were asked to distribute an unspecified budget among research categories and subcategories. This approach is believed to be a good indication of relative priority. Research category descriptions and budget distributions are shown in Table 1.

Regardless of professional affiliation, the workshop participants indicated by a large margin that engineering research should be given priority over management research. Within the engineering category, more emphasis was placed on stray current reduction than on corrosion protection (27 percent and 19 percent of the available research budget, respectively). In fact, research to improve methods for monitoring stray currents and corrosion was given nearly equal importance with corrosion protection research. Within the management category, education slightly outweighs other research areas. Examination of budget distributions showed that there was little dependence on professional affiliation for any category or subcategory.

ESTIMATE OF 5-YR RESEARCH BUDGET

Workshop participants also considered the present research budget established by the Transportation Research Board for stray current corrosion control problems. Only two participants expressed satisfaction with the current budget. Twenty-nine respondents proposed budgets substantially higher than current funding. Two participants offered formulas by which to calculate yearly budgets. One suggested the present budget be increased by 12 percent, plus inflation, for each of the next 5 yr. The other suggested a yearly budget of 0.5 percent of the value of existing transit systems plus 2 percent of the cost of newly planned routes and systems. A summary of estimates is shown in Table 2.

TABLE 1 RESEARCH CATEGORY BUDGET DISTRIBUTIONS

Research Category Description	Mean Percentage
Corrosion Control Engineering: Technology and techniques for measuring and controlling stray current corrosion, including activities on behalf of both transit systems and affected systems.	74
Measurement/Monitoring: Survey inspection and data acquisition techniques to determine current, potential, corrosion parameters, and system conditions.	17
Corrosion Protection: Methods and technology, usually employed by owners of buried structures, intended to counteract the corrosive effects of stray current.	19
Stray Current Reduction: Methods and technology, usually employed by the transit agency, intended to reduce the magnitude of stray currents.	27
Safety: Effects stray current generation or corrosion protection methods may have on public and worker safety, including electric shock hazards and buried structure integrity.	11
System Management: Nontechnical activities of corrosion control, including activities on behalf of both the transit agency and affected systems.	26
Interagency Management: Organization and mechanism of cooperation among the affected parties and transit systems (i.e., corrosion coordinating committees). Also legal and economic agreements between parties on responsibility for corrosion control.	8
Internal Management: Upper management's point of view and corrosion engineer's influence on it. Includes new systems and extension planning, retrofitting existing systems, maintenance, cost factors and trade-offs, safety, and liabilities.	8
Education: Availability of documentation on practices and techniques. Role of national organizations (i.e., NACE and others) and regional organizations (i.e., corrosion coordinating committees) in establishing and maintaining consistency and quality of corrosion control activities, including standards, regulations, and guidelines. Role of training programs in maintenance and testing.	10

TABLE 2 ESTIMATED 5-YR RESEARCH BUDGETS

Workshop Groupings	No. of Partic-ipants	Mean 5-Yr Budget in 1986 Dollars (million)	Range of Estimates in 1986 Dollars (million)
All participants	29	4.3	0.4–10.0
Consultants	8	3.5	2.0–5.0
Transit agencies	8	4.3	0.4–10.0
Electric utilities	7	5.3	1.0–10.0
Pipeline operators	4	5.6	3.5–5.0

Unlike most other areas of workshop input, budget estimates varied widely and depended on professional affiliation. The 5-yr budget estimates ranged from $400,000 to $10 million in 1986 dollars. However, group mean by affiliation ranged only from $3.5 million to $5.6 million. Interestingly, the low and high extremes of the mean were estimated by consultants and pipeline operators, respectively. In both cases, the range of estimates within each of these groups was less than for other groups. These results probably indicate relative familiarity with costs: prices charged by entrepreneurs in the case of consultants; and costs incurred by institutions in the case of pipeline operators.

PROPOSED STRAY CURRENT CORROSION CONTROL RESEARCH PROGRAM

As stated previously, the workshop participants were the primary sources for developing the proposed research plan described below. Each participant worked within one of six groups to evaluate and clarify 19 research projects previously developed by IIT Research Institute staff on the basis of literature review and survey results. Each group was composed of a cross section of the professional interests in order to fairly evaluate each project. The working groups suggested an additional 12 projects.

The results of the working groups were consolidated and resubmitted to the participants. A scale of 1 (no apparent benefit) to 5 (critical need) was used to rate each project. Individual ranks were then assigned based on the computed mean rating and the accuracy of the mean as inferred from the 95 percent confidence interval. (The 95 percent confidence interval establishes the range around the computed mean within which the true mean falls with 95 percent probability.) The results are listed in Table 3.

An examination of final ranks revealed differences dependent on professional affiliation were greatest for the 10 most highly rated projects. Dependence diminished considerably for the last 10 projects.

The final proposed research plan illustrated in Figure 3 is a result of the priorities given by workshop participants. Note that there is some duplication of research shown in Table 3. This duplication was omitted from the final proposed plan. A complete discussion of the plan and detailed descriptions of each research project are included in the research plan report (*6*).

The emphasis of the proposed program is engineering. Nearly all projects contribute directly to the development of an engineering handbook for transit system stray current corrosion control. As such, most projects emphasize collecting and coordinating existing information. Most other projects present possibilities for cost sharing with industry. Management projects stress cost in both dollar and liability terms. The relative effort in each research category is not quite the same as that obtained from workshop ratings. However, the areas most important to workshop participants are consistent.

The proposed plan can be accomplished over a period of 6½ fiscal years for an estimated cost of $5 million (1986 dollars). The scheduling allows a logical flow of findings from one project to others requiring that information. It recognizes the realities of national priorities and federal budget limitations. The program can be implemented entirely, starting with a modest investment of $500,000 in the first fiscal year, followed by a 50 percent commitment of the total budget during the subsequent three fiscal years. Funding between the fourth and fifth years would drop by 10 percent, and only about 10 percent

TABLE 3 PRIORITIZATION OF RESEARCH PROJECTS

Project Title	Average Score
1. Engineering Handbook for Transit System Stray Current Corrosion Control	3.91
2. Insulation Fastener for Wood Ties	3.51
3. Corrosion Control Measurement Methods	3.47
4. Effectiveness and Applicability of Stray Current Drainage Technologies	3.41
5. Application of Automatic Stray Current and Corrosion Monitoring Systems	3.29
6. Development of Track/Rail Insulating Fasteners	3.27
7. Track Bed and Tunnel Maintenance Requirements and Practices	3.26
8. Analyses of Costs Associated with Corrosion Prevention and Corrosion Damage	3.23
9. Development of Techniques and Equipment for Measurements in Stray Current Areas	3.18
10. Isolation Between Transit Facilities and Traction Circuits	3.17
11. Stray Current Reduction, Corrosion Protection, and Safety	3.11
12. Effectiveness and Applicability of Cathodic Protection in Stray Current Environment	3.11
13. Corrosion Effects of Stray Current Transients	3.09
14. Safe Voltage Levels in DC Transit Systems	3.08
15. Causes of Stray Currents and Their Effects on Reinforced Concrete Facilities and Structures	2.96
16 Wet Weather Performance of Insulating Track Fasteners	2.96
17. Causes of Stray Currents and Their Effects on Transit System Facilities	2.93
18. Influences of Electric Substation Separation on Stray Currents	2.93
19. Development of Faster and More Effective Reverse Current Switches Considering Both Mechanical and Semiconductor Technology	2.90
20. Survey Guidelines in Candidate Locations for DC Powered Transit Systems	2.88
21. Computer Software for Modeling Interactions Between Transit Systems and Collocated Buried Structures	2.66
22. Predictive Stray Current Corrosion Experiments	2.63
23. The Causes of Stray Currents from DC-Powered Transit Systems	2.60
24. Compendium of Legal Precedents Regarding Responsibility for Corrosion Control	2.53
25. Predictive Stray Current Corrosion Experimental Facilities	2.48
26. Trade-Offs Between Designing and Retrofitting Mitigation Engineering in Transit System Planning	2.41
27. The Causes of Stray Currents and Their Effects on Buried Metallic Structures	2.33
28. Installation of Ground Fault Interrupt (GFI) Circuitry at a Transit System DC Substation	2.28
29. The Causes and Effects of Stray Current on Affected Facilities Other Than the Transit Agency	2.19
20. Benefits and Disadvantages Associated with Transforming Solidly Grounded Transit Systems into Diode-Grounded or Isolated Systems	2.05
31. Alternative Propulsion Methods	2.03

of the total budget would be required during the last two fiscal years. In order to facilitate the program, a program management task has been included at approximately 15 percent of the research budget.

CONCLUSIONS

The work reported here illuminates the present state of stray current corrosion problems associated with DC powered transit systems. From published literature, personal interviews, mail questionnaires, and group evaluations, the issues have been identified, engineering practices evaluated, and a research plan proposed to develop the information needed to control stray current corrosion practically and effectively.

What has been found, with few exceptions, is that the necessary engineering knowledge is sufficiently developed to control and resolve stray current corrosion control problems. However, this knowledge cannot now be used easily or efficiently. There is therefore a strong need to develop a detailed compendium of engineering knowledge and make it available to both transit agency personnel and the owners and operators of affected structures. The groundwork for such a source has been laid in this work.

It has also been found that managers are most hampered by lack of sufficient information. There is a marked lack of information quantifying the true costs of stray current corrosion and its control. Likewise, very little is available to offer guidance in judging legal obligations and liabilities. These factors, perhaps more than any other, contribute to inadequate stray current corrosion control. To address this need, a brochure has been published as a result of this study describing the stray current corrosion problem in nontechnical terms for distribution to key management personnel. Work on the proposed research plan that will improve understanding of the nontechnical aspects of stray current corrosion has also been included.

The stray current corrosion problem needs to be controlled if DC powered transit systems are to continue to be safe, reliable, and efficient. There is ample room for improvement at present. The areas where improvement will be most beneficial have been identified and a plan by which to do so has been developed. The proposed plan can be accomplished over a period of $6^1/_2$ fiscal years for an estimated cost of $5 million (1986 dollars). If implemented, the results of the plan will enhance stray current corrosion control through knowledge and cooperation. Only then can DC transit systems be a benefit without the drawback of stray current corrosion.

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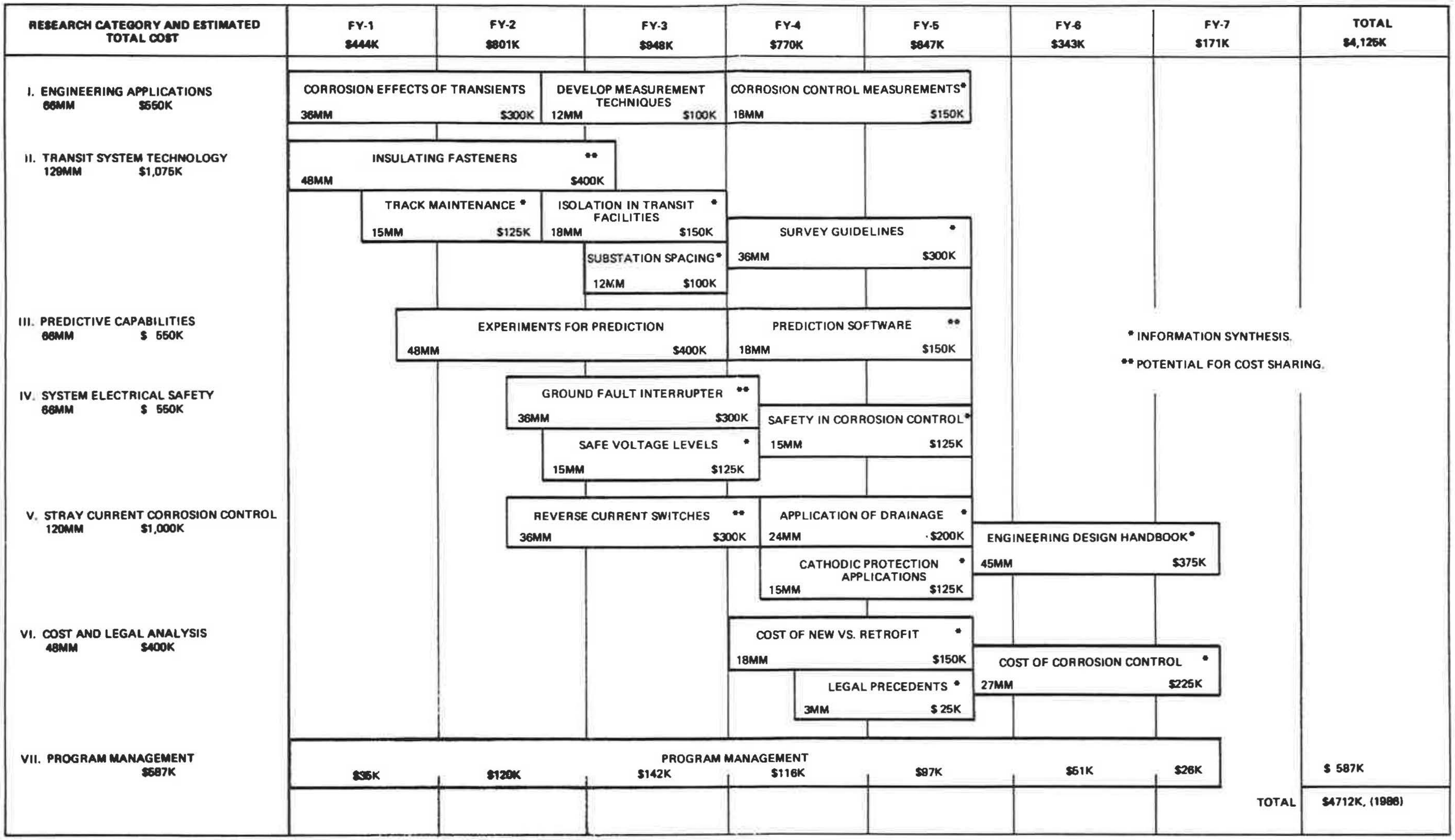

FIGURE 3 Proposed research program (and estimated cost in 1986 dollars based on $100,000/man year) for stray current corrosion from DC powered transit systems.

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