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# BUOY TECHNOLOGY SURVEY RECOMMENDATIONS FOR DEVELOPMENT

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AD-A252 346



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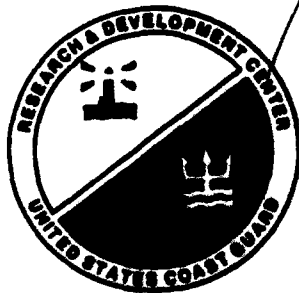
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16. Abstract  THIS REPORT PRESENTS THE RESULTS OF THE THIRD AND FINAL PART (TASK C) OF THE U.S.C.G. PROJECT "BUOY TECHNOLOGY SURVEY". DRAWING FROM THE FINDINGS OF TWO PRECEDING TASKS OF THE PROJECT (TASK A - "USCG BUOY DEVELOPMENT REVIEW" AND TASK B - WORLDWIDE BUOY TECHNOLOGY SURVEY"), FOLLOWING WORK WAS ACCOMPLISHED:  - BUOY TECHNOLOGIES TO BE CONSIDERED AS CANDIDATES FOR DEVELOPMENT WERE IDENTIFIED. - A SET OF EVALUATION CRITERIA WAS DEVELOPED FOR DETERMINING WHAT BUOY DESIGN FEATURES OR BASIC CHARACTERISTICS HAVE SUFFICIENT MERIT TO WARRANT FUTURE DEVELOPMENT EFFORTS. - CANDIDATE TECHNOLOGIES WERE EVALUATED USING THE CRITERIA AND THE WEIGHTING/GRADING SYSTEM DEVELOPED FOR THIS PURPOSE TO ASCERTAIN AND SELECT THOSE TECHNOLOGIES SHOWING PROMISE FOR IMPROVEMENT. - ECONOMIC ANALYSES OF PROMISING TECHNOLOGIES WERE CONDUCTED.  IT WAS FOUND THAT NINETEEN (19) OUT OF A TOTAL OF THIRTY-ONE (31) BUOY HULL RELATED CANDIDATE TECHNOLOGIES SHOWED PROMISE FOR IMPROVEMENT IN BUOY SYSTEMS WITH POTENTIAL ECONOMIC SAVING RANGING FROM \$4 TO \$63 MILLION IN LIFE CYCLE COSTS.					
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# METRIC CONVERSION FACTORS

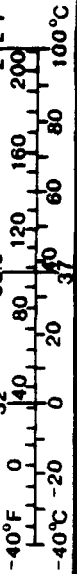
## Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
in	inches	* 2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	6.5	square centimeters	cm <sup>2</sup>
ft <sup>2</sup>	square feet	0.09	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.8	square meters	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.6	square kilometers	km <sup>2</sup>
	acres	0.4	hectares	ha
<b>MASS (WEIGHT)</b>				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
<b>VOLUME</b>				
tsp	teaspoons	5	milliliters	ml
tblsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft <sup>3</sup>	cubic feet	0.03	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.76	cubic meters	m <sup>3</sup>
<b>TEMPERATURE (EXACT)</b>				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

## Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
<b>AREA</b>				
cm <sup>2</sup>	square centimeters	0.16	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	1.2	square yards	yd <sup>2</sup>
km <sup>2</sup>	square kilometers	0.4	square miles	mi <sup>2</sup>
ha	hectares (10,000 m <sup>2</sup> )	2.5	acres	
<b>MASS (WEIGHT)</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
<b>VOLUME</b>				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m <sup>3</sup>	cubic meters	35	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.3	cubic yards	yd <sup>3</sup>
<b>TEMPERATURE (EXACT)</b>				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

\* 1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price \$2.25. SD Catalog No. C13.10.286.



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## LIST OF ABBREVIATIONS

ALERP	Aluminum Lighted Emergency Reinforced Plastic
ANA	ANA Nav aids Ltd. (India - Manufacturer)
API	Automatic Power, Inc. (U.S. Manufacturer)
ATON	Aids to Navigation
BB	Buoyant Beacon
BTIS	Buoy Technolgy Information System.
BTS	Buoy Technology Survey
CCG	Canadian Coast Guard
DECCA	A radio navigation system
DW	Deep Water
ECV	Office of Engineering, Logistics, and Development (USCG)
ELB	Exposed Location Buoy
FLT X	Floatex (Italy - Manufacturer)
FRP	Fiber Reinforced Plastic (can be glass or other fibre)
FV	Farwandsvaesenet (Denmark's Nav. Authority)
GFI/GFE/GFM	Government Furnished Information/Equipment/Material
GPS	Global Postitioning System
GRP	Glass Reinforced Plastic (FRP with glass fibre)
GTK	Gakuyo Toki Kogyo (Japan - Manufacturer)
HMP	Hippo Marine Products (UK Manufacturer)
IALA	International Association of Lighthouse Authorities (AISM)
KWH	KWH Pipe Ltd. (Finland Manufacturer)
LANBY/LNB	Large Navigation Buoy
LORAN	Long Range Aids To Navigation
MBS	Maritime Buoyage System
MTS	Marine Technology Society
NAVFAC	Naval Facilities Engineering Command
NBS	New Buoy Systems
NKK	Nippon Kogi Kogyo (Japan - Manufacturer)



LIST OF ABBREVIATIONS (cont'd)

NOAA	National Oceanic and Atmospheric Administration
NSR	Office of Navigation and Waterway Safety (USCG)
NTB	Net Total Benefit
NTDC	Net Total Discounted Cost
NTIS	National Technical Information Service
PB	Pintsch Bamag (Germany - Manufacturer)
PC	Personal Computer
PV	Present Value
PVC	Polyvinyl Chloride
RACON	Radar transponder used as aid to navigation
R&D	Research and Development
R&DC	Research & Development Center
RPS	Reinforced Plastic Structures (UK Manufacturer)
RS	Ryokuseisha Corp. (Japan - Manufacturer)
S/H	Staff Hours
SNAME	Society of Naval Architects and Marine Engineers
SOW	Statement of Work
SRA	Short Range Aids
STPB	Service Technique des Phares & Balises (France: Authority)
SW	Shallow Water
SZVF	Seezeichenversuchsfeld (Germany: ATON R&D Center)
TBE	Technology Background for Evaluations
TDP	Technology Development Plan
TGC	The Gilman Corp. (U.S. Manufacturer)
USCG	United States Coast Guard
UT	Urethane Technologies, Inc. (U.S. Manufacturer)
VTS	Vessel Traffic Services
WAMS	Waterway Analysis and Management Systems
WATG	Wave Activated Turbine Generator
WB	Weiseler Bojen (Germany - Manufacturer)
ZLBC	Zeni Lite Buoy Co. (Japan - Manufacturer)

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# 1. INTRODUCTION

## 1.1 Background

The Marine Aids to Navigation (ATON) System of the United States is an extensive and comprehensive array of devices external to a vessel intended to promote safe and economic movement of marine traffic. The United States Coast Guard (USCG) operates and administers this system which services the needs of and benefits the maritime commerce, the general boating public and the armed forces. A subgroup of this system is the Short Range Aids (SRA) to navigation system including navigational devices within visual, audible, radar or low power radiobeacon range. The New Buoy Systems, Buoy Technology Survey, the subject of this study, is concerned with the buoy element of the buoyage segment of the SRA system. The buoy element is defined as consisting of the hull, superstructure and the counterweight.

The evolution of buoys as aids to navigation is a continuing process. Possibilities exist for the improvement of buoys both through evolution and innovation. The USCG has identified a number of specific problem areas that need to be addressed: River Buoys, Large Lightweight Buoys, Bouyant Beacons, LNB Replacement, Measure of Buoy Effectiveness and Unlighted Sound Buoys.

In anticipation of potential technologies which could advance the state of the art in buoys as aids to navigation, the USCG has developed a "New Buoy Systems Project". The Buoy Technology Survey is the first step in the new project with the purpose of developing an overall technology assessment of buoy systems. The project was therefore broken down into three task efforts:

- TASK A - Review of the research and development efforts by the USCG on aid to navigation buoy development since 1962: this includes interviews with USCG personnel involved in buoy placement, design, maintenance and development. This task has been completed and the final report has been submitted (Ref.1).
- TASK B - Worldwide survey of existing buoys and related buoy technology and compilation of survey data in a computer database (the Buoy Technology Information System, "BTIS"): this task included attendance at the 1990 meeting of the International Association of Lighthouse Authorities (IALA). Nearly 400 buoy types have been identified. The computer database has been developed and installed at the USCG R&D Center and at the USCG Headquarters (G-ECV and G-NSR). The final report has been submitted (Ref.2).
- TASK C - Formulation of recommendations for the development of improved aid to navigation buoys for the USCG. The specific aspects of this task are the subject of this report.

## 1.2 Objective

As stated above, the main concern of this project is the buoy hull and excludes the direct and detailed consideration of such related matters as mooring systems, signalling devices and the much broader consideration of SRA type, arrangement and effectiveness. The fact that the mooring system and signalling devices are sometimes integrated with the buoy hull has resulted in an indirect consideration of these features as will be evident in the material that follows.

The larger questions of type, arrangement and effectiveness of the complete system is currently being considered by the USCG in the Waterway Analysis and Management System (WAMS). However, it was felt that the exposure to these wider considerations gleaned during this project and more importantly the dependence of those aspects of the system concerned with this project on the make-up of the whole system require this matter to be addressed as a background.

The specific objectives of Task C are to:

- Identify candidate technologies.
- Develop evaluation criteria for determining what buoy design features or basic technologies have sufficient merit to warrant future development efforts.
- Evaluate buoy technologies to ascertain those showing promise for improvement.
- Prepare development plans for promising technologies including schedules and costs.

Within this slate of objectives the first, i.e. the identification of candidate technologies, was utilized as the vehicle by which technologies outside the realm of the project but still germane to it could be touched upon. Consequently, the identification of technologies has been expanded well beyond those directly concerned with the buoy hull itself. As such they provide a backdrop to those technologies recommended for improvement of buoys, and in themselves they identify important areas which may be considered by others.

## 1.3 The Marine Aids To Navigation System

### 1.3.1 Maritime Navigation

Navigation is the process of directing the movement of a vessel expeditiously and safely from one point to another. The task of the vessel's navigator is to ascertain its position with sufficient accuracy to avoid dangers in order to accomplish a safe and timely voyage (Ref.3).

The principal methods utilized in navigation are:

DEAD RECKONING is navigation based on speed, elapsed time and direction from a known position.

PILOTING (or PILOTAGE) is navigation involving frequent or continuous determination of position or a line of position relative to geographic points or aids to navigation, and usually requiring need for close attention to the vessel's draft with respect to the depth of water.

TERRESTRIAL NAVIGATION is accomplished by means of information obtained by earth-based aids to navigation including short range aids (SRA).

CELESTIAL OR ASTRONOMICAL NAVIGATION is accomplished using information obtained from celestial bodies, i.e. sun, moon, planets and stars.

RADIONAVIGATION is accomplished using radio waves for determination of position or a line of position. The radio waves may be transmitted from terrestrial-based or space-based sources.

RADAR NAVIGATION involves the use of radio waves to determine the distance and direction of an object reflecting the waves to the transmitter, and the use of Racons, strategically placed active radar targets.

Since the beginning of the nineteenth century, and even earlier, lights, buoys and beacons have been used as sources for terrestrial navigation. However, during this century, radio navigation systems have been developed which are now in use as important aids to navigation.

The development of these systems for improved positioning and navigation along with recent progress in electronic charting has raised questions as to the future role of the traditional visual and audible aids to navigation.

### 1.3.2 ATON For Geographical Areas of Navigation

The geographical areas where marine navigation occurs dictate the type of ATON utilized:

- Ocean Navigation: Navigation beyond a Continental Shelf and/or more than 50 n.miles from land or other obstructions. Decca Navigation, Loran-C and other electronic position fixing systems are currently available in many parts of the world. Space-based radionavigation systems are expanding in availability.
- Coastal Navigation: Navigation within 50 n.miles from land or the outer limit of offshore shoals or other hazards, or where navigation is subject to restriction. The USA Federal Radionavigation Plan also defines this phase as covering those areas where restrictions such as traffic separation schemes, restriction on cargo,

Vessel Traffic Services (VTS), control of traffic flow, i.e. one way traffic, etc. are applied. Decca Navigation, Loran-C and other electronic position fixing means are currently available. Lighted buoys and beacons may be utilized.

- Harbor Approaches and Harbor Navigation: In general, waters inland from those of the coastal area. Lighted buoys and beacons coupled with radar navigation prevail.
- Inland Waterway Navigation: Navigation in restricted areas similar to harbors or harbor approaches. Buoys and beacons coupled with radar navigation prevail.
- River Navigation: Navigation in long, winding channels with high unidirectional currents and shifting shoals. Unlighted buoys and ranges are used in conjunction with radar.

Clearly if the radio navigation systems become sufficiently accurate to extend their influence into the harbour areas and inland waterways, this may have a significant impact on buoyage. As an example, IALA believes that the greatest changes due to satellite navigation will occur in the coastal areas.

Finally, IALA has recently identified the following changes that have taken place which have caused lighthouse authorities to reconsider the needs of the mariner and the navigation aids that are required:

- The increasing use of radar and radar devices requiring the introduction of radar reflectors, racons, etc. either instead of or supplementary to lights and daymarks.
- The establishment of vessel routing systems and greater management of traffic via VTS or radio communications.
- An increased awareness of and reliance upon electronic rather than traditional ATON.
- An enormous increase in the number of pleasure craft.
- An enhanced need for short range navigation accuracy as ships are larger and the safety margins in terms of depth and width of channels are smaller.

IALA is currently considering the development of a document which describes the various ATON systems and advises on the means and criteria to be adopted by a navigation authority in determining a mix of ATON most appropriate for an authority to meet the user requirements. The document has not yet been completed and published.

## 1.4 The Buoy

A brief review of the general characteristics and function of the buoy hull is in order since it is the main concern of this project.

The buoy hull, the primary component of the floating aid, must provide the necessary buoyancy and positive stability for all conditions. It must support its own payload including power supplies, electronic equipment and antennae. It must also sustain the mooring forces and those of the environment including wind, current and wave drag. The positive stability will assure the buoy will not capsize due to the environmental loads or during routine maintenance operations. This may be accomplished by the proper location of weights, counterweights and by the design of the buoy geometry itself. The buoy hull must also have adequate structural integrity to resist damage during deployment/retrieval operations and while on station.

Figures 1 and 2 show the buoy components and the terms used in identifying them for a typical lighted buoy and for a buoyant beacon, respectively. The complete buoy nomenclature used by the USCG for identifying all types and sizes of aid to navigation buoys is shown in Table I.

The USCG has detailed data sheets for its buoys in COMDINST M16500.3, "Aids to Navigation Manual-Technical". The data sheets provide the functions physical and operational characteristics, equipment, and other additional data applicable to the specific buoy. Buoys are classified as suitable for exposed, semi-exposed, or protected environmental conditions in both ocean and fast water (i.e. high current) environments.

In selecting a buoy the following must be considered:

- o Application
- o Environment
- o Signal Requirements
- o Positional Accuracy Requirements

The standard floating aid to navigation buoys currently being used by the USCG in coastal and inland waterways, in the Great Lakes, and the western rivers regions are shown in the following illustrations:

- Figure 3: Standard 9' Buoys
- Figure 4: Standard Lighted Buoys
- Figure 5: Standard Unlighted Buoys
- Figure 6: Standard Plastic Buoys
- Figure 7: Standard Foam Buoys
- Figure 8: Standard River Buoys
- Figure 9: Standard Ice Buoys

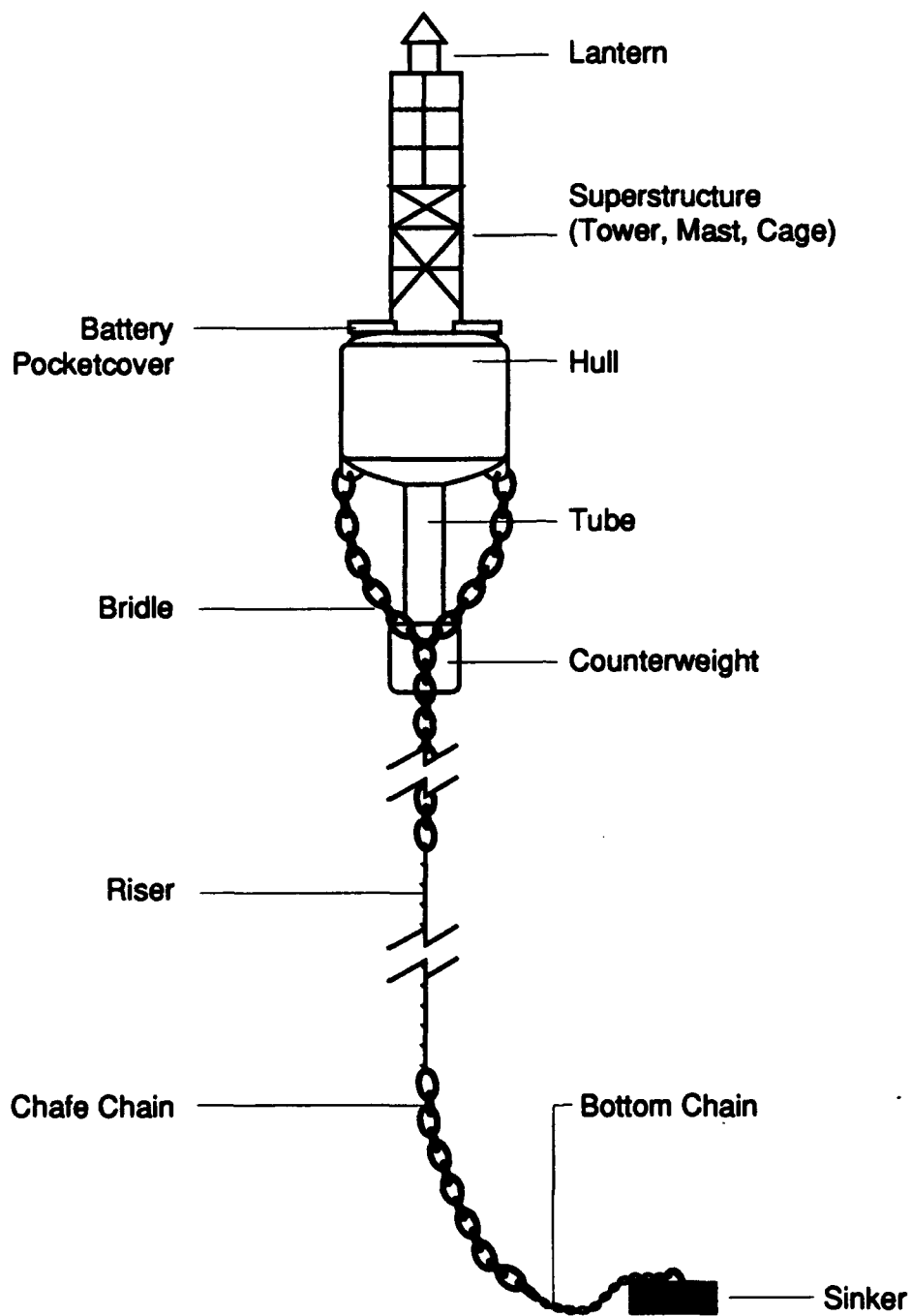


FIGURE 1 Typical Navigation Buoy System



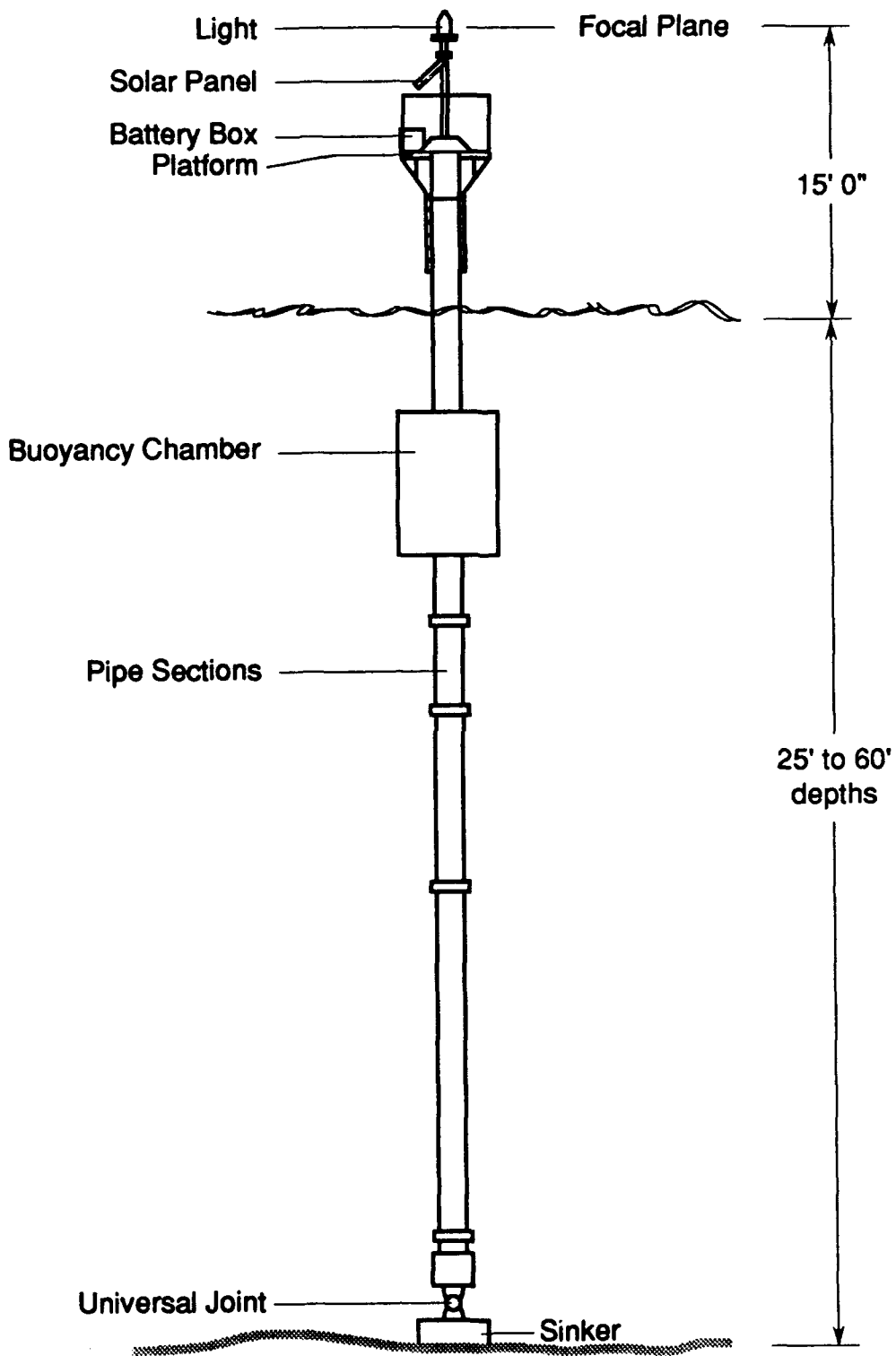


FIGURE 2 Components of a Buoyant Beacon

TABLE I  
ABBREVIATIONS USED IN THE CLASSIFICATION  
AND DESIGNATION OF USCG ATON BUOYS

For Unlighted Buoys:

(Except Unlighted Sound)

C	CAN (Cylindrical Buoy Shape)
N	NUN (Conical Buoy Shape)
T	Tall Buoy
S	Special Buoy
P	Plastic Buoy
F	Foam Buoy
R	Buoy with Radar Reflector
FW	Fast Water Buoy

For Lighted Buoys and  
Unlighted Sound Buoys:

L	Lighted Buoy
B	Bell Buoy
G	Gong Buoy
W	Whistle Buoy
H	Horn
I	Ice Buoy

Standard Buoy Designations

9x35 LR  
 9x32 LR, LGR, LBR, LWR  
 9x20 BR, GR  
 8x26 LR, LBR, LGR, LWR, WR  
 8x20 LR  
 7x17 LR  
 7x20 LI  
 6x20 LR, LBR  
 5x11 LR  
 3½x8 LR  
 1 CR, NR, CFR, NFR  
 2 CR, NR, CFR, NFR  
 3 CR, NR, CI, NI, CFR, NFR  
 4 CR, NR, CFR, NFR  
 5 CPR, NPR, CI, NI, CFR, NFR  
 FCPR

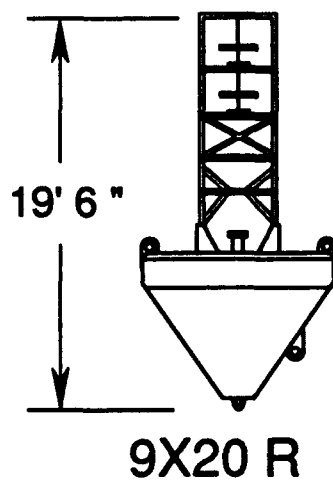
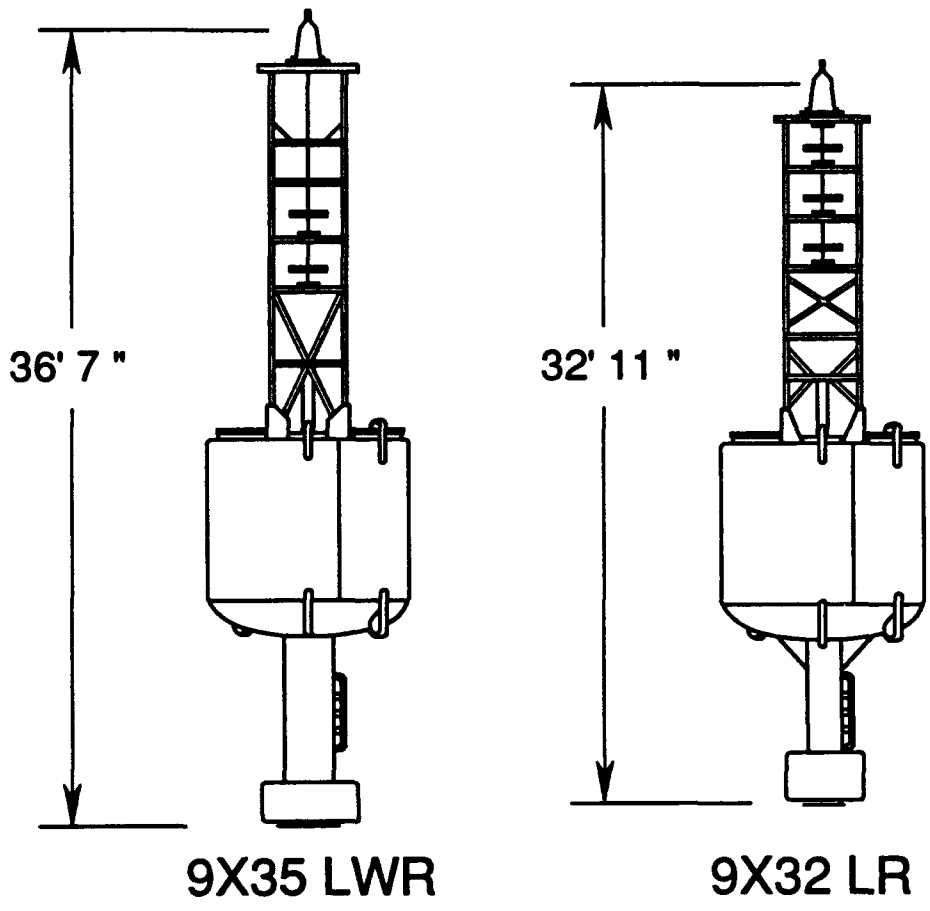
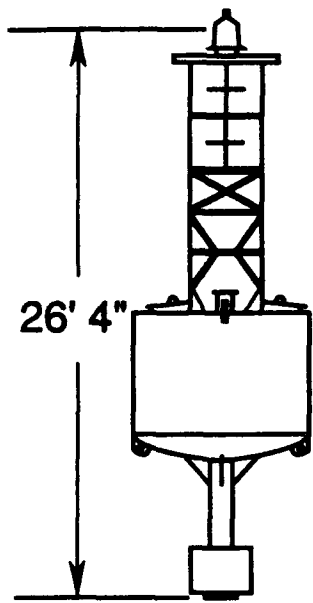
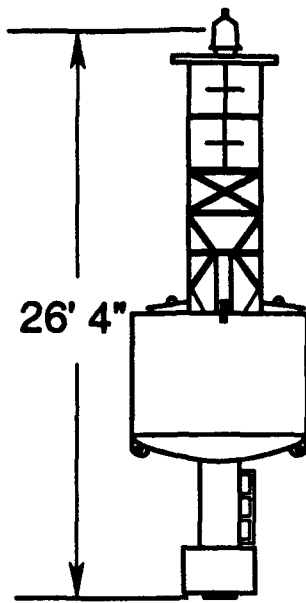


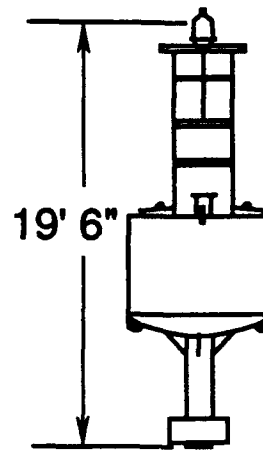
FIGURE 3 Standard 9' Buoys



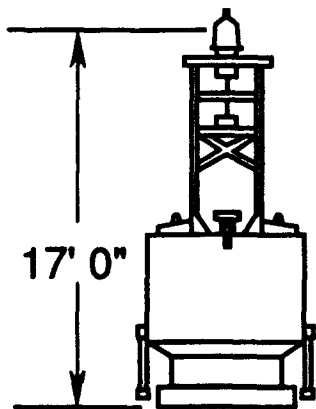
8x26 LR



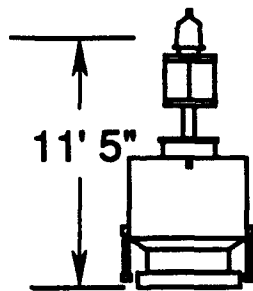
8x26 LWR



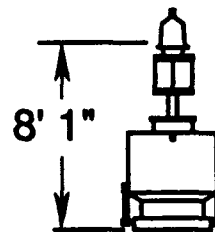
6x20 LR



7x17 LR



5x11 LR



3 1/2 x 8 LR

FIGURE 4 Standard Lighted Buoys

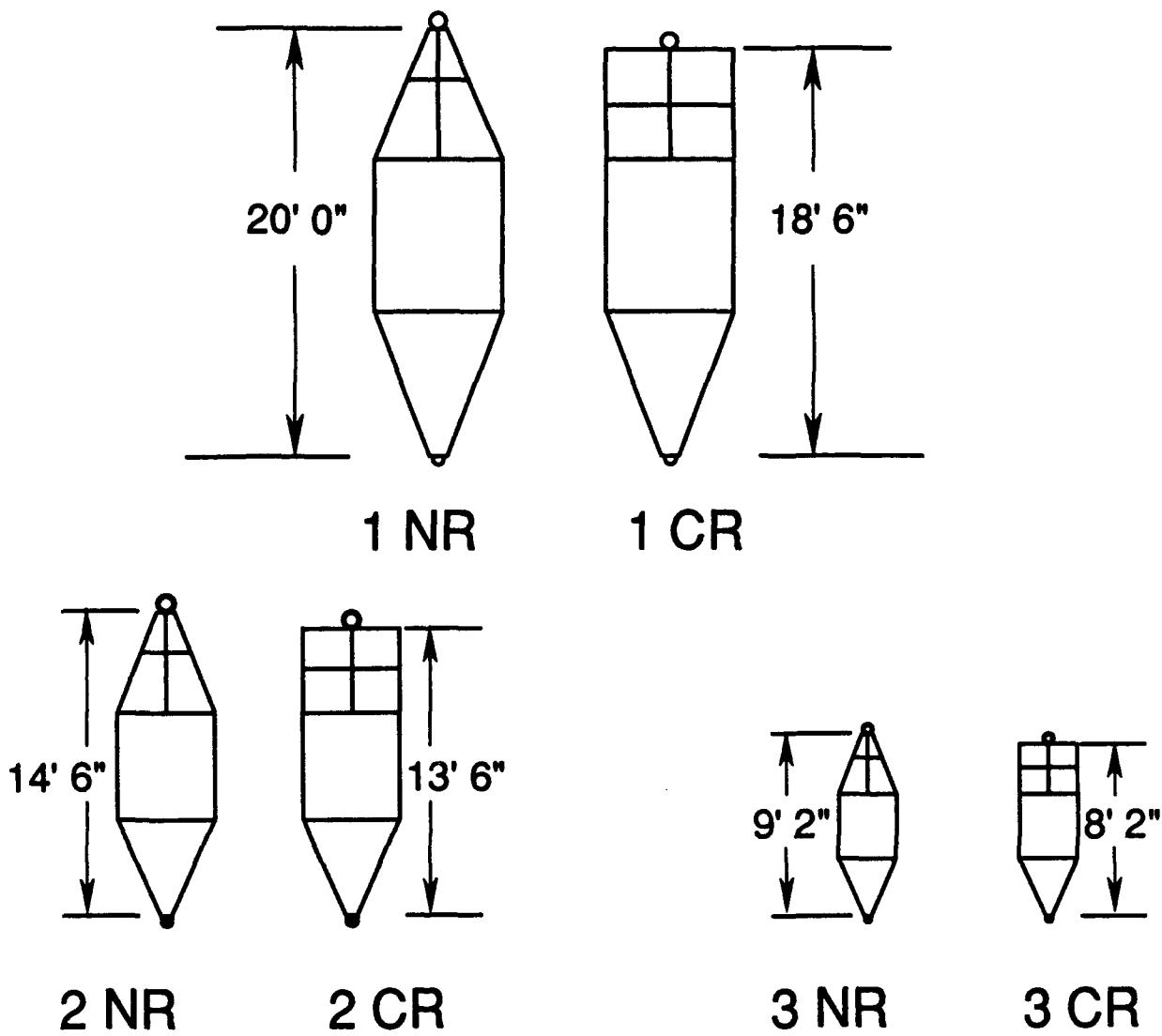
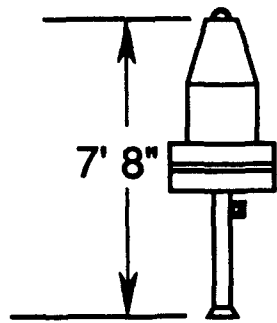
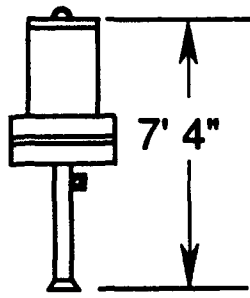


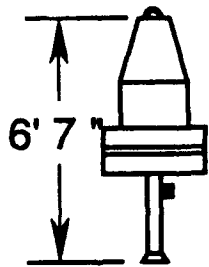
FIGURE 5 Standard Unlighted Buoys



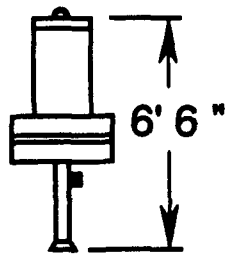
5 NPR



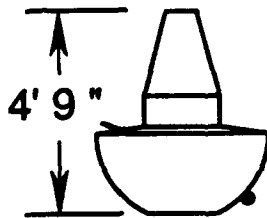
5 CPR



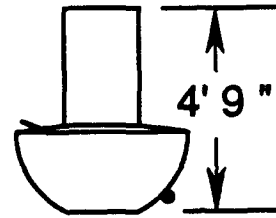
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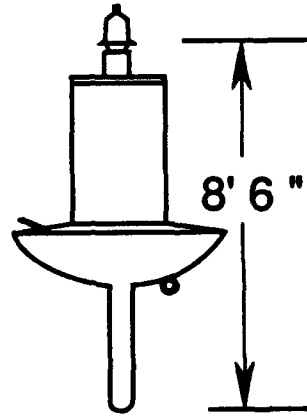
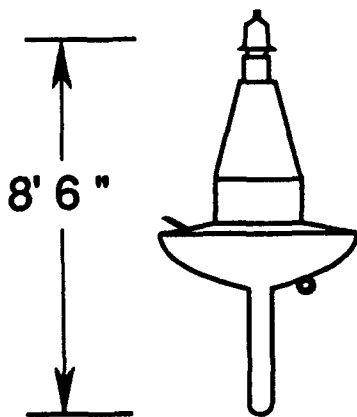
6 CPR



FNPR

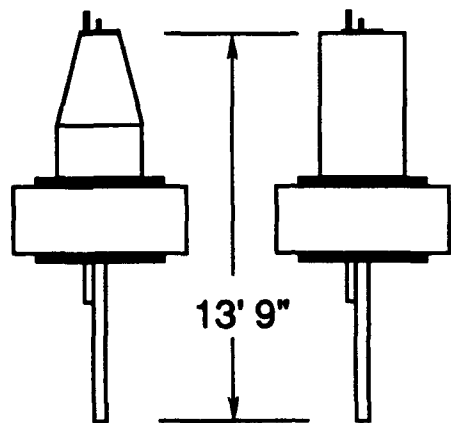


FCPR



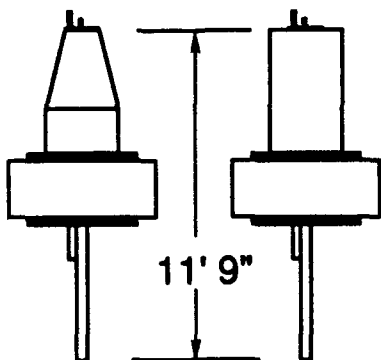
Discrepancy

FIGURE 6 Standard Plastic Buoys



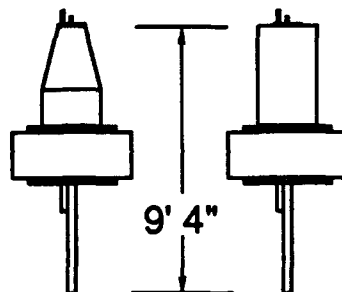
2 NFR

2 CFR



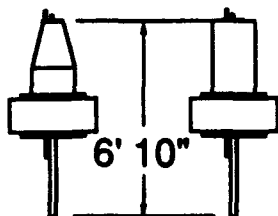
3 NFR

3 CFR

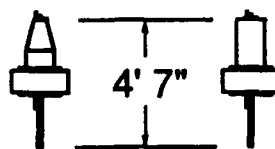


4 NFR

4 CFR



5 NFR 5 CFR



6 NFR 6 CFR

FIGURE 7 Standard Foam Buoys

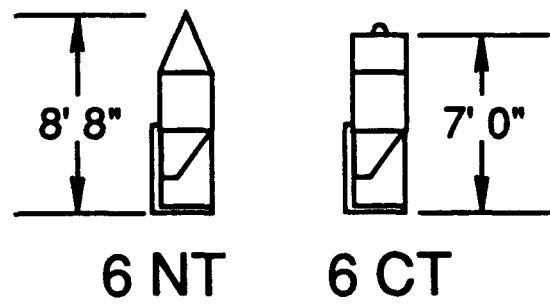
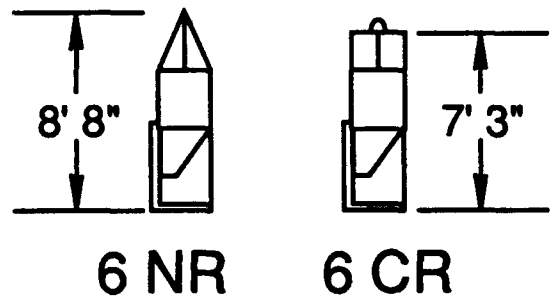
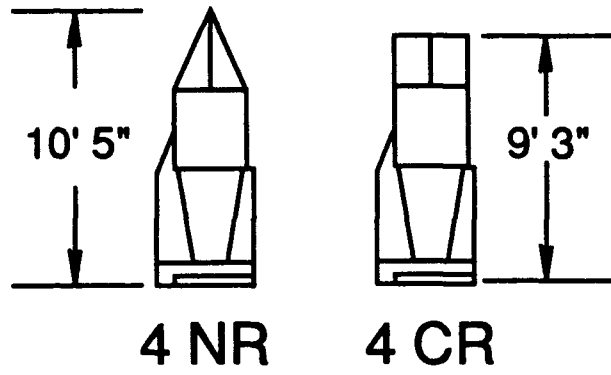
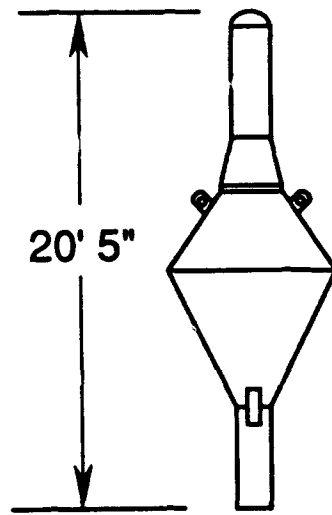
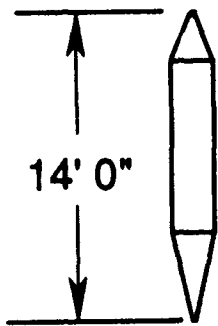


FIGURE 8 Standard River Buoys

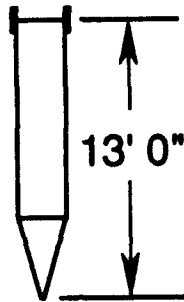




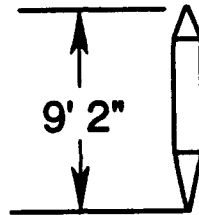
7x20 LI



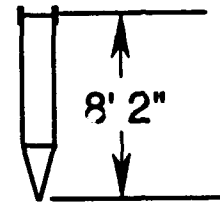
3 NI



3 NI



5 NI



5 Ni

Figure 9 Standard Ice Buoys

The ATON manual contains complete illustrations and data sheets for all of these standard buoys as well as their variations such as bell/gong/whistle buoys, etc.

### 1.5 Approach

The approach to accomplishing the current task follows the objectives identified in Section 1.2.

The first step was the determination of candidate technologies from among those identified in Task A and Task B reports (Ref.1 and 2) as well as from subsequent discussions with and presentation to personnel within and outside the USCG. This was followed by the development of evaluation criteria to determine which of the technologies show promise for improving the USCG's ATON buoys. The criteria were determined on the basis of results from Task A interviews with staff members of the USCG, G-NSR, G-ECV and the R&DC. The criteria were subdivided into a number of measures of merit for use in the grading process.

The grading of technologies was accomplished in accordance with the following step-by-step procedure:

- Weight factors were assigned to each category and to the criteria within the categories.
- Each criterion under individual categories was independently graded by three reviewers on the basis of to which extent it meets the measures of merit for that criterion.
- The grades assigned by the reviewers were averaged, rounded out to the nearest whole number, and multiplied by the weight factors to obtain "points" for each specific criterion.
- The criterion "points" within each category were added up to obtain a "Subtotal for Category".
- The subtotals for all categories were added up to result in a "Total Evaluation" point score for the technology in question.
- In the resultant listing, the higher total point scores reflect the more promising technologies. However, in order to allow for the uncertainties in the assumptions made and the subjectivity factor in the grading process, a cut-off level was determined and candidate technologies with total point scores below this level were considered risky for further development.

The grading process is described in Section 2.0 in greater detail, complete with sample evaluation forms, and results are presented in Sections 4.2 and 4.3.

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## **2.0 IDENTIFICATION OF TECHNOLOGIES**

### **2.1 Approach**

The identification of technologies stemmed from the review of USCG research and development efforts under Task A (Ref.1), and the worldwide surveys Task B (Ref.2). The results of these tasks were reviewed to identify all those technologies which had the potential for the development of improved ATON buoys as well as improvements to the entire marine ATON system. The identified technologies were categorized and a determination made as to whether the technology applied to buoy hulls or to other elements of the ATON system.

Following the initial identification of technologies, the results were presented to sources within and outside the USCG to obtain additional opinions. These included:

- USCG personnel
- Representatives of the New York/New Jersey Pilots Association (Captains Peterson, Black and Walsh)
- Captain S. Fraser Sammis, Commissioner, Board of Pilots of New York/ New Jersey
- Vice Admiral Robert Price (USCG, ret)

### **2.2 Results**

A thorough compilation of all the findings from worldwide buoy surveys resulted in a list consisting of 57 technologies. Upon a closer review of this list, it was found that three of them overlapped three other technologies and these were combined as follows:

- A. Use of Modular Daymarks/Topmarks: This technology was considered closely related to another one entitled "Slat Covered Frame Superstructures" since the purpose of slats is to provide shape significance as well. It was decided to combine these two into one technology and to name it "Slat Covered Frame Superstructure Shape Significance Versus Topmarks".
- B. GRP Superstructure for Estuarine Environment: It was found more meaningful and cost effective to treat this technology within the framework of another one entitled "GRP/FRP Material for Buoys".
- C. Use of Retro-reflective Surfaces: Since this technology involves the use of retro-reflective paint materials as well, it was decided to combine it with the technology entitled "Coating and Preservation Systems".

The total number of identified technologies was thus reduced to 54. No claim is made that these 54 represent all new technologies for the entire ATON system. These are simply those that resulted from the investigations presented in the Task A and Task B reports and subsequent discussions and presentations.

The identification process is summarized in Table II wherein the 54 technologies for screening are subdivided into fifteen different categories. Also included in the table is an indication of the action taken with regard to evaluating the technology as applicable to the New Buoy Systems Project (Ref.4) or deferring the technology for evaluation by others as part of projects apart from the current study. In this context, "Evaluate" indicates that the subject technology directly affects the buoy hull and superstructure and is therefore a part of the current project, i.e. it will be included in the evaluation effort. "Defer" indicates that the subject technology does not directly affect the buoy hull and superstructure; therefore is not a part of the current project, and will not be included in the evaluation effort.

Exceptions had to be made to this general rule in the case of some specific technologies. These are marked in Table II with numbered notes to the right of the "Action" column and are summarized below:

- Note (1): Even though directly related to buoy hull, this technology was excluded from further study due to the fact that it is not suitable for USCG's main fast water buoy areas (see "Review of Buoy Technologies" in Appendix A for Technology No. 4.3).
- Note (2): Mooring concepts for "Buoyant Beacons" are slated for evaluation despite the fact that mooring systems are not part of the "buoy element". The reason for this exception to the rule is that the buoyant beacon is a unique aid to navigation for which there is considerable interest in the USCG.
- Note (3): Wave activated turbine generators (WATG) and seawater primary batteries belong to "power sources" element of the ATON system and at first sight they do not appear to be directly related to the buoy hull. However, both are slated for evaluation since:
  - WATG's are installed within flooded compartments built-in to the buoy and therefore impact the hull design.
  - Seawater primary battery is connected to the buoy hull by means of a large and heavy flange which also impacts the hull design.
- Note (4): These technologies are directly related to the buoy hull and are therefore worthy of evaluation. However, they are already under study by the USCG and are therefore not included for further investigation.

**TABLE II: TECHNOLOGIES IDENTIFIED FOR SCREENING**

<b>1.</b>	<b><u>IMPROVEMENTS TO EXISTING USCG BUOYS</u></b>	<b><u>ACTION</u></b>
1.1	Slat Frame Superstructure Shape Significance	Evaluate
1.2	Reduced Weight of Superstructure	Evaluate
1.3	Better Venting and/or Changing the Shape of Battery Pockets	Evaluate
1.4	Quick Acting Buoy Hatch Covers	Evaluate
1.5	Anti-Fouling Chain in Tail Tube	Evaluate
<b>2.</b>	<b><u>BUOY CONSTRUCTION MATERIALS</u></b>	
2.1	Foam Material for Buoys	Evaluate
2.2	Elastomer Skin For Buoys	Evaluate
2.3	GRP/FRP Buoys Material for Buoys	Evaluate
2.4	Off the Shelf Plastic/Foam Buoys	Evaluate
<b>3.</b>	<b><u>BUOYS FOR OPEN SEA APPLICATIONS</u></b>	
3.1	Semi-Submersible Hulls	Evaluate
3.2	Off the Shelf Buoys	Evaluate
<b>4.</b>	<b><u>BUOYS FOR RIVERS/ESTUARINE ENVIRONMENTS</u></b>	
4.1	Debris Shedding Buoy Hulls	Evaluate
4.2	Gimballed Lantern to Improve Light Signal in Heeled Condition	Evaluate
4.3	Anti-heeling Plates	Defer (Note 1)
4.4	Off the Shelf Buoys	Evaluate
<b>5.</b>	<b><u>BUOYS FOR ICE ENVIRONMENTS</u></b>	
5.1	Compartmented Ice Buoys	Evaluate
5.2	Plastic Spar Buoys for Ice Service	Evaluate
<b>6.</b>	<b><u>BUOYANT BEACONS</u></b>	
6.1	Evaluation of Mooring Concepts	Evaluate (Note 2)
6.2	Off the Shelf Beacons	Evaluate
<b>7.</b>	<b><u>BUOYS FOR EMERGENCY USE</u></b>	
7.1	Inflatable Buoys	Evaluate
<b>8.</b>	<b><u>POWER SOURCES AND PAYLOAD</u></b>	
8.1	Deck or Superstructure Mounted Battery Boxes	Evaluate
8.2	Solar Panel Supplement to Bolster WATG Power	Defer
8.3	Wave Activated Generators	Evaluate (Note 3)
8.4	Seawater Primary Battery - Norway - Alu power	Evaluate (Note 3)
8.5	Wind Generators	Defer
8.6	Low Energy (MIRA) Light Beacon	Defer
8.7	LED Lights	Defer
8.8	Modular Buoy Payload	Defer
8.9	Electronic and Gas Sound Devices	Defer

TABLE II: continued

9.	<u>IDENTIFICATION &amp; REMOTE MONITORING OF BUOYS</u>	<u>ACTION</u>
9.1	Buoy Position Monitoring	Defer
9.2	LORAN & Receivers/Transponders on Buoys	Defer
9.3	Collision Marking Systems	Defer
9.4	Synchronization of Flashing Lights in Ports with Bright Background and Lighting	Defer
9.5	Recognizability of Buoy Symbols and Lettering	Defer
9.6	Solid Superstructure Instead of Latticework and Topmarks	Evaluate
9.7	Remotely Visible Low Battery Indicator	Defer
10.	<u>MOORING IMPROVEMENTS</u>	
10.1	Use of Synthetic Lines in Mooring	Defer
10.3	Use of Iron Sinkers in High Current Areas	Defer
11.	<u>PRESERVATION/PROTECTION</u>	
11.1	Coating & Preservation Systems	Evaluate
11.2	Fenders on Buoy Hull	Evaluate
12.	<u>STANDARDIZATION OF BUOYS &amp; BUOY PARTS</u>	
12.1	Modular Buoy Designs	Evaluate
12.2	Use of Commercially Available Reflectors	Defer
13.	<u>TECHNOLOGIES AND DESIGN CRITERIA FOR BUOYS</u> (These are general and not buoy specific. Some buoy specific criteria studies are under specific buoy types).	
13.1	Systems Approach to Design	Evaluate
13.2	Increased Buoy Motions	Evaluate
13.3	Buoy Model Tests	Evaluate
13.4	Effect of Mooring and Payload Weight on Buoy Design	Evaluate
13.5	Measure of Effectiveness	Evaluate (Note 4)
13.6	Improved Damage Stability by Increased Compartmentation	Evaluate
14.	<u>COMPUTER DATABASES/PROGRAMS FOR ATON</u>	
14.1	Computer Analysis of Buoy Hydrodynamics	Evaluate (Note 4)
14.2	Buoy Statistics and Inspection Databases	Defer
15.	<u>TRAFFIC ENGINEERING</u>	
15.1	Vessel Navigation by Buoyage	Defer
15.2	Vessel Navigation by Navigation System	Defer
15.3	Two Way Traffic	Defer
15.4	Range Lights	Defer

Technology No. 14.1 "Computer Analysis of Buoy Hydrodynamics" was excluded from the evaluation since the USCG is currently undertaking this technology as the Buoy Design and Analysis Program (Ref. 5). It is intended to support the Office of Engineering during the development and evaluation of new buoy systems. The project is a joint effort with the Naval Civil Engineering Laboratory and the NOAA Data Buoy Center. The buoy design and analysis software will be the result of integrating three major components: a menu-driven user interface, a CAD/hydrostatics application package, and a dynamic response simulation program.

Also excluded from the evaluation is Technology No. 13.5 "Measure of Buoy Effectiveness" on which the USCG had already conducted studies. It was felt that the treatment of this technology within the context of constructing buoys incorporating the technology was too broad. In order to provide the most positive view of the technology, it would have been necessary to make the assumption that virtually all buoys could be improved somewhat by this technology as it would seek to prioritize the requirements for a specific buoy with the most important requirements highlighted and designed into that buoy. A broad conclusion of this type would not be overly helpful in identifying specific buoy improvements; however, it is firmly believed that the USCG should continue its efforts to identify measures of effectiveness for all types of buoys in the system and make them available to buoy designers.

For each of the 54 identified technologies, a statement describing the rationale in selecting and the approach to analyzing the technology was prepared. A sample of these statements is shown in Table III for Technology No. 4.1 "Debris Shedding Buoy Hulls". Appendix A contains these summary statements for the "deferred" technologies in Table II. The summary statements for the technologies selected for evaluation are presented in their entirety in Appendix B.

Figure 10 is a schematic illustration of the identification, screening, evaluation, and selection procedure. As shown, out of the 54 identified technologies, 21 were excluded from further consideration (deferred) due to the fact that they are not directly related to the buoy hull. Furthermore, two of these technologies are already currently under study by the USCG and these were also excluded. This left a total of 31 candidate buoy technologies for evaluation.

The criteria utilized in evaluating the candidate technologies are described in detail in Section 3.0 and the details of the evaluation process itself is given in Section 4.0 along with the resulting recommendations for development.



## TABLE III: SAMPLE "RATIONALE & APPROACH" STATEMENT

### REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.	4	<u>RIVER BUOYS</u>
TECHNOLOGY NO.	4.1	<u>DEBRIS SHEDDING BUOY HULLS</u>

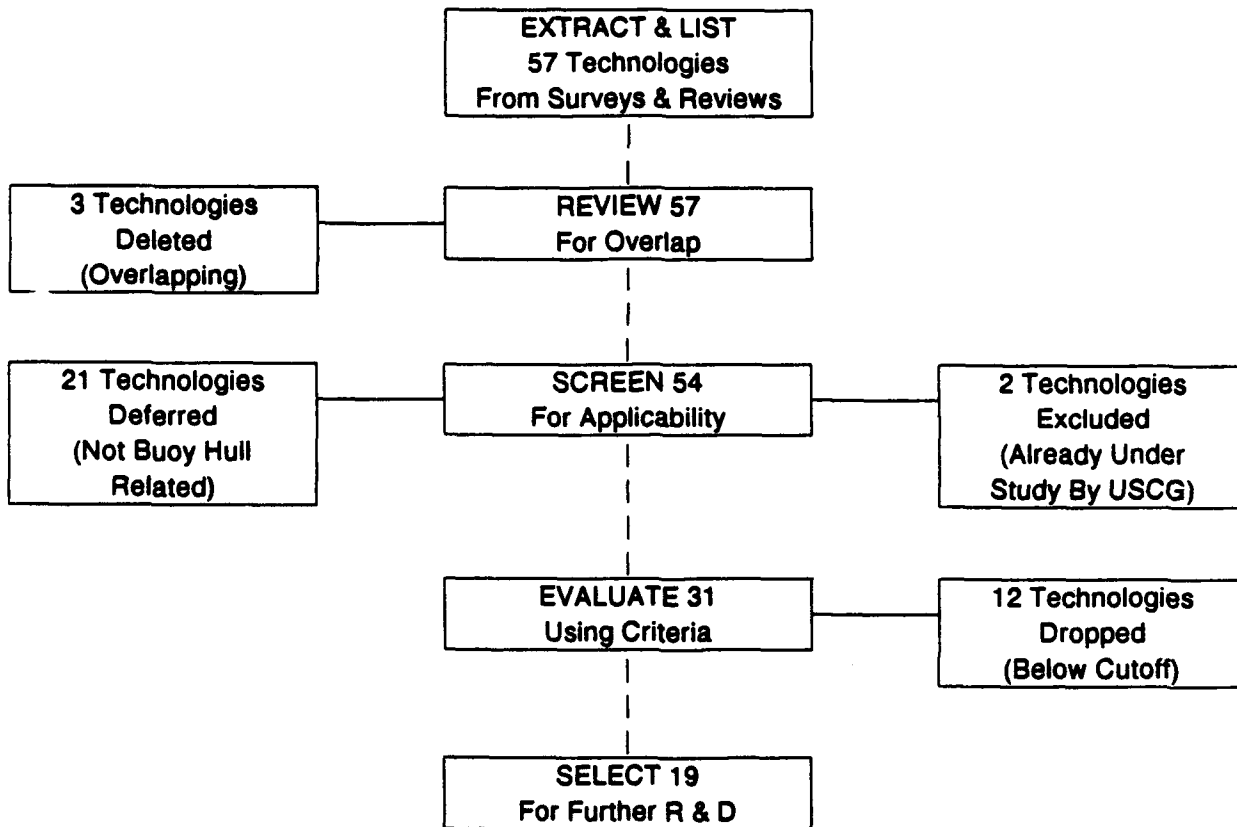
#### RATIONALE

The U.S. Coast Guard has not yet been able to develop a survivable, low cost, lightweight buoy for fast water environments, capable of shedding debris. The debris shedding capability of the current spherical USCG buoys is considered poor however, it was chosen primarily for its ability to recover from a capsize. Where debris is a problem the USCG uses small foam-filled steel buoys that are considered throw-aways as they are usually damaged and/or lost.

#### APPROACH

Research in detail past USCG projects and foreign authority/commercial manufacturer literature on the subject of fastwater buoys and debris shedding. Identify the properties that make for good fast water and/or debris shedding buoy design. Design a new buoy system(s) to address the problems of fast water survivability and debris shedding. Study the advantages/ disadvantages of existing USCG and foreign river buoy designs including the following:

- Gilman's Log Shedding Foam Buoy
- Gilman's River Buoy Design for Canada
- Germany's Steel/Foam Inland Waterways Buoy
- Japan's (Zeni Lite) Large Fast Water Discus Buoy
- Boat Hull For High Currents
- India's Catamaran River Buoy
- Canada's (JANKO) Fast Water Buoy



**FIGURE 10 Evaluation and Selection Process for Buoy Technologies**

### 3. DEVELOPMENT OF CRITERIA FOR EVALUATION

For use as a tool in evaluating various candidate technologies, a set of criteria was developed to determine which technologies show promise for improving the ATON Buoys and therefore warrant further development efforts by the USCG. Improvements in operational effectiveness, cost effectiveness, and handling safety were specified by the USCG to be included as factors in establishing the evaluation criteria. Drawing from the insight afforded by the USCG personnel and foreign national navigation authorities as well as US and foreign buoy manufacturers and designers interviewed during Task A and Task B efforts, the factors to be included in the considerations for evaluation criteria were expanded into following categories:

- o Operational Effectiveness
- o Servicing and Handling
- o Logistics
- o Miscellaneous Factors
- o Special Functions
- o Economic Impact

Within each of the above specific categories, applicable criteria were listed which were deemed useful and practical for grading of technologies for the category in question. As an example, for the "Operational Effectiveness" category, the following characteristics of the buoy were listed as important criteria for judging its operational effectiveness:

- o Effectiveness as a Daytime Visual Aid: This criterion includes consideration of the buoy's stability and motions as they impact its effectiveness as a visual aid to mariners.
- o Effectiveness as a Radar Target: This criterion is useful in evaluating the impact of a candidate technology on the performance of a buoy as a radar target.
- o Survivability in Collisions: Since a great number of buoys are being lost due to collisions, any improvements in their survivability in collisions is clearly an important criterion in determining operational effectiveness.
- o Payload Support/Flexibility: This criterion can be used in evaluating the impact of a candidate technology on providing support to the payload equipment installed on buoys and the flexibility in allowing the installation of different (larger or heavier) payload elements.
- o Position Keeping/Watch Circle: This criterion will enable individual graders to judge the impact of a candidate technology on the operational effectiveness of a buoy in terms of its position keeping performance and increased or decreased watch circle.

- **Reliability:** The longer a buoy remains in position while functioning properly, the better its operational effectiveness. Accordingly, this criterion will give the graders a tool for evaluating the impact of candidate technologies on the degree of reliability a buoy will provide in terms of the maintenance-free periods it remains on site.

Table IV lists the criteria established for all of the remaining categories of evaluation. It also lists, on the extreme right hand column, the measure of merit for each criterion in each category which can be used by the individual graders in judging the impact of the specific technology.

With the objective of establishing the overall impact of a specific technology on all categories of evaluation, a weighting system was developed to account for the relative importance of individual criteria within each category and of individual categories comprising the whole system. As an example, again for the "Operational Effectiveness" category, following weight factors were assigned to the criteria:

Effectiveness as Visual Aid:	8
Effectiveness as Radar Target:	3
Survivability in Collisions:	4
Payload Support/Flexibility:	2
Position Keeping/Watch Circle:	3
Reliability:	5
<b>Total</b>	<b>25</b>

The weight factors assigned to the criteria in other evaluation categories are listed under the second left hand column of Table IV. As it can be seen, the total of all weight factors is 100:

Operational Effectiveness:	25
Servicing and Handling:	15
Logistics:	10
Miscellaneous Factors:	10
Special Functions:	20
Economic Impact:	20
<b>Total</b>	<b>100</b>

The weight factors are used in reflecting the relative importance of grades given by individual reviewers to each criterion under the categories. The reviewers' grades are multiplied by the weight factors to obtain points which are then added up to obtain total point scores for use in the evaluation of candidate technologies.

The development of evaluation criteria, their categorization, and the determination of weight factors and measures of merit have all been accomplished in an interactive process wherein they were submitted to and comments received from the USCG HQ and R&DC on specific items and these comments were incorporated into the final version of the evaluation criteria given in Table IV.

TABLE IV: EVALUATION CRITERIA

EVALUATION CRITERIA FOR BUOY TECHNOLOGY NO. \_\_\_\_\_

CRITERION	WEIGHT FACTOR (0) TO (100)	GRADE (-5) TO (+5)	POINTS	MEASURE OF MERIT
EFFECTIVENESS AS A DAYTIME VISUAL AID (INCLUDES STABILITY, MOTION, ETC.)	8		AVG.	Improved visual detectability and recognition in daylight.
EFFECTIVENESS AS A RADAR TARGET	3			Increased radar detectability (cross section or range).
SURVIVABILITY IN COLLISIONS	4			Improved damage stability or resistance to damage.
PAYLOAD SUPPORT/FLEXIBILITY	2			Capability to support larger payloads or alternate payloads.
POSITION KEEPING/WATCH CIRCLE	3			Better position keeping/reduced watch circle.
RELIABILITY	5			Improved Mean Time Between Failures.
SUBTOTAL FOR OPERATIONAL EFFECTIVENESS	25			
ACCESS TO COMPONENTS	2			Improved ease of access to buoy and superstructure, signal and payload.
EQUIPMENT/FACILITIES REQUIRED TO HANDLE	2			Ease of handling with minimum or no additional equipment or facilities. Consider weight size and appendages.
SAFETY IN SERVICING (MOTION, HANDLING)	6			Decreased probability of danger to personnel during servicing and maintenance. Consider weight, size and appendages.
MAINTENANCE FREQUENCY AND RELIEF CYCLE	3			Reduced number of visits and increased relief cycle. The impact of the mooring system is most important.
NUMBER OF SERVICING PERSONNEL REQUIRED	1			Possibility of servicing buoy with smaller number of persons.
PERSONNEL SKILL LEVEL REQUIRED	1			No increase in skill levels compared to conventional buoys
SUBTOTAL FOR SERVICING & HANDLING	15			
AVAILABILITY OF THE TECHNOLOGY	2			Technology readily available from a large number of sources.
SIMPLICITY OF CONSTRUCTION & IMPLEMENTATION	2			Ease of incorporating the technology to existing or new buoys.
EXTENT OF APPLICATION	2			Incorporation of technology impacts a large number of buoys.
TIME FRAME TO IMPLEMENT	2			Possibility of implementing the technology within a shorter period. Short, 1 year or less; Moderate, 1-5 years; Long, more than 5 years.
COMPATIBILITY WITH BUOY TENDERS	2			Appropriate existing buoy tenders (large, medium, and small) can handle a buoy with this technology.
SUBTOTAL FOR LOGISTICS	10			

TABLE IV: continued

EVALUATION CRITERIA FOR BUOY TECHNOLOGY NO. \_\_\_\_\_ CONTINUED.

CRITERION	WEIGHT FACTOR (0) TO (100)	GRADE (-5) TO (+5)		POINTS	MEASURE OF MERIT
RESISTANCE TO VANDALISM AND/OR THEFT	2		AVG.		Decreased vulnerability to vandalism and theft.
USER ACCEPTANCE	5				Readily and widely acceptable to users of the buoy. Determined from responses of Task A interviews.
IMPACT ON NUMBER OF AIDS REQUIRED IN THE OVERALL SRA SYSTEM	3				Deployment of buoys with this technology decreases the total number of aids in the SRA system.
SUBTOTAL FOR MISCELLANEOUS	10				
EFFECTIVENESS AS A LIGHTED BUOY	4				Improved detectability of buoy light. For instance, reduced buoy motion.
EFFECTIVENESS AS A SOUND SIGNAL	2				Increased audible range of sound signal through motion characteristics.
EFFECTIVENESS IN ICE CONDITIONS	3				Increased resistance to damage due to ice. Also, resistance to knockdown by ice.
EFFECTIVENESS IN FASTWATER CONDITIONS	2				Improved capability to maintain position and minimum heel in fastwater environment.
EFFECTIVENESS IN RIVER CONDITIONS (DEBRIS, COLLISION, ETC.)	2				Decreased probability of damage from debris and collisions with ships/boats. Ability to shed debris and maintain position.
EFFECTIVENESS IN EXPOSED LOCATIONS	3				Improved performance under severe weather environments in exposed location buoys.
DEPTH AND CURRENTS FOR BUOYANT BEACONS	4				Increased depths and currents at which the buoy can be deployed.
SUBTOTAL FOR SPECIAL FUNCTIONS	20				
COST TO DESIGN & TEST	2				Minimum cost to complete design and testing for acceptance of technology.
COST TO MANUFACTURE & IMPLEMENT	2				Low cost to accomplish technology and redeploy. Includes cost of disposal.
ANNUALIZED CAPITAL COST	6				Incorporation of technology decreases the Annualized Capital Cost.
ANNUAL OPERATING AND MAINTENANCE COST	10				Incorporation of technology decreases the Operating and Maintenance Costs.
SUBTOTAL FOR ECONOMIC IMPACT	20				
TOTAL SCORE FOR TECHNOLOGY	100				

#### 4. EVALUATION OF TECHNOLOGIES

##### 4.1 Technology Background for Evaluations

For each of the 31 candidate technologies, brief qualifying statements entitled "Technology Background for Evaluations (TBE)" were prepared. The TBE's address the buoy technologies that have been deemed to directly affect the buoy body and superstructure and are therefore to be further studied as part of the Buoy Technology Survey Project.

The TBE statements are intended to provide pertinent information for the evaluation of technologies to:

1) describe the applicability and impact of the technology in terms of the Evaluation Criteria.

2) assure that all individuals conducting evaluations of the technologies are considering the impact of the technology on the same basis.

The TBE's are divided into three sections:

- o Area of Applicability
- o Components Replaced
- o Impact

The first two are intended to identify the extent and nature of the applicability. The last addresses the specific Evaluation Criteria that are affected. When criteria are not mentioned it has been deemed that they are not affected by the technology under consideration.

A sample TBE is given in Table V for candidate technology No. 4.1 "Debris Shedding Buoy Hulls". Complete TBE's for all candidate technologies are included in Appendix B. Along with the TBE's, Appendix B also contains the one page statements of "Rationale and Approach" which preceded the TBE's and which were used in the initial screening of technologies.

##### 4.2 Grading of Technologies

The evaluation of candidate technologies was accomplished by three individuals following the background and guidelines contained in the TBE's. The system used in grading was as follows:

- o If it is deemed that a candidate technology greatly improves the measure of merit for the specific criterion, a grade of up to (+5) was assigned to the criterion.



**TABLE V: SAMPLE  
TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            4        RIVER BUOYS  
**TECHNOLOGY NO.**        4.1     DEBRIS SHEDDING BUOY HULLS

**A. AREA OF APPLICABILITY**

All USCG river buoys.

**B. COMPONENTS REPLACED**

The entire buoy.

**C. IMPACT**

**C. 1 Operational Effectiveness**

- As debris accumulation can completely neutralize a buoy, an improvement would increase effectiveness as a daytime visual aid and as a radar target.
- Improved debris shedding would increase survivability, position keeping and reliability.

**C. 2 Servicing and Handling**

- Access would be improved as buoys would be upright and floating properly more often. Handling safety would be improved as well.
- Maintenance frequency would be reduced as a result of reductions in debris accumulation.

**C. 3 Logistics**

- There are a number of off the shelf buoys touted as having demonstrated debris shedding capability, however, the best technology which allows this to be accomplished has not been identified.

### TABLE V: continued

- It is anticipated that a short R & D study can be conducted to identify the technology and prepare a prototype design. If this should prove effective, production could begin in a moderate time frame.
- The principal difference between the new and existing river buoy types would be a modification of the buoy hull within current geometric boundaries and probably a re-positioning of the mooring attachment. Accordingly the buoy would be similar to existing types and be adaptable to the system in all respects.

#### C. 4 Economic Impact

- Cost to design and test is expected to be minimal for a new buoy design.
- Cost to manufacture and implement is expected to be identical to current buoys and the capital cost is expected to be nearly identical as well.
- Annual operating and maintenance costs are expected to be significantly reduced as fewer buoys will be required to replace lost buoys and fewer tender trips will be required to replace lost buoys and clear debris from other buoys.

#### C. 5 Miscellaneous

- As these buoys will be similar to existing types the user acceptance should be automatic.
- The USCG currently loses more river buoys than any other types. Accordingly, a significant inventory of the buoys must be maintained. This could be reduced by a buoy better able to survive.

#### C. 6 Special Functions

- Effectiveness in fastwater conditions is expected to increase significantly.
- Effectiveness in river conditions is expected to increase significantly.

- If the measure of merit remains unchanged, i.e. is not affected, a grade of (0) was assigned.
- If the application of candidate technology adversely affects the measure of merit, a negative grade was given; the most adverse effect, i.e. a great reduction in the measure of merit, was given a grade of up to (-5).

The grading process was continued in this manner. The grades given by individual reviewers to each criterion within each category were averaged, rounded out to the nearest whole number, and then multiplied by the respective weight factors shown in Table IV to obtain the point scores for use in the evaluation.

By summing the point scores for the criteria under each category, the subtotals were obtained as well as the total points for all categories. A sample evaluation form showing the grades assigned by the three reviewers, the average point scores for criteria, categories, and the total evaluation score is given in Table VI. This form was used for the evaluation of candidate technology No. 4.1 "Debris Shedding Buoy Hulls". The subtotal point scores for the categories for this technology are:

Operational Effectiveness:	107
Servicing and Handling:	31
Logistics:	34
Miscellaneous Factors:	40
Special Functions:	32
Economic Impact:	86
<b>Total Evaluation</b>	<b>330</b>

Evaluations of all other undeferred candidate technologies in Table II of Section 2.0 were completed in the same manner. Table VII lists the total point scores obtained for all candidate technologies.

#### 4.3 Selection of Promising Technologies

The selection of candidate technologies should be performed in such a way that:

- Detrimental technologies are summarily eliminated.
- Those technologies that receive low point scores but are relatively important and may be easily accomplished within a small budget are reconsidered.
- Only truly promising and not marginal technologies are retained.

TABLE VI: SAMPLE EVALUATION

EVALUATION CRITERIA FOR BUOY TECHNOLOGY NO. 4.1 DEBRIS SHEDDING BUOY HULLS.

CRITERION	WEIGHT FACTOR (0) TO (100)	GRADE (-5) TO (+5)		POINTS	MEASURE OF MERIT
EFFECTIVENESS AS A DAYTIME VISUAL AID (INCLUDES STABILITY, MOTION, ETC.)	8	5 4 3	AVG. 5	40	Improved visual detectability and recognition in daylight.
EFFECTIVENESS AS A RADAR TARGET	3	5 5 5	5	15	Increased radar detectability (cross section or range).
SURVIVABILITY IN COLLISIONS	4	5 5 4	5	20	Improved damage stability or resistance to damage.
PAYLOAD SUPPORT/FLEXIBILITY	2	0	0	0	Capability to support larger payloads or alternate payloads.
POSITION KEEPING/WATCH CIRCLE	3	5 4 3	4	12	Better position keeping/reduced watch circle.
RELIABILITY	5	4 4 2	4	20	Improved Mean Time Between Failures.
SUBTOTAL FOR OPERATIONAL EFFECTIVENESS	25			107	
ACCESS TO COMPONENTS	2	1 2 1	1	2	Improved ease of access to buoy and superstructure, signal and payload.
EQUIPMENT/FACILITIES REQUIRED TO HANDLE	2	0	0	0	Ease of handling with minimum or no additional equipment or facilities. Consider weight size and appendages.
SAFETY IN SERVICING (MOTION, HANDLING)	6	4 3 3	3	18	Decreased probability of danger to personnel during servicing and maintenance. Consider weight, size and appendages.
MAINTENANCE FREQUENCY AND RELIEF CYCLE	3	3 3 4	3	9	Reduced number of visits and increased relief cycle. The impact of the mooring system is most important.
NUMBER OF SERVICING PERSONNEL REQUIRED	1	2 3 2	2	2	Possibility of servicing buoy with smaller number of persons.
PERSONNEL SKILL LEVEL REQUIRED	1	0	0	0	No increase in skill levels compared to conventional buoys
SUBTOTAL FOR SERVICING & HANDLING	15			31	
AVAILABILITY OF THE TECHNOLOGY	2	2 3 2	2	4	Technology readily available from a large number of sources.
SIMPLICITY OF CONSTRUCTION & IMPLEMENTATION	2	3 2 2	2	4	Ease of incorporating the technology to existing or new buoys.
EXTENT OF APPLICATION	2	5 5 5	5	10	Incorporation of technology impacts a large number of buoys.
TIME FRAME TO IMPLEMENT	2	3 3 2	3	6	Possibility of implementing the technology within a shorter period. Short, 1 year or less; Moderate, 1-5 years; Long, more than 5 years.
COMPATIBILITY WITH BUOY TENDERS	2	5 5 5	5	10	Appropriate existing buoy tenders (large, medium, and small) can handle a buoy with this technology.
SUBTOTAL FOR LOGISTICS	10			34	

TABLE VI: continued

EVALUATION CRITERIA FOR BUOY TECHNOLOGY NO. 4.1 CONTINUED.

CRITERION	WEIGHT FACTOR (0) TO (100)	GRADE (-5) TO (+5)		POINTS	MEASURE OF MERIT
			AVG.		
RESISTANCE TO VANDALISM AND/OR THEFT	2	0	0	0	Decreased vulnerability to vandalism and theft.
USER ACCEPTANCE	5	5 5 5	5	25	Readily and widely acceptable to users of the buoy. Determined from responses of Task A interviews.
IMPACT ON NUMBER OF AIDS REQUIRED IN THE OVERALL SRA SYSTEM	3	5 5 5	5	15	Deployment of buoys with this technology decreases the total number of aids in the SRA system.
SUBTOTAL FOR MISCELLANEOUS	10			40	
EFFECTIVENESS AS A LIGHTED BUOY	4	3 4 4	4	16	Improved detectability of buoy light. For instance, reduced buoy motion.
EFFECTIVENESS AS A SOUND SIGNAL	2	0	0	0	Increased audible range of sound signal through motion characteristics.
EFFECTIVENESS IN ICE CONDITIONS	3	0	0	0	Increased resistance to damage due to ice. Also, resistance to knockdown by ice.
EFFECTIVENESS IN FASTWATER CONDITIONS	2	4 4 4	4	8	Improved capability to maintain position and minimum heel in fastwater environment.
EFFECTIVENESS IN RIVER CONDITIONS (DEBRIS, COLLISION, ETC.)	2	4 5 4	4	8	Decreased probability of damage from debris and collisions with ships/boats. Ability to shed debris and maintain position.
EFFECTIVENESS IN EXPOSED LOCATIONS	3	0	0	0	Improved performance under severe weather environments in exposed location buoys.
DEPTH AND CURRENTS FOR BUOYANT BEACONS	4	0	0	0	Increased depths and currents at which the buoy can be deployed.
SUBTOTAL FOR SPECIAL FUNCTIONS	20			32	
COST TO DESIGN & TEST	2	4 5 3	4	8	Minimum cost to complete design and testing for acceptance of technology.
COST TO MANUFACTURE & IMPLEMENT	2	4 4 5	4	8	Low cost to accomplish technology and redeploy. Include cost of disposal.
ANNUALIZED CAPITAL COST	6	5 5 5	5	30	Incorporation of technology decreases the Annualized Capital Cost.
ANNUAL OPERATING AND MAINTENANCE COST	10	4 3 3	4	40	Incorporation of technology decreases the Operating and Maintenance Costs.
SUBTOTAL FOR ECONOMIC IMPACT	20			86	
TOTAL SCORE FOR TECHNOLOGY	100			330	

These aims were accomplished in the following manner:

- o All technologies with negative points were eliminated from further consideration.
- o An average point score level was computed.
- o All technologies which have point scores less than the average were dropped with the exception of the following four technologies which were reconsidered and assigned relative scores:

- Technology No. 1.1 (Slat Frames versus Topmarks) was selected despite its below average score since, if desired by the USCG, it could be accomplished easily and at small cost to enhance the shape significance of existing buoys. The total point score for this technology, on the basis of all evaluation categories, was 52 as shown in Table VII. However, introduction of this technology into buoys would impact only three evaluation categories, i.e. "operational effectiveness", "servicing and handling", and "logistics"; the remaining categories of evaluation criteria would not be affected at all. Consequently, when this technology is evaluated on the basis of three impacted categories, the total point score would still be 52 out of a maximum of 250 rather than a maximum of 500 for all categories, and would be equivalent to a relative score of  $[500/250] \times 52 = 104$  points.

- Technology No. 9.6 (Solid Superstructure instead of Latticework and Topmarks) was also selected despite its below average score since it could dramatically increase the effectiveness of some 3500 cage type buoys in the USCG ATON system. Furthermore, it is closely related to the "Slat Frame" technology noted above, and one or the other of these two technologies would have to be accomplished as a minimum if the IALA daymark recommendations are to be met by the USCG. The total point score for this technology was 102. Since it has no impact on the "Special Functions" category, its relative point score, based on a maximum score of 400, becomes  $[500/400] \times 102 = 128$  points.

- Technology No. 13.3 (Buoy Model Tests) is one that is applicable to all new buoy designs and will reduce the cost of optimizing the design before prototype construction. For this reason, it was selected even though its point score was less than the average. This technology does not impact evaluation criteria in the "operational effectiveness", "servicing/handling", and "miscellaneous" categories. Modifying its total point score of 96 on the basis of the remaining impacted categories, a relative point score of  $[500/250] \times 96 = 192$  is obtained.

- The fourth technology with a point score less than the average was No. 13.6 (Improved Damage Stability by Increased Compartmentation). Allowing for the fact that its introduction will not affect the "Special Functions" category of

evaluation criteria, its total point score of 111 is modified to obtain a relative point score of  $[500/400] \times 111 = 139$ .

Nine other technologies were also of such a nature that their incorporation into buoy designs would not impact one or more of the categories of evaluation criteria. The relative scores for these technologies, computed in the same manner as for the four cited above, were still below the average score of 124, and consequently they were dropped from further consideration.

The relative scores for all such technologies are shown under a separate column in Table VII.

The total of point scores for all 31 technologies is 3838, as shown in Table VII, and the average score rounded out to the nearest integer is 124 points. It was decided to take this as the cut-off point in choosing the promising technologies since it was deemed that with decreasing scores the risk in achieving the expected improvement increases. In other words, any candidate technology with a score equal to or better than the average would most likely introduce the benefits envisioned. Consequently, all those with total points less than 124 would be dropped from further consideration.

The action taken with regard to each technology is shown on the right-hand column of Table VII. As seen, candidates with less than 124 point score have been dropped. Among the selected candidates, a total of 17 technologies have received total scores of 124 or better and with the addition of technologies No. 1.1 and 9.6 cited above, the total number of technologies found to be promising and worthy of further review has become 19.

#### 4.4 Economic Analyses

In support of the recommendations for promising technologies which resulted from the evaluation, economic analyses were conducted for each technology in accordance with NAVFAC P-422 : "Economic Analysis Handbook" (Ref. 6). A "Design Analysis Class" type format was utilized in the computations as follows:

- Discount rate of 10% was used.
- Analyses were based on annual unit costs.
- In accordance with the USCG statement of work, acquisition and maintenance costs of only the navigation aids (buoys) themselves were considered and the costs of servicing platforms were excluded from the analysis.

**TABLE VII: EVALUATION OF TECHNOLOGIES**

<b>Tech. No.</b>	<b>Description</b>	<b>Evaluated Point Score</b>	<b>Relative Point Score</b>	<b>Action</b>
1.1	Slat Covered Frame Superstructure	52	104	Selected
1.2	Reduced Weight of Superstructure	61	68	Dropped
1.3	Battery Pockets and Vent Lines	92	115	Dropped
1.4	Quick Acting Buoy Hatch Covers	55	122	Dropped
1.5	Free Hanging Pieces of Chain in Tail Tube to Reduce Fouling	115		Dropped
2.1	Foam Material for Buoys	205		Selected
2.2	Elastomer Skins for Buoys	141		Selected
2.3	FRP & GRP Materials	166		Selected
2.4	Off-The-Shelf Plastic/Foam Buoys	252		Selected
3.1	Semi-Submersible Hulls	-60		Dropped
3.2	Off-The-Shelf Open Sea Buoys	220		Selected
4.1	Debris Shedding River Buoys	330		Selected
4.2	Gimballed Lanterns	-8		Dropped
4.4	Off-The-Shelf River Buoys	230		Selected
5.1	Compartmented Ice Buoys	171		Selected
5.2	Plastic Spar Buoys for Ice Service	217		Selected
6.1	Buoyant Beacon Mooring Improvements	171		Selected
6.2	Off-The-Shelf Buoyant Beacons	134		Selected
7.1	Inflatable Buoys	36	80	Dropped
8.1	Deck or Superstructure Mounted Battery Boxes	206		Selected
8.3	New Wave Activated Generators	9	11	Dropped
8.4	Seawater Primary Batteries	86	108	Dropped
9.6	Solid Superstructure	102	128	Selected
11.1	Coatings and Preservation Systems	166		Selected
11.2	Fenders on Buoy Hulls	167		Selected
12.1	Modular Buoy Designs	50	111	Dropped
13.1	Systems Approach to Design	137		Selected
13.2	Increased Buoy Motions	69	125	Dropped
13.3	Buoy Model Tests	96	192	Selected
13.4	Effect of Mooring and Payload Weight on Buoy Design	59	74	Dropped
13.6	Improved Damaged Stability by Increased Compartmentation	111	139	Selected

**Total Score: 3838**  
**Average Score: 124**



It was necessary to introduce several assumptions in order to avoid undue and unjustifiable complexities for a "Design Analysis" type undertaking. Those assumptions affecting all technologies were:

- Service life of all buoys, whether constructed of steel or plastic materials, was assumed to be 30 years except for river buoys which were assumed to have a life of 15 years. The rationale for this assumption is as follows:
  1. It has been documented during the Worldwide Buoy Technology Survey that steel buoys do provide well over 30 years of service life.
  2. Plastic, GRP, and foam buoys have not yet had a long enough period to prove their life expectancy. However, European navigation authorities have been using plastic buoys successfully for more than fifteen years. It is foreseen that with proper design and employment of most suitable materials, the service life of these buoys can be extended to 30 years.
  3. For some of the river buoys used by foreign navigation authorities, up to fifteen years of service life has been obtained. For the purposes of this economic analysis, it is assumed that the technology will be successful and the service life of new design USCG river buoys will be extended to 15 years.
- The costs of the current USCG buoyage system were obtained from various published and unpublished USCG reports and articles or other study documents to the best extent possible (References 7, 8, 9). Revised buoy population and cost data was made available by the USCG in Ref. 10. A tabulation was prepared using appropriate data from these compilations to list all sizes of USCG buoys along with their replacement, preparation, annual servicing and 6 year rehabilitation costs for use as a basis for determining the economic impact of selected technologies on the existing USCG system. Table VIII shows this tabulation which includes listings for unit costs (where necessary adjusted to 1989 dollars) as well as total costs for the complete USCG buoy system including spares.
- It was not possible to obtain published cost and distribution data for some classes and sizes of buoys, and these values were estimated by comparison and extrapolation when necessary, and marked on Table VIII with the designation "c".

The analyses for most of the individual technologies were based on the guidelines contained in the previously developed TBE's (see Section 4.1) but it was also necessary to make additional assumptions and/or educated guesses in certain areas in order to simplify the process. Table IX summarizes such additional assumptions or estimates made for each of the 19 technologies. The term "base" as used in this table refers to the existing USCG ATON system

to which the individual technology may be incorporated.

A PC spreadsheet was developed for use in the computations for economic analyses in accordance with the "Economic Analysis Handbook". The spreadsheet requires the following entries as input to the program:

- **Service Life:** The expected service life of the specific type of buoys equipped with the technology in question.
- **Total Number of Buoys:** Number of buoys of the specific type and size that currently exist in the USCG ATON system.
- **R&D Costs:** All costs for non-recurring research and development to prepare concept and detail designs, to test and evaluate, and to prepare procurement specifications for buoys equipped with the technology in question. R&D costs include one-time costs of constructing or purchasing and testing the prototype buoys(s) but excludes the costs of USCG buoy tenders and shore facilities involved in the tests.
- **Investment Costs:** Costs associated with the acquisition of buoys equipped with the technology in question after successful tests with and USCG approval of the prototype buoy excluding costs associated with servicing platforms and shore facilities.
- **Servicing Cost:** Annual cost of servicing the buoy while on station but exclusive of buoy tender costs.
- **6 Year Rehabilitation Cost:** Annualized cost of equipment renewals and repairs to and painting/preservation of buoys at USCG shore facilities once every 6 years.
- **Replacement of Losses:** Annualized cost of replacing buoys which are lost, or damaged beyond repair, with new buoys.
- **Terminal Value:** Estimated value of the buoy at the end of its expected service life reduced by the cost of disposal.

The entries for these inputs were made for newly constructed or modified buoys equipped with the technology in question as well as for the existing USCG buoys. The program computes the economic analyses and outputs the following results:

- **Total Non-Recurring Cost:** Sum of R&D and investment costs.

- Total Recurring Cost: Sum of annualized servicing, 6 year rehabilitation, and replacement of losses costs.
- Discount Factor: Multiplier for a specific interest rate which translates costs in a future year into its present value.
- Present Value (PV): Present worth of future costs determined by applying discount procedures given in NAVFAC P-442.
- PV of Recurring Life Cycle Cost: Calculation of annualized recurring costs multiplied by its discount factor and summed over all years of the service life.
- Discounted Total Life Cycle Cost: Sum of total non-recurring costs and present value of recurring life cycle costs.
- Net Total Discounted Cost: Discounted total life cycle cost reduced by the discounted terminal value.

A sample economic analysis is shown in Table X for the "Debris Shedding Buoy Hulls" technology. The economic analyses for all promising technologies are included in Appendix C and the overall results of all 19 economic analyses are summarized in Table XI.

**TABLE VIII: COSTS OF CURRENT USCG BUOY SYSTEM**

CPI, 1986\$ to 1989\$: 1.0995

BUOY TYPE	No. of Stations	Spares	Total No. of Buoys	CAPITAL COST		PREPARATION COST			
				Unit 1986	Unit 1989	Unit 1986	Unit 1989	Total 1989	
<b>Lighted</b>									
9 ft.	111	33	144	c.	\$21,990	\$3,166,526	\$1,700	\$1,869	\$207,473
8 ft.	1643	296	1939		\$15,176	\$32,353,828	\$1,165	\$1,281	\$2,104,525
7 ft.	606	344	950		\$12,960	\$13,536,898	\$949	\$1,043	\$632,309
6 ft.	1091	153	1244		\$11,407	\$15,602,075	\$872	\$959	\$1,046,000
5 ft.	771	124	895		\$8,827	\$8,686,138	\$330	\$363	\$279,743
3 1/2 ft.	267	49	316		\$7,462	\$2,592,584	\$152	\$167	\$44,622
Discrepancy (TRB)	(TRB)	350	350		\$750	\$262,500	\$0	\$0	\$0
<b>Subtotal Lighted</b>	<b>4489</b>	<b>1349</b>	<b>5838</b>			<b>\$76,200,550</b>			<b>\$4,314,672</b>
<b>Unlighted</b>									
9x20 R	168	26	194		\$11,000	\$2,134,000	c.	\$1,400	\$235,200
1st Class	299	86	385		\$9,983	\$3,843,455		\$627	\$187,473
2nd Class	951	228	1179		\$5,531	\$6,521,049		\$270	\$256,770
3rd Class	2102	397	2499		\$3,098	\$7,741,902		\$171	\$359,442
3rd Class Ice	621	492	1113		\$3,098	\$3,448,074		\$171	\$106,191
4th Class	10816	2163	12979		\$300	\$3,893,760		\$0	\$0
5th Class	1116	223	1339		\$300	\$401,760		\$0	\$0
5th Class Ice	910	182	1092		\$1,000	\$1,092,000		\$0	\$0
5th Class Plastic	(TRB)	721	721		\$300	\$216,300		\$0	\$0
5th Class Foam	182	36	218		\$1,000	\$218,400		\$0	\$0
6th Class	11631	2326	13957		\$130	\$1,814,436		\$0	\$0
6th Class Plastic	(TRB)	870	870		\$150	\$130,500		\$0	\$0
6th Class Foam	21	4	25		\$500	\$12,600		\$0	\$0
<b>Subtotal Unlighted</b>	<b>28,649</b>	<b>7,729</b>	<b>36,378</b>			<b>\$29,334,236</b>			<b>\$909,876</b>
<b>TOTAL</b>	<b>33,138</b>	<b>9,078</b>	<b>42,216</b>			<b>\$105,534,786</b>			<b>\$5,224,548</b>

Notes: 1. "c." indicates value is estimated. 2. TRB = Temporary Replacement Buoy

**TABLE VIII, Cont.: COSTS OF CURRENT USCG BUOY SYSTEM**

BUOY TYPE	ANNUAL SERVICING COST				6 YEAR REHABILITATION				TERMINAL VALUE			
	Unit		Total	1989	Unit	S-hr	Reqd.	Unit	Annualized Cost	Weight	Unit	Total
	1986	1989	1989						Lbs.	Terminal Value	Terminal Value	Terminal Value
<b>L ight e d</b>												
9 ft.	c.	\$1,250	\$1,374	\$152,554	c.	200		\$1,667	\$185,000	18,222	\$244	\$35,141
8 ft.		\$1,104	\$1,214	\$1,994,331		154		\$1,283	\$2,108,517	11,757	\$157	\$305,302
7 ft.		\$972	\$1,069	\$647,634	c.	130		\$1,023	\$656,500	7,810	\$105	\$99,368
6 ft.		\$900	\$990	\$1,079,587	c.	115		\$958	\$1,045,542	6,023	\$81	\$100,347
5 ft.		\$720	\$792	\$610,348	c.	90		\$750	\$578,250	3,004	\$40	\$36,008
3 1/2 ft.		\$660	\$726	\$193,752	c.	75		\$625	\$166,875	1,487	\$20	\$6,293
Discrepancy		\$0	\$0	\$0				\$0	\$0		\$0	\$0
<b>Subtotal Lighted</b>				<b>\$4,678,206</b>					<b>\$4,740,683</b>			<b>\$582,460</b>
<b>U n l i g h t e d</b>												
9x20 R	c.	\$1,000	\$1,000	\$168,000	c.	100		\$833	\$140,000	17,000	\$228	\$44,170
1st Class		\$540	\$540	\$161,460	c.	55		\$458	\$137,042	5,500	\$74	\$28,359
2nd Class		\$312	\$312	\$296,712	c.	40		\$333	\$317,000	2,650	\$35	\$41,844
3rd Class		\$192	\$192	\$403,584	c.	28		\$233	\$490,467	950	\$13	\$31,795
3rd Class Ice		\$192	\$192	\$119,232	c.	28		\$233	\$144,900	950	\$13	\$14,161
4th Class		\$72	\$72	\$778,752				\$0	\$0	468	\$6	\$81,265
5th Class		\$72	\$72	\$80,352				\$0	\$0		\$0	\$0
5th Class Ice		\$72	\$72	\$65,520				\$0	\$0		\$0	\$0
5th Class Plastic		\$72	\$72	\$0				\$0	\$0		\$0	\$0
5th Class Foam		\$72	\$72	\$13,104				\$0	\$0		\$0	\$0
6th Class		\$72	\$72	\$837,432				\$0	\$0		\$0	\$0
6th Class Plastic		\$72	\$72	\$0				\$0	\$0		\$0	\$0
6th Class Foam		\$72	\$72	\$1,512				\$0	\$0		\$0	\$0
<b>Subtotal Unlighted</b>				<b>\$2,757,660</b>					<b>\$1,089,408</b>			<b>\$197,424</b>
<b>TOTAL</b>				<b>\$7,435,866</b>					<b>\$5,830,092</b>			<b>\$779,884</b>

Notes: 1. "c." indicates value is estimated.

TABLE IX: ASSUMPTIONS FOR EVALUATION  
OF CANDIDATE TECHNOLOGIES

TECH. NO.	TECHNOLOGY DESCRIPTION	INVESTMENT	ANNUAL SERVICING	6 YEAR REHABILITATION	ANNUAL LOSSES	TERMINAL VALUE	OTHER ASSUMPTIONS
1.1	Slat Covered Frame Superstructure vs. Topmarks, for Lighted Buoys	\$500 per buoy. \$400 per buoy.	105% of base.	Same as base.	10% of Investment. 20% of investment.	nil. nil.	
2.1	Foam Material for Buoys	80% of base for lighted, similar to Gilman for unlighted. Preparation 90% of base.	75% of base.	75% of base.	Same as base: 10%, except river: 35%, and ice: 15%.	\$100 per truckload; (3 buoys)	25% reduction of spares.
2.2	Elastomer Skins for Buoys	110% of base capital cost, same preparation.	85% of base.	85% of base.	Same as base: 10%, except river: 30%, and ice: 15%.	Same as base.	10% reduction of spares.
2.3	FRP & GRP Materials	70% of base for lighted, 100% to 120% for unlighted. Preparation 90% of base.	85% of base.	85% of base.	Same as base: 10%, except river: 55%, and ice: 20%.	\$100 per truckload; (3 buoys)	
2.4	Off-The-Shelf Plastic/Foam Buoys	80% of base for lighted, similar to Gilman for unlighted. Preparation 90% of base.	75% of base.	75% of base.	Same as base: 10%, except river: 35%, and ice: 15%.	\$100 per truckload; (3 buoys)	25% reduction of spares.
3.2	Off-The-Shelf Open Sea Buoys	Same as base.	90% of base.	85% of base.	Same as base: 10%.	Same as base.	8' & 9' buoys.
4.1	Debris Shedding Buoy	\$635 / buoy vs. \$577 / base buoy,	75% of base.	25% of new buoys remain.	20% of Investment vs. 70% of base Investment.	Same as base, nil.	64% reduction of spares.
4.4	Off-The-Shelf River Buoys	Same as base.	75% of base.	20% of new buoys remain.	30% of investment vs. 70% of base Investment.	Same as base, nil.	50% reduction of spares.
5.1	Compartmented Ice Buoys	115% of base capital cost, same preparation.	90% of base.	Same as base.	15% of Investment vs. 25% of base Investment.	Same as base.	

**TABLE IX, Cont.: ASSUMPTIONS FOR EVALUATION  
OF CANDIDATE TECHNOLOGIES**

TECH. NO.	TECHNOLOGY DESCRIPTION	INVESTMENT	ANNUAL SERVICING	6 YEAR REHABILITATION	ANNUAL LOSSES	TERMINAL VALUE	OTHER ASSUMPTIONS
5.2	Plastic Spar Buoys for ice service	Capital cost from KWH, 60% of base preparation.	50% of base.	50% of base.	15% of investment vs. 25% of base investment.	nil.	
6.1	Buoyant Beacon Mooring Improvements	Same as base.	60% of base.	60% of base.	Same as base, 10% of investment.	Same as base.	All but 8' & 9' & river buoys.
6.2	Off-The-Shelf Buoyant Beacons	Same as base.	60% of base.	60% of base.	Same as base, 10% of investment.	Same as base.	All but 8' & 9' & river buoys.
8.1	Deck or Superstructure Mounted Battery Boxes	90% of base capital cost, same preparation.	50% of base.	90% of base.	Same as base, 10% of investment.	Same as base.	All lighted buoys.
9.6	Solid Superstructure	115% of base capital cost, same preparation.	90% of base.	90% of base.	10% of investment.	Same as base.	All lighted cage superstructure buoys.
11.1	Coatings and Preservation Systems	105% of base capital cost, same preparation.	80% of base.	80% of base.	Same as base, 10% of investment.	Same as base.	
11.2	Fenders on Buoy Hull	+\$2500/buoy for large to +\$800/buoy for small buoys.	80% of base.	75% of base.	6% of investment vs. 10% of base investment.	Same as base.	
13.1	Systems Approach to Design	90% of base capital cost, same preparation.	75% of base.	70% of base.	Same as base, 10% of investment.	Same as base.	
13.3	Buoy Model Tests	Same as base.	85% of base.	85% of base.	Same as base: 10%.	Same as base.	
13.6	Improved Damaged Stability By Increased Compartmentation	115% of base capital cost, same preparation.	90% of base.	90% of base.	4% of investment vs. 10% of base investment.	Same as base.	

**TABLE XI: CANDIDATE TECHNOLOGIES  
SUMMARY OF NET TOTAL DISCOUNTED COSTS**

<b>TECH. NO.</b>	<b>TECHNOLOGY DESCRIPTION</b>	<b>NEW CONSTRUCTION BUOYS (\$K)</b>	<b>EXISTING BUOYS (\$K)</b>	<b>NET TOTAL BENEFIT (\$K)</b>
1.1	Slat Covered Frame Superstructure	99,911	98,703	(1,208)
2.1	Foam Material for Buoys	362,875	380,675	17,800
2.2	Elastomer Skins for Buoys	351,425	380,675	29,250
2.3	FRP & GRP Materials	317,547	380,675	63,128
2.4	Off-The-Shelf Plastic/Foam Buoys	362,573	380,675	18,102
3.2	Off-The-Shelf Open Sea Buoys	110,121	115,239	5,118
4.1	Debris Shedding Buoy	31,888	43,248	11,360
4.4	Off-The-Shelf River Buoys	23,801	43,248	19,447
5.1	Compartmented Ice Buoys	22,564	27,020	4,456
5.2	Plastic Spar Buoys for Ice Service	5,934	27,020	21,086
6.1	Buoyant Beacon Mooring Improvements	151,039	175,524	24,484
6.2	Off-The-Shelf Buoyant Beacons	151,074	175,524	24,449
8.1	Deck or Superstructure Mounted Battery Boxes	203,938	245,174	41,236
9.6	Solid Superstructure	209,488	198,415	(11,072)
11.1	Coatings and Preservation Systems	325,673	340,184	14,510
11.2	Fenders on Buoy Hull	333,819	338,923	5,104
13.1	Systems Approach to Design	285,910	340,184	54,273
13.3	Buoy Model Tests	321,790	340,184	18,394
13.6	Improved Damaged Stability By Increased Compartmentation	261,410	310,555	49,145



## 5. TECHNOLOGY RESEARCH AND DEVELOPMENT

### 5.1 General

The USCG has prepared a draft Statement of Work (SOW, Ref.4) for the "New Buoy Systems (NBS) Development Project". The requirements of the current study include the preparation of "Technology Development Plans (TDP)" for the recommended technologies consistent with this approach. It is the intent of the USCG to review these plans and select those technologies that have significant potential for enhancing its ATON buoys. These will then be implemented within the framework of the NBS SOW.

### 5.2 Technology Development Plans

Accordingly, the Technology Development Plans have been developed following the guidelines of the draft SOW. The plans are divided into the following phases and tasks:

- Phase I: Requirements, Design and Test Plan - This phase of the technology development program encompasses the development of prototype designs or procedures and the test plans for them.
  - Task A: Requirements Definition - Generation of a set of design requirements to be met by the prototype hardware or procedure.
  - Task B: Prototype Design - Preparation of a detailed design for the developmental hardware or procedure.
  - Task C: Test Plan Preparation - Preparation of a detailed test plan for each item selected for development intended to quantitatively determine the prototype's performance compared to its requirements as identified in Task A.
- Phase II: Prototype Fabrication, Test and Evaluation - This phase of the technology development program encompasses the prototype construction, testing and evaluation efforts for the hardware or procedure.
  - Task D: Prototype Fabrication - Fabrication of the selected prototype hardware or procedural model in accordance with the design development in Task B.
  - Task E: Test and Evaluation - Conduct of the testing and evaluation of the prototype hardware or procedural model as specified in the approved test plan developed in Task C.

- Task F: Procurement Specification Development - Development of a specification package for each prototype item and preparation of a cost estimate and schedule for production units.

A sample TDP developed for the "Debris Shedding Buoy Hulls" is shown in Table XII in its entirety. As seen it includes sections on:

- o Background
- o Scope
- o Applicable Documents
- o Requirements
- o Reporting
- o Government Furnished Information/Equipment/Material

The "Background" section contains an introduction to the development plan and summarizes the reasons for the need to investigate this technology.

The "Scope" briefly states the objective of the development and summarizes the major requirements.

The "Applicable Documents", "Reporting", and "GFI/GFE/GFM" sections are essentially the same for all technologies with only very minor changes.

The "Requirements" section describes in detail the work to be accomplished in each task of the two phases of development.

The complete Technology Development Plans (TDP) are intended for Coast Guard internal use only, and are not included in this document.

### 5.3 Cost Estimates

Cost estimates have been prepared for the execution of the TDPs for the nineteen candidate technologies discussed in Section 5.2. The approach adopted for the preparation of cost estimates is as follows:

- o The labor staff-hours necessary for each task of the development plan are estimated but no labor rates are applied.
- o When the development plan requires several buoys to be designed, fabricated, tested and evaluated, only the per buoy labor staff-hours and direct costs are estimated. These per buoy costs can be multiplied with the number of buoys to be specified by the USCG after a decision is made to implement the specific technology.

A sample cost estimate is given in Table XIII for the recommended technology "Debris Shedding Buoy Hulls". For this candidate, as for some other technologies, it was not possible to estimate a total number of staff-hours of labor nor a total dollar value for direct costs since the totals would depend on the number of buoy sizes or classes to be specified by the USCG at the time of decision. Accordingly, only the "Requirements Definition" task is applicable to all buoys and all other staff-hours and costs are per buoy.

## TABLE XII: SAMPLE "TECHNOLOGY DEVELOPMENT PLAN"

### TECHNOLOGY DEVELOPMENT PLAN #4.1 DEBRIS SHEDDING RIVER BUOY HULLS

#### 1. BACKGROUND

The U.S. Coast Guard needs a survivable, low cost, lightweight buoy for fast water environments, capable of shedding debris. The debris shedding capability of the current spherical USCG buoy is considered poor; it was chosen primarily for its ability to recover from a capsize. Where debris is a problem the USCG uses small foam-filled steel buoys that are considered throw-aways as they are usually damaged and/or lost.

During the Worldwide Buoy Technology Survey (available Document No. 4), it was found out that several manufacturers in several countries have river buoys on station which are reported to perform well in currents and provide good protection against debris accumulation. Included among these are the following buoys the complete data as well as illustrations for which can be found in the above cited document:

- Gilman's Log Shedding Foam Buoy
- Gilman's River Buoy Design for Canada
- Germany's Steel/Foam Inland Waterways Buoy
- Japan's (Zeni Lite) Large Fast Water Discus Buoy
- Boat Hull For High Currents
- India's Catamaran River Buoy
- Canada's (JANKO) Fast Water Buoy

#### 2. SCOPE

This project will review in detail past USCG projects and foreign authority/commercial manufacturer literature on the subject of fastwater buoys and debris shedding. The properties that make for good fast water and/or debris shedding buoy design will be identified and the requirements for a new design will be developed for approval by the USCG. A new prototype buoy system(s) to address the problems of fast water survivability and debris shedding will be designed.

Prototype hardware will be fabricated for the new design debris shedding buoys(s) and these will be tested in the field and evaluated in accordance with a USCG approved test plan. Cost estimates and procurement specifications will be prepared for the successfully tested buoys.

**TABLE XII: continued**

**3. APPLICABLE DOCUMENTS**

**3.1 PROVIDED DOCUMENTS**

The following documents will be provided by the USCG :

- (1) USCG DOT 1700.18B, Acquisition, Publication and Dissemination of DOT Scientific and Technical Reports, dated 18 March 1976 as amended.
- (2) International Association of Lighthouse Authorities (IALA), Marine Buoyage System, First Edition, dated November 1980.
- (3) Tailoring of Prototype Design Drawings per DOD-D-1000B.
- (4) Tailoring of Production Design Drawings per DOD-D-1000B.

**3.2 AVAILABLE DOCUMENTS**

The following documents are available for review at the USCG Research and Development Center (USCG R&D), Groton, CT:

- (1) USCG G-D-50-78, Buoy Reference Library Index, dated March 1978.
- (2) USCG COMDTINST.M16500.3, Aids to Navigation Manual - Technical.
- (3) USCG COMDTINST.M16500.7, Aids to Navigation Manual - Administration.
- (4) "Buoy Technology Survey: USCG Buoy Development Review", Final Report, October 1990.
- (5) "Buoy Technology Survey: Worldwide Buoy Technology Survey", Final Report, February 1991.
- (6) Buoy Technology Information System (BTIS) Database.
- (7) Worldwide Buoy Authority and Manufacturer data on file.

**3.3 REQUIRED DOCUMENTS**

The following documents are required in the performance of this contract:

**TABLE XII: continued**

- (1) NAVFAC P-442, Economic Analysis Handbook, dated 1986.
- (2) USCG COMDTINST M4121.3, Specification Development Manual.

These documents are available from the Government Printing Office in Washington, D.C.

**4. REQUIREMENTS**

**4.1 REQUIREMENTS, DESIGN AND TEST PLAN**

This phase of the technology development program encompasses the development of the prototype designs and the test plans for these designs. Task A will involve the development of the requirements for the prototype design. Task B is the detailed design of the prototype hardware, and Task C encompasses the development of the test plans. Specific requirements are detailed below.

**4.1.1 Task A: Requirements Definition**

The first step in this task shall be the investigation of debris shedding characteristics that have been incorporated in previous buoys and the identification of additional characteristics which may be beneficial. This shall be accomplished by investigating the debris shedding and river buoys identified during the Buoy Technology Survey and contained in the BTIS.

The contractor shall generate a set of design requirements to be met by the prototype hardware. These requirements shall be formulated from USCG technical reports, documentation, reviews and data researched under the Buoy Technology Survey. Requirements shall include, but not be limited to: IALA shapes and IALA top marks, visual range, radar range, color characteristics, reserve buoyancy, hydrodynamic damping, materials, coating systems, ability to support standard USCG visual and audible signals, buoy stability, serviceability (including safety), durability and compatibility with existing aid to navigation equipment, maintainability, cost and documentation requirements, and interface requirements such as mounting and power requirements for payload equipment.

The contractor shall document the results of this Task in a report containing the requirements and a full description of the basis of each requirement. The contractor shall submit these proposed design requirements to the Government for approval or modification prior to proceeding to Task B of this phase.

**TABLE XII: continued**

**4.1.1.1 Deliverables**

The contractor shall deliver to the USCG R&DC five copies of a draft report for Task A. The USCG will review the draft report and return it to the contractor for revision. The contractor shall make the required revisions and submit a final report to the USCG R&DC. All reports shall be prepared using the guidelines specified in DOT 1700.18B.

**4.1.1.2 Schedule**

The contractor shall deliver the draft report for Task A within 60 days from commencement of Task A. The USCG will return the document with comments for revision within 45 days after receipt from the contractor. The contractor shall make the required revisions and submit a final report within 30 days of receipt of USCG comments. The USCG will advise the contractor of approval/disapproval of design requirements within 30 days of submission of the final report.

**4.1.2 Task B: Prototype Design**

The first step in this task will be the preparation of concept designs incorporating the debris shedding characteristics. These shall be evaluated to determine the most potentially successful concept(s). The evaluation shall include a description of the debris shedding principle, identification of data supporting the functionality of this principle, the risk associated with successful operation, and an estimate of the implementation and operating costs of the design.

A "Concept Design Review Meeting" will be held as instructed by the USCG.

Based on approved design requirements, and concept design, the contractor shall prepare a detailed design for the developmental hardware. The design shall conform to the requirements established under Task A. The contractor shall prepare a detailed cost estimate for the fabrication of prototype items. The design shall be documented with drawings conforming to Level 2 of DOD-D-1000B as specified in Provided Document (3). Specifications for materials and quality assurance shall be ANSI or other generally accepted industry standards and shall be specified in the design. Design documentation shall specify the engineering parameters that shall be measured on the prototype hardware and acceptance criteria for the hardware.

**4.1.2.1 Deliverables**

The contractor shall deliver to the USCG R&DC five copies of draft design documentation and cost estimate for the development hardware. The USCG will review the draft reports and return them to the contractor for revision. The contractor shall make the required

**TABLE XII: continued**

revisions and submit final reports to the USCG R&DC.

**4.1.2.2          Schedule**

Task B shall commence upon receipt of approval of design requirements prepared under Task A. The contractor shall deliver the draft design documentation and cost estimate for the developmental hardware within 180 days after the receipt of this approval. The USCG shall return the document with comments for revision within 45 days of receipt from the contractor. The contractor shall make the required revisions and submit a final report within 30 days of receipt of USCG comments.

**4.1.3            Task C: Test Plan Preparation**

For each prototype buoy design selected for development, the contractor shall prepare a detailed test plan. The test plan shall be designed to quantitatively determine the prototype's performance compared to its requirements. The test plan shall specify the overall test schedule, test locations, quantities of prototype hardware, markings and identification of hardware, assembly and installation plans, materials and instrumentation required, installation schedules, data requirements, reporting formats and evaluation factors. In the event that the contractor has proposed the use of government facilities, the specifics of when, where and for how long shall be clearly specified by the contractor. The contractor shall prepare a detailed cost estimate of all contractor activities and materials associated with prototype test and evaluation as required under the following element.

**4.1.3.1          Deliverables**

The contractor shall deliver five copies of a draft test plan for each prototype buoy design selected for development and five copies of the T&E cost estimate to the USCG R&DC. The USCG will review the draft test plans and return them to the contractor for revision. The contractor shall make the required revisions to the design and the cost estimate and submit final test plan(s) and revised cost estimate to the USCG R&DC.

**4.1.3.2          Schedule**

The contractor shall deliver the draft test plan for each prototype buoy design selected for development and the T&E cost estimate within 45 days from the delivery of the Task B Draft Report. The USCG will return the test plan(s) with comments for revision within 35 days of receipt from the contractor. The contractor shall make the required revisions and submit a final test plan(s) and cost estimate (if applicable) within 30 days of receipt of USCG comments.



**TABLE XII: continued**

**4.2 PROTOTYPE FABRICATION, TEST AND EVALUATION**

This Phase of the technology development program encompasses the prototype fabrication, testing and evaluation efforts for the developmental hardware. Task D involves the fabrication of the prototype hardware. Task E includes the testing and evaluation of this hardware and the preparation of test reports. Specific requirements are detailed below.

**4.2.1 Task D: Prototype Fabrication**

The Government will select prototype designs for future development. The contractor shall then fabricate the selected prototype hardware in accordance with the design developed in Task B, and in the quantities specified in the approved test plan. The contractor shall provide the quality assurance and oversight necessary to assure conformance with the design and the intended use of the hardware. The contractor shall also insure that engineering parameters that were specified to be measured in the design documentation are measured and that acceptance test data are determined and documented prior to the delivery of the prototype hardware. The contractor shall package and ship the prototype hardware as specified in the approved test plan upon completion of fabrication and inspection and after acceptance by the Government.

**4.2.1.1 Deliverables**

The contractor shall deliver the prototype hardware to the locations specified in the approved test plan. Associated engineering and acceptance test data shall be delivered to the Contracting Officer.

**4.2.1.2 Schedule**

Prototype hardware and associated documentation shall be delivered within 120 days after USCG approval of selected designs.

**4.2.2 Task E: Test and Evaluation**

The contractor shall conduct the testing and evaluation of the prototype hardware as specified in the approved test plan. Contractor personnel will be authorized to travel on USCG buoy tenders which will locate prototype buoys for testing at no cost to the contractor. In the event of loss of or damage to prototype hardware or instrumentation which affects the validity of the test results, the contractor shall prepare a report to be submitted to the contracting officer which includes the circumstances and assessment of the impact on the test program, recommendations for correcting and for working around the problem, and cost and schedule impact.

**TABLE XII: continued**

The USCG will have the option to terminate the test and evaluation program 12, 18 and 24 months from commencement. The USCG will also have the option to terminate test and evaluation in the event of a system failure which adversely impacts the test and evaluation program, upon recommendation by the contractor, or upon assessment by the Government that the prototype item is not meeting its established design goals.

The contractor shall prepare a cost estimate for developing the procurement specification for each prototype undergoing test and evaluation.

The contractor shall prepare interim and final reports for each hardware prototype under test. The contractor shall include any data collected in an Appendix to the report or, if not appropriate because of format, medium or volume, include a complete description of the data format and medium and where it is located. The final report shall include:

- Background summary
- Performance requirements
- Design description
- Description of test program including instrumentation
- Data collected
- Data reduction methods
- Data summaries
- Evaluation of results
- Recommendations for improvements, modifications, and enhancements to the prototype hardware.

Interim reports shall include:

- A summary of the intent and scope of the test and evaluation program
- A description of any equipment failures or other significant events impacting the test/evaluation program during the term of the interim report
- A summary of the data collected during the term of the interim report.

## **TABLE XII: continued**

- Assessment of the quality of the data
- The results of preliminary evaluation of the data from the beginning of the testing
- Recommendations for continuation, changes in, or termination of the test, if applicable.

### **4.2.2.1 Deliverables**

The contractor shall deliver a draft interim report to the USCG R&DC at the end of each six-month period of test and evaluation. The test period will be a minimum of one year. The USCG will review the draft report and return it to the contractor for revision. The contractor shall make the required revisions and resubmit the interim report to the USCG R&DC. At the completion of the Test and Evaluation the contractor shall deliver a draft final report and cost estimate to the USCG R&DC. The USCG will review the draft final report and return it to the contractor for revision. The contractor shall make the required revisions and submit final report to the USCG R&DC. All reports shall be prepared within the guidelines specified in DOT1700.18B.

### **4.2.2.2 Schedule**

The contractor shall deliver the draft interim reports at the end of each six-month period of testing, except the last. USCG will return the document with comments for revision within 21 days of receipt of USCG comments.

The contractor shall deliver the cost estimate 30 days after completion of each prototype hardware test and evaluation. The contractor shall deliver the draft final report 30 days after the completion of prototype hardware test and evaluation. The USCG will return the document with comments for revision within 45 days of receipt from the contractor. The contractor shall make the required revisions and submit the final reports within 30 days of receipt of USCG comments.

## **4.3 PROCUREMENT SPECIFICATIONS**

This element of the New Buoy Systems Project requires the development of procurement specifications for production of hardware which has shown to be an improvement over that currently in use. Based on the results of the test and evaluation program, the government will select those prototypes to be included for development in this element. Specific requirements are detailed below.

**TABLE XII: continued**

**4.3.1 Task F: Procurement Specifications Development**

Under this contract task element the contractor shall:

- Develop a technical specification package, in accordance with Required Document (2), for each prototype buoy design selected for production by the government. The specification will be used for competitive procurement of production units of the development hardware. The design of the production units shall include any enhancements, modifications or improvements determined by the Government to be desirable or necessary as a result of field testing.
- Prepare a cost estimate for production units based on production quantities specified by the Government. The Cost Estimate shall be broken down to clearly show tooling, materials, fabrication, finishing, and quality assurance costs.

The specification package shall consist of design drawings corresponding to Level 3 of DOD-D-1000B as specified in Provided Document (4). The written specification shall follow the form and content specified in Required Document (2).

**4.3.1.1 Deliverables**

The contractor shall deliver five copies of the draft specifications and the cost estimate for each prototype included in this phase to the USCG R&DC. The USCG will review the submission and return it to the contractor for revision. The contractor shall make the required revisions and submit the final specifications and cost estimate to the USCG R&DC.

**4.3.1.2 Schedule**

The contractor shall deliver draft specification for each prototype within 90 days from receipt of a notice to proceed. The USCG shall return the specifications with comments for revision within 45 days of receipt from the contractor. The contractor shall make the required revisions and submit final versions within 30 days of receipt of USCG comments.

**5. PROGRESS REPORTS**

The contractor shall provide monthly progress reports. These reports will cover the contractors progress for each month commencing from time of contract award. The contractor shall deliver the report to the USCG R&DC within one week from the end of the progress period. Progress reports are to be a narrative in letter format and shall include:

**TABLE XII: continued**

- Title, contract number, contractor identification and phase/option and task identification
- Summary of accomplishments during the report period
- Meetings and trips
- Problem areas
- Open issues
- Unresolved action items
- Statement of adherence to program schedule
- Summary of staff-hour expenditure by task
- Notification of changes in key personnel
- Summary of costs by task
- Schedule summary

**6. GOVERNMENT FURNISHED EQUIPMENT (GFE) - GOVERNMENT FURNISHED MATERIALS (GFM)**

Government Furnished Equipment (GFE) and Government Furnished Material (GFM) requirements shall be proposed by the contractor in Task C: Test Plan Preparation. GFE/GFM as agreed upon by the Government in the approved test plan(s) will be provided by the Government.

**TABLE XIII: TECHNOLOGY DEVELOPMENT PLAN  
COST ESTIMATE**

Buoy Technology No.: 4.1  
 Technology Description: Debris Shedding River Buoy Hulls

<b>TASK</b>	<b>DESCRIPTION</b>	<b>LABOR, (Staff-Hours)</b>		<b>DIRECT CHARGES</b>
A	Requirements Definition	80	+	\$100 + travel
B	Prototype Design	1000	+	\$1,000 per buoy
C	Test Plans	120	+	\$500 per buoy design selected
D	Prototype Fabrication			\$10,000 per buoy
E	Test & Evaluation	600	+	\$500 + travel, per buoy
F	Procurement Specification	450	+	\$550 for each prototype design selected.
<hr/>				
<b>TOTALS:</b>		<b>80 StaffHours</b>		<b>\$100 + travel</b>
		<b>+ 1720 StaffHours</b>		<b>\$12,000 + travel, per buoy</b>
		<b>+ 450 StaffHours</b>		<b>\$550 for each prototype design selected.</b>

TABLE XIV: TECHNOLOGY DEVELOPMENT PLANS  
SUMMARY OF COST ESTIMATES

TECH. NO.	TECHNOLOGY DESCRIPTION	PROJECT DIRECT COSTS		PER BUOY		PER MATERIAL		PER PROTOTYPE SELECTED	
		LABOR	DIRECT COSTS	LABOR	DIRECT COSTS	LABOR	DIRECT COSTS	LABOR	DIRECT COSTS
1.1	Slat Covered Frame Superstructure	1640	S/H + \$17,250 + travel						
2.1	Foam Material for Buoys	400	S/H + \$700 + travel	1720	S/H + \$36,500 + travel	280	S/H + \$8,100 + travel	450	S/H + \$550
2.2	Elastomer Skins for Buoys	280	S/H + \$400 + travel	880	S/H + \$18,800 + travel	160	S/H + \$7,100 + travel	260	S/H + \$450
2.3	FRP & GRP Materials	400	S/H + \$700 + travel	1720	S/H + \$36,500 + travel	280	S/H + \$8,100 + travel	450	S/H + \$550
2.4	Off-The-Shelf Plastic/Foam Buoys	660	S/H + \$1,000 + travel	1020	S/H + \$11,600 + travel			280	S/H + \$550
3.2	Off-The-Shelf Open Sea Buoys	380	S/H + \$600 + travel	1020	S/H + \$20,600 + travel			280	S/H + \$550
4.1	Debris Shedding Buoy	80	S/H + \$100 + travel	1720	S/H + \$12,000 + travel			450	S/H + \$550
4.4	Off-The-Shelf River Buoys	520	S/H + \$800 + travel	820	S/H + \$11,100 + travel			450	S/H + \$550
5.1	Compartmented Ice Buoys	80	S/H + \$100 + travel	1720	S/H + \$32,000 + travel			450	S/H + \$550
5.2	Plastic Spar Buoys for Ice Service	660	S/H + \$1,000 + travel	1020	S/H + \$11,600 + travel			280	S/H + \$550

TABLE XIV, Cont.: TECHNOLOGY DEVELOPMENT PLANS  
SUMMARY OF COST ESTIMATES

TECH. NO.	TECHNOLOGY DESCRIPTION	PROJECT		PER BUOY		PER MATERIAL		PER PROTOTYPE SELECTED	
		LABOR	DIRECT COSTS	LABOR	DIRECT COSTS	LABOR	DIRECT COSTS	LABOR	DIRECT COSTS
6.1	Buoyant Beacon Mooring Improvements	160 S/H +	\$200 + travel	1120 S/H +	\$35,900 + travel			200 S/H +	\$450
6.2	Off-The-Shelf Buoyant Beacons	500 S/H +	\$900 + travel	1020 S/H +	\$50,600 + travel			280 S/H +	\$550
8.1	Deck or Superstructure Mounted Battery Boxes	140 S/H +	\$250 + travel	360 S/H +	\$6,300 + travel			160 S/H +	\$250
9.6	Solid Superstructure	1740 S/H +	\$17,250 + travel						
11.1	Coatings and Preservation Systems	560 S/H +	\$500 + travel						
11.2	Fenders on Buoy Hull	760 S/H +	\$7,900 + travel						
13.1	Systems Approach to Design	1540 S/H +	\$3,100 + travel						
13.3	Buoy Model Tests	100 S/H +	\$100 + travel						
13.6	Improved Damaged Stability By Increased Compartmentation	80 S/H +	\$100 + travel	1000 S/H +	\$19,500 + travel			300 S/H +	\$1,000
						Per Material System			
						304 S/H +	\$3,050 + travel	96 S/H +	\$70
						Per Concept			
						980 S/H +	\$16,100 + travel		



## 6. SUMMARY AND CONCLUSIONS

A total of 57 technologies have been identified as being possible candidates for improving the USCG ATON system. Three of these were found to overlap three other technologies in the compilation and were combined with those. The remaining 54 technologies were subdivided into fifteen different categories and were screened with regard to their affecting the buoy hull and superstructure directly and therefore being a part of the current project, the "Buoy Technology Survey". It was found that 21 of these did not directly affect the buoy hull or superstructure and therefore were not part of the current project. Two more technologies were found to be already currently under study by the USCG. Accordingly, 23 technologies were designated for "deferred" consideration by the USCG in the framework of studies outside the current project. The remaining 31 technologies were found to be directly related to the buoy hull and superstructure and these were subjected to an evaluation using criteria specifically developed for this purpose and approved by the USCG.

The evaluation criteria consisted of several categories of buoy performance characteristics including operational effectiveness, servicing and handling ease, logistics considerations, and economic impact. Weight factors were assigned to each criterion under each category and measures of merit were established for use in grading them. The highest possible grade of (+5) was assigned to those criteria which would result in meeting its measure of merit to the fullest degree with the incorporation of the technology in question to an ATON buoy. A minimum grade of (-5) was assigned to those criteria which would very adversely impact the measure of merit. The grading was independently conducted by three different reviewers. The grades for each criterion were averaged to the nearest integer and multiplied by the corresponding weight factors to obtain point scores for individual criteria. The sum of all point scores constituted the evaluation score for the technology in question. The evaluation scores obtained in this manner are presented in Table VII of Section 4 for all of the 31 technologies which have been evaluated.

In selecting the most promising technologies resulting from the evaluation, the following approach was used:

- All technologies with negative point scores were dropped from consideration.
- An average point score level was computed and used as the cut-off point since it was deemed that technologies with scores less than the average may have great risk in achieving the expected improvement.
- All technologies with scores less than the average were dropped except for the following:
  - Three technologies with less than average scores (Nos. 9.6, 13.3 and 13.6) were reconsidered and retained for further study since they were deemed to be easily implementable or particularly useful to the USCG. (Section 4.3 discusses this rationale in detail).

- Another technology with less than average point score (No.1.1) was also deemed worthy of further study since it could be accomplished easily and at small cost to enhance the shape significance of existing buoys.

Consequently, a total of 19 different buoy technologies were selected as promising to provide improvements and potential economic savings for the USCG ATON system and 12 technologies were dropped.

Economic analyses were conducted for each of the 19 technologies to determine the benefits that they may provide. The analyses were based on the acquisition and maintenance costs of the aids to navigation only. The costs of servicing platforms and shoreside facilities were not included in this analysis but since they are significant components of the overall system, their costs should also be considered in any final analysis.

The results of economic analysis show considerable net total benefit to be derived from incorporation of most technologies into the USCG ATON system. The maximum benefit is provided by Technology No. 2.3 (FRP/GRP Materials) with a Net Total Discounted Cost (NTDC), for new buoys equipped with this technology, of more than 317 million dollars vs 380 million for existing buoys, resulting in a net total benefit of more than 63 million dollars over a life period of 30 years. The NTDC for the new construction buoys equipped with individual technologies and for the existing buoys as well as the "Net Total Benefit" (NTB) to be derived by incorporation of respective technologies are listed in Table XV in the order of decreasing benefits. As seen, the NTB's range from a maximum of approximately 63 million dollars for "FRP/GRP Material" to a minimum of more than four million dollars for "Compartmented Ice Buoys". Two of the technologies, i.e. "Slat Covered Frame Superstructure" and "Solid Superstructure" cause increases in life cycle costs. These have been deleted from the recommended technologies in Table XV since the results of economic analysis imply that buoy shape significance, the objective of these two technologies, may be accomplished more economically by using topmarks only.

It must be pointed out that the results obtained from economic analyses are quite sensitive to the assumptions made in Table IX of Section 4.4 for the annual loss percentages of different types of buoys.

On the basis of assumptions made in this project, the listing shown in Table XV should give a good indication of the order in which the USCG could proceed in following a course for buoy technology research and development.

**TABLE XV: RESULTS OF ECONOMIC ANALYSES  
FOR RECOMMENDED BUOY TECHNOLOGIES**

TECH. NO.	TECHNOLOGY DESCRIPTION	NET TOTAL DISCOUNTED COST		NET TOTAL BENEFIT (\$K)
		FOR NEW BUOYS (\$K)	FOR EXISTING BUOYS (\$K)	
2.3	FRP & GRP Materials	317,547	380,675	63,128
13.1	Systems Approach to Design	285,910	340,184	54,273
13.6	Improved Damaged Stability By Increased Compartmentation	261,410	310,555	49,145
8.1	Deck or Superstructure Mounted Battery Boxes	203,938	245,174	41,236
2.2	Elastomer Skins for Buoys	351,425	380,675	29,250
6.1	Buoyant Beacon Mooring Improvements	151,039	175,524	24,484
6.2	Off-The-Shelf Buoyant Beacons	151,074	175,524	24,449
5.2	Plastic Spar Buoys for Ice Service	5,934	27,020	21,086
4.4	Off-The-Shelf River Buoys	23,801	43,248	19,447
13.3	Buoy Model Tests	321,790	340,184	18,394
2.4	Off-The-Shelf Plastic/Foam Buoys	362,573	380,675	18,102
2.1	Foam Material for Buoys	362,875	380,675	17,800
11.1	Coatings and Preservation Systems	325,673	340,184	14,510
4.1	Debris Shedding Buoy	31,888	43,248	11,360
3.2	Off-The-Shelf Open Sea Buoys	110,121	115,239	5,118
11.2	Fenders on Buoy Hull	333,819	338,923	5,104
5.1	Compartmented Ice Buoys	22,564	27,020	4,456

## 7. REFERENCES

1. "Buoy Technology Survey: USCG Buoy Development Review". Final Report, October 1990.
2. "Buoy Technology Survey: Worldwide Buoy Technology Survey", Final Report, February 1991.
3. International Association of Lighthouse Authorities (IALA), Aids to Navigation Guide (NAVGUIDE), 1990.
4. "Draft Statement of Work", New Buoy Systems Development, USCG R&D Center, October 5, 1989.
5. Daidola, J.C., Basar, N.S. and Walker, R.T., "New Buoy Systems Research", Marine Technology Society Transactions, 1990.
6. "Economic Analysis Handbook", NAVFAC P-442, NAVFAC 0525-LP-037-7150, June 1986.
7. "Project Master Plan Narrative-New Buoy Systems" Project No.2710, 30 April 1987, US Coast Guard.
8. S. Walker, R. Boy, D. Strahl and K. Davis, "Developments in Floating Aids to Navigation", IALA XIIIth Conference Paper No.3.2.1, June 1990.
9. P.J. Glahe, "A History of the Development of Plastic Buoys by the US Coast Guard", IALA Xth Conference Paper No. 3.1.5, 1980.
10. USCG R&D Center Telefax dated June 3, 1991, "Revised Buoy Population and Cost Data".

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## APPENDIX A

### REVIEW OF BUOY TECHNOLOGIES (RATIONALE AND APPROACH FOR DEFERRED TECHNOLOGIES)

<u>Technology No</u>	<u>Description</u>	<u>Page</u>
4.3	Anti-Heeling Plates	A-1
8.2	Solar Panel Supplement to Wave Powers	A-2
8.5	Wind Generators	A-3
8.6	Low Energy Light Beacons	A-4
8.7	LED Lights	A-5
8.8	Modular Buoy Payload	A-6
8.9	Electronic Bells and Gongs	A-7
9.1	Buoy Position Monitoring	A-8
9.2	LORAN Receivers/Transponders	A-9
9.3	Collision Marking Systems	A-10
9.4	Synchronization of Flashing Lights	A-11
9.5	Recognition of Buoy Symbols and Lettering	A-12
9.7	Remotely Visible Low Battery Indicator	A-13
10.1	Use of Synthetic Lines in Mooring	A-14
10.2	Cast Iron Sinkers for Fast Current Applications	A-15
12.2	Use of Commercially Available Radar Reflectors	A-16
14.2	Buoy Statistics and Inspection Databases	A-17
15.1	Vessel Navigation by Buoyage	A-18
15.2	Vessel Navigation by Systems	A-19
15.3	Two-Way Traffic	A-20
15.4	Range Lights	A-21

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## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.           4       RIVER BUOYS  
TECHNOLOGY NO.       4.3     ANTI-HEELING PLATES

### RATIONALE

The Koreans have done some investigation into using plate fins attached to the tail-tube of a fast water buoy to prevent heeling due to current and the corresponding reduction in visual range of the buoy light. The research has shown that the heel can be reduced using these plates, but the current must be steady and predictable for the system to work correctly. At current speeds lower than the design speed, the force on the plates tends to heel the buoy into the current, thus defeating the purpose of the device. Such a device does not seem suitable for the USCG's main fast-water buoy area, the Western Rivers, since the currents tend to vary greatly and this design would be particularly susceptible to debris accumulation and damage. For some coastal areas, however, it may be more appropriate.

### APPROACH

Investigate the benefit of the device on various USCG buoys intended for fast water applications by utilizing the Korean's results.



## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.           8       POWER SOURCES AND PAYLOAD  
TECHNOLOGY NO.       8.2     SOLAR PANEL SUPPLEMENT TO WATG POWER

### RATIONALE

The Japanese have widespread experience in wave activated turbine generators (WATG) as the primary buoy power source. In some areas, they are using solar power as a back-up or secondary power source.

The use of solar panels in conjunction with WATGs may provide added power capacity, increased reliability, and increased payload support capability to offshore ATONs. Because WATGs depend on wave action to work, prolonged periods of calm water may result in low power production. Solar panels used as supplemental power sources can compensate for these dips in performance. Also, solar panels can allow higher payload electrical loads than WATGs can support alone. This will allow more powerful lamps and/or more payload items to be installed on the buoy.

### APPROACH

The power generation capabilities of USCG WATGs should be evaluated both alone and with a supplemental solar panel. Any increase in payload capability should be weighed against the cost of retrofitting buoys with solar panels.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            8        POWER SOURCES AND PAYLOAD  
TECHNOLOGY NO.        8.5      WIND GENERATORS

### RATIONALE

The Danish Navigation Authority (Farvandsvaesenet) is using wind generators for illuminating the superstructure of lighted beacons in connection with the Ocean Data Acquisition System (ODAS). Wind-powered generators could be used as alternative power sources for floating ATONS as well. Unfortunately however, these generators are prone to mechanical failure in the marine environment and their power production capacities are rather limited.

### APPROACH

Any evaluation of this technology should include a review of the USCG experience with wind generators and a review of Denmark's application of wind power for illumination of superstructures.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.           8       POWER SOURCES AND PAYLOAD  
TECHNOLOGY NO.       8.6     LOW ENERGY LIGHT BEACONS

### RATIONALE

"Electronic Supply Company" of Denmark has developed a new low energy light beacon called "MIRA Beacon Omnidirectional". The "MIRA" is an ATON light source which requires less power than conventional buoy beacons. This beacon does not need a lens, so it possesses a very wide angle of divergence and may be suitable for application on the USCG 7X20 LI buoy. Furthermore, the beacon has an expected life of 5 years and its characteristic may be changed using a hand-held infrared remote control. These last two items would likely improve maintenance frequency and operational flexibility.

### APPROACH

The evaluation of this technology should review Denmark's experience with this beacon and weigh the maintenance and operational benefits against expected liabilities such as cost, light intensity, and availability of the technology.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.           8       POWER SOURCES AND PAYLOAD  
TECHNOLOGY NO.       8.7     LED LIGHTS

### RATIONALE

The Japanese (Nippon Kogi Kogyo Co., Ltd.) are developing an LED (Light Emitting Diode) light for use on floating aids that could mitigate the problem of buoy motions by displaying a broader beam. The use of LED lights for ATON buoy signals offers advantages in the areas of signal life and switching response. The LED light technology, however, is still developing and suffers from very low light intensity relative to current light sources, although advances are being made in these areas.

### APPROACH

The evaluation of this technology should weigh the maintenance advantage of long signal life against the disadvantage of poor signal quality, small divergence angle and immaturity of the technology.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.           8        STANDARDIZATION OF BUOYS AND BUOY PARTS  
TECHNOLOGY NO.       8.8      MODULAR BUOY PAYLOAD

### RATIONALE

A significant part of buoy maintenance and tending is affected by the payload (consisting of batteries, lights, horns, bells, solar panels, generators, radar reflectors, RACONS, etc.). The important factors include size weight, location on the buoy, and access. If payloads could be modularized with a maximum number of components in one unit, then a significant reduction in maintenance and tending could accrue. Buoy design could also benefit by the isolation of the payload to be located on and carried by the buoy into fewer number of components or a single component. Lower inventory may also be possible if the modular payload can be made suitable for a range of buoys.

### APPROACH

Itemize the individual payload technologies involved in navigation buoys in accordance with buoy type. Investigate the possible grouping of components into a minimum discrete number with maximum applications between buoy types. Develop systems, outline arrangements and module envelopes. Evaluate the impact on inventory and buoy maintenance.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.           8       POWER SOURCES AND PAYLOAD  
TECHNOLOGY NO.       8.9     ELECTRONIC BELLS & GONGS

### RATIONALE

Some U.S.C.G. district o.a.n.'s have reported damage to buoy equipment due to shock and vibration imparted by the mechanical gongs and bells of the sound buoys. It may be possible to eliminate this problem through the use of commercially available electronic bells and gongs. It should be noted however, that IALA has recommended that all sound signals be eliminated.

### APPROACH

Determine the actual extent and seriousness of damage to buoy equipment and structure due to shock and vibration imparted by mechanical gongs and bells. Review and compile data on commercially available electronic bells and gongs. Establish the feasibility, the advantages/disadvantages, and the cost impact of using same on USCG sound buoys.

### Sources:

USCG District #1 (o.a.n.)  
USCG District #1 Weymouth Base  
Automatic Power

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            9        IDENTIFICATION & REMOTE MONITORING  
TECHNOLOGY NO.        9.1     BUOY POSITION MONITORING

### RATIONALE

The USCG buoys are not remotely monitored and any off-station buoys are either observed by servicing buoy tenders or reported by users of aids. The technology is commercially available, and is used in a number of foreign countries or under consideration by others, to accomplish remote monitoring of buoy positions as well as additional data on buoy performance and statistics. The adoption of an existing system or the development of a new system customized for USCG is desirable.

### APPROACH

Review the data gathered on buoy monitoring systems during the Worldwide Buoy Technology Survey to include the Japanese GPS system with fail-safe signal generator, Denmark's research on "Intelligent Buoy" with radio link to a shoreside monitoring center, England's (MIDAR Systems) Interrogator/ Receiver/Transponder system, and U.S. manufacturer RACAL's Micro-Fix and Hyper-Fix Positioning systems. Obtain more detailed data on these and any other commercially available monitoring systems in the U.S. and worldwide. Analyze the benefits and costs of adopting such systems against developing a new system tailored to the needs of USCG's Aton service.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            9        IDENTIFICATION & REMOTE MONITORING  
TECHNOLOGY NO.        9.2      LORAN & RECEIVERS/TRANSPONDERS ON BUOYS

### RATIONALE

It has been suggested by many interviewees during the Worldwide Buoy Technology Survey that by installing LORAN receivers/transponders or other homing devices on floating aids in critical areas, the chance of losing them will be reduced. There are several commercially available LORAN transponders as well as RACON's that can be installed on buoys. The feasibility and benefits of outfitting buoys with such equipment is desired.

### APPROACH

Review the literature from all U.S. and foreign manufacturers who have commercially available LORAN, RACON, or other homing devices that are suitable for use on floating aids. Compare costs and operational effectiveness of each. Determine the best equipment and the best method of application to buoys for recommending to the USCG.



## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            9        IDENTIFICATION & REMOTE MONITORING  
TECHNOLOGY NO.        9.3     COLLISION MARKING SYSTEMS

### RATIONALE

Especially in congested waterways such as the New York Harbor and to some extent the Western Rivers waterways, the number of buoys lost due to collisions with ships is very high. The offending ships remain mostly unidentified. By the introduction of a paint spraying system developed by Japanese, cost savings may be realized as a result of positively identifying the ships that cause damage to buoys.

### APPROACH

Study the Paint Spraying and Radio Transmission Systems developed by Japan's "Nippon Kogi Kogyo Co." and "Ryokuseisha Corp." Establish the cost of acquiring and installing the systems as well as the shore based monitoring center costs. Conduct a cost/benefit analysis on the adoption of the collision-marking system for use in the USCG ATON system.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            9        IDENTIFICATION & REMOTE MONITORING  
TECHNOLOGY NO.        9.4      SYNCHRONIZATION OF FLASHING LIGHTS

### RATIONALE

The Japanese have synchronized flashing systems on the articulated beacons deployed in the Tokyo and Osaka Bay regions. The feasibility of using such systems in similar U.S. waterways, if proven economically feasible, may improve the safety of navigation in these areas.

### APPROACH

Review the Japanese approach to synchronized flashing lights by contacting the Japanese Maritime Safety Agency and the Manufacturers Ryokuseisha Corp. and obtaining details of the flashing equipment, operational performance experience and cost information. Locate the parts of U.S. waterways where the synchronized flashing lights may be useful and effective. Determine the cost of equipping existing floating aids in these areas with synchronized flashers.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            9        IDENTIFICATION & REMOTE MONITORING  
TECHNOLOGY NO.        9.5      RECOGNITION OF BUOY SYMBOLS AND LETTERING

### RATIONALE

The USCG currently uses the marking system described in "Aids to Navigation, Technical - COMDT/INST. M 16500.3", Chapter 3. However, a paper was presented to the IALA 1990 Conference (No. 3.1.1) by German authors on the "Recognizability of Symbols and Letterings on the Aids to Navigation." A review of the findings from this study, as well as any other similar studies worldwide, may bring new approaches for use on buoys to improve their identification.

### APPROACH

Review the IALA 1990 Paper No. 3.1.1 and also conduct a search for other studies of similar nature that may have been conducted by other national navigation authorities. Compare the findings with the approach used currently by the USCG. Determine if any changes to the current approach or the adoption of a different approach is feasible and recommendable.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            9        IDENTIFICATION & REMOTE MONITORING  
TECHNOLOGY NO.        9.7      REMOTELY VISIBLE LOW BATTERY INDICATOR

### RATIONALE

The British have suggested designing a low battery indicator which can be seen with binoculars to avoid unnecessary visits to ATONS. The USCG performs a number of maintenance tasks other than just battery checking when they visit an ATON, such as mooring inspection, bulb changing, and minor damage repair. In general, failures of buoys due to battery drain seem to be much less frequent than other failures. Given all of this, it would seem that any effort in producing a remotely visible battery indicator would not prove cost-effective.

### APPROACH

Determine whether there would be an operational savings for the USCG in avoiding actually visiting a buoy to check battery charge condition. If found economically feasible, consider incorporating the remotely visible low battery indicators.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.        10    MOORING IMPROVEMENTS  
TECHNOLOGY NO.    10.1 USE OF SYNTHETIC LINES IN MOORING

### RATIONALE

The use of synthetic mooring lines in lieu of standard steel chain provides an advantage in terms of reduced weight. Reduced mooring weight will allow current buoys to be moored in deeper areas while providing adequate freeboard. It will also allow more payload to be carried at the present maximum depths. Finally, new buoy designs incorporating synthetic moorings would require less buoyancy to counter the weight of the mooring and would therefore be expected to have less displaced volume and consequently lighter hull weight.

### APPROACH

The evaluation of this technology should begin with a review of past USCG and National Data Buoy Center experience with synthetic mooring lines. Foreign experience with such moorings should also be reviewed.



## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            12    STANDARDIZATION OF BUOYS AND BUOY PARTS  
TECHNOLOGY NO.        12.2 USE OF COMMERCIALY AVAILABLE REFLECTORS

### RATIONALE

The USCG buoys currently use dihedral or trihedral radar reflectors either internally or externally located in the buoys. There are other types of radar reflectors (such as corner clusters, e.g. Germany's SR-6 type, and the Luneburg lens) that provide a larger radar cross section without increased volume. Use of such commercially available radar reflectors may improve the radar ranges of USCG buoys. The utilization of these radar reflectors could simplify the construction of buoys.

### APPROACH

All commercially available radar reflectors that are being used by domestic and foreign buoy manufacturers will be documented and physical/operational characteristics compiled. The benefits of using these in lieu of the current biplane reflectors will be investigated. A cost analysis will be performed to include both the acquisition costs of commercial reflectors, advantages to be obtained in construction of new buoys and the effect on standardization.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.        14     COMPUTER DATA BASES/PROGRAMS FOR ATON  
TECHNOLOGY NO.    14.2   BUOY STATISTICS AND INSPECTION DATABASES

### RATIONALE

Several foreign authorities have developed computerized databases for tracking distribution and maintenance of their ATONs. Such databases, while useful for ATON operations, are not directly applicable to buoy hull design. It should be noted that the USCG already has a database, the Aids to Navigation Information SYSTEM (ATONIS), which contains much of the same information that the foreign databases contain.

### APPROACH

This effort should begin with a complete review of foreign approaches and the current USCG systems. From there the USCG needs can be identified.



## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            15    TRAFFIC ENGINEERING AND WATERWAY  
MANAGEMENT

TECHNOLOGY NO.        15.1 VESSEL NAVIGATION BY BUOYAGE

### RATIONALE

USCG ATON buoy placement in terms of types and numbers has been instituted by a number of methods. It has been proposed, most recently by Finland and Korea at the IALA Conference of 1990, that the types and number of buoys provided at any location be based on the vessel traffic volume and the level of danger. If the U.S. buoy system were analyzed in this fashion there is a possibility that the amount of buoyage could be re-distributed for more effectiveness, increased if inadequate, reduced if overly adequate and/or altered in its make-up in accordance with the indicated aid types.

### APPROACH

Review the procedures proposed in the cited references as well as any more current literature for analyzing buoyage systems in this manner. Based on these approaches, synthesize a procedure to be applied to the USCG navigation buoyage system. Apply the procedure to a sample U.S. buoyage situation. Compare the results to existing conditions. Conclude on the applicability and effectiveness and recommend accordingly.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            15    TRAFFIC ENGINEERING AND WATERWAY  
MANAGEMENT

TECHNOLOGY NO.        15.2   VESSEL NAVIGATION BY SYSTEMS

### RATIONALE

The widespread availability of navigation devices on ships and the introduction of RACONS on aids to navigation buoys or other offshore structures has raised the possibility of navigation by these means rather than by visual utilization of buoyage. Most recently the Dutch have presented a study on this at the IALA 90 Conference considering the North Sea waters along the coast of the Netherlands. The results indicate the possibility of significant offshore buoy reductions.

### APPROACH

Review studies carried out by others on buoy reduction by utilization of other means for navigation. Review the U.S. ATON system and identify geographic areas where the conditions are similar to those of the aforementioned studies where a meaningful reduction of navigation buoyage had resulted. Apply the technique and determine the cost saving and risk that would be inherent in such an approach.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.        15    TRAFFIC ENGINEERING AND WATERWAY  
MANAGEMENT

TECHNOLOGY NO.    15.3   TWO WAY TRAFFIC

### RATIONALE

The Japanese and Dutch have provided one way traffic lanes separated by fairway buoys in areas of heavy ship traffic. This reduces the potential for collisions.

This approach may provide a more effective way to mark heavily travelled channels in the U.S.A.

### APPROACH

Evaluate the effectiveness of this system where it has been employed. If favorable results have been obtained, identify possible locations for applications in the U.S.A. Design and analyze two way traffic schemes for these locations.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            15    TRAFFIC ENGINEERING AND WATERWAY  
MANAGEMENT

TECHNOLOGY NO.        15.4    RANGE LIGHTS

### RATIONALE

Range lights fixed to land based structures have been employed around the world especially in Norway and Denmark. These are usually provided as means of positive reckoning of direction at pivotal points such as changes in channel direction.

These may provide a more foolproof means of identifying exact changes in channel boundaries.

### APPROACH

Evaluate the effectiveness of this system where it has been employed. If favorable results have been obtained, identify possible locations for applications in the U.S.A. Design and test.

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## APPENDIX B

### REVIEWS OF AND BACKGROUNDS FOR CANDIDATE BUOY TECHNOLOGIES

<u>Technology No</u>	<u>Description</u>	<u>Page</u>
1.1	Slat Covered Frame Superstructure Shape Significance Versus Topmarks	B-1
1.2	Reduced Weight of Superstructure	B-4
1.3	Battery Pockets and Vent Lines	B-7
1.4	Quick Acting Buoy Hatch Covers	B-10
1.5	Free Hanging Pieces of Chain in Tall Tube to Reduce Fouling	B-13
2.1	Foam Material For Buoys	B-16
2.2	Elastomer Skin For Buoys	B-19
2.3	FRP and GRP Materials	B-22
2.4	Off the Shelf Plastic/Foam Buoys	B-25
3.1	Semi-Submersible Hulls	B-29
3.2	Off the Shelf Open Sea Buoys	B-32
4.1	Debris Shedding Buoy Hulls	B-36
4.2	Gimballed Lanterns	B-39
4.4	Off the Shelf River Buoys	B-42
5.1	Compartmented Ice Buoys	B-45
5.2	Plastic Spar Buoys for Ice Service	B-48
6.1	Buoyant Beacon Mooring Concepts	B-51
6.2	Off the Shelf Buoyant Beacons	B-56

7.1	Inflatable Buoys	B-59
8.1	Deck or Superstructure Mounted Battery Boxes	B-62
8.3	New Wave Actuated Generators	B-65
8.4	Seawater Primary Batteries	B-69
9.6	Solid Superstructure Instead of Latticework and Topmarks	B-72
11.1	Coatings and Preservation Systems	B-75
11.2	Fenders on Buoy Hull	B-78
12.1	Modular Buoy Designs	B-81
13.1	Systems Approach to Buoy Design	B-84
13.2	Increased Buoy Motions	B-87
13.3	Buoy Model Tests	B-90
13.4	Effect of Mooring and Payload Weight on Buoy Designs	B-93
13.5	Measure of Effectiveness	B-96
13.6	Improved Damage Stability by Increased Compartmentation	B-99

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.	1	<u>IMPROVEMENTS TO EXISTING USCG BUOYS</u>
TECHNOLOGY NO.	1.1	<u>SLAT COVERED FRAME SUPERSTRUCTURE SHAPE SIGNIFICANCE VERSUS TOPMARKS</u>

### RATIONALE

Most existing ocean buoys are made of steel with an open frame steel superstructure or cage (a latticework) which is either bolted or welded to the buoy hull. By fitting the cage with slats of plastic or even wood as a cosmetic covering, the shape significance required by IALA can be provided without the use of topmarks.

Many foreign authorities have utilized slat covered frames on their buoy superstructures. The slat covered frames provide sufficient daymark visibility while providing for lighter weight and decreased lateral area for wind loads to act upon than solid superstructures. The size of the shape signified will be much larger than can be achieved with topmarks.

### APPROACH

The feasibility of adding slats to the cages of existing buoys will be investigated and advantages/disadvantages will be determined. Any evaluation of this technology should compare the weight, wind load, shape significance, daymark visibility and maintenance of slat covered frames, solid superstructures and topmarks. The experience of foreign authorities, especially the British, should be considered.



## **TECHNOLOGY BACKGROUND FOR EVALUATIONS**

<b>CATEGORY NO.</b>	<b>1</b>	<b><u>IMPROVEMENTS TO EXISTING USCG BUOYS</u></b>
<b>TECHNOLOGY NO.</b>	<b>1.1</b>	<b><u>SLAT COVERED FRAME SUPERSTRUCTURE SHAPE SIGNIFICANCE VERSUS TOPMARKS</u></b>

### **A. AREA OF APPLICABILITY**

All USCG steel cage buoys.

### **B. COMPONENTS REPLACED**

A substitute for topmarks as a means of providing shape significance. As the USCG has not yet complied with the IALA recommendation for shape significance signalling for steel cage buoys this would be a straight trade-off between installing slats or topmarks, although new solid superstructures could also be considered as an alternative. Solid superstructures are considered under a separate technology (9.6). As the USCG has been considering topmarks only for the purpose of shape significance, it will be assumed that the trade-off is to be based on a replacement of topmarks with slats.

### **C. IMPACT**

#### **C. 1 Operational Effectiveness**

- Slats will provide a much larger area for shape significance identification (in daylight) and therefore will have superior signalling characteristics. The USCG has already determined that it is likely the topmark shape will only be recognized at a distance smaller than that required for color distinction, making the topmark of little value except in backlit conditions.

## C. 2 Servicing and Handling

- Slats would reduce othe access into the cage and up to the light platform for maintenance. Topmarks will require more careful handling of the buoy as they are in buoy position vulnerable to damage. This is considered an even impact on maintenance for both.

## C. 3 Logistics

- Both topmarks and slats will be transportable to different buoy types and hence there is no distinction in this category.
- Both can be introduced quickly as the technology is available.
- As the slat covered frame does not increase the outer buoy and cage dimensions it will be more compatible with existing buoy tenders.

## C. 4 Economic Impact

- The cost of constructing topmarks will be more than slats whereas the cost of installing slats is expected to be greater. Overall capital and installation costs are expected to be similar.

## C. 5 Miscellaneous

- No significant impact.

## C. 6 Special Functions

- No significant impact.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.	1	<u>IMPROVEMENTS TO EXISTING BUOYS</u>
TECHNOLOGY NO.	1.2	<u>REDUCED WEIGHT OF SUPERSTRUCTURE</u>

### RATIONALE

The Japanese have proposed reducing the weight of buoy superstructures in order to lower floatation and stability requirements of buoys. This is intended to be accomplished by utilizing materials with reduced strength/ stiffness as compared to steel. Such strength reduction might reduce the payload that the buoy could carry and increase the probability of failure due to vibration and handling loads. Unless the reduction in strength could be coupled with a reduction in payload component weight, there appears to be little, if any, gain in reducing the superstructure stiffness on USCG buoys. The Gloucester Harbor Trustees in England have also utilized GRP superstructures to eliminate corrosion and the maintenance associated with it.

### APPROACH

Identify the strength and stiffness requirements of buoy superstructures. If these can be reduced, investigate the potential benefits.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**        1        IMPROVEMENTS TO EXISTING USCG BUOYS  
**TECHNOLOGY NO.**    1.2      REDUCED WEIGHT OF SUPERSTRUCTURES

**A. AREA OF APPLICABILITY**

All USCG steel cage buoys.

**B. COMPONENTS REPLACED**

The cages would be replaced with those based on reduced weight schemes.

**C. IMPACT**

**C. 1 Operational Effectiveness**

- Capability to support heavier payloads would be decreased.

**C. 2 Servicing and Handling**

- The structure would be designed to retain robustness for servicing and handling.
- The utilization of less corrosive materials (e.g. GRP) would increase maintenance frequency of the cage superstructure.

**C. 3 Logistics**

- The technology is available in terms of materials and structural design technology.

- It could be implemented in a short time frame on all buoys with simplicity of construction as many other materials such as GRP can be obtained with high strength.

#### C. 4 Economic Impact

- Cost to design and test would be small.
- Cost to manufacture and implement should be comparable to current cage structure.
- Capital cost would be the same.
- Operating and maintenance costs would decrease substantially for maintaining cage structure.

#### C. 5 Miscellaneous

- No significant impact.

#### C. 6 Special Functions

- Should help increase lighted buoy and sound signal effectiveness as heavier and more powerful payloads could be fitted to the buoy.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.	1	<u>IMPROVEMENTS TO EXISTING BUOYS</u>
TECHNOLOGY NO.	1.3	<u>BATTERY POCKETS AND VENT LINES</u>

### RATIONALE

The battery pockets on lighted steel USCG buoys are cylindrical in shape while the batteries are rectangular and they are sized for primary batteries. Additionally, the battery vent pipes have tended to be clogged thereby restricting the air flow to the batteries. Improvements in these two areas will provide more space within the buoy hull and extend the battery life, respectively.

### APPROACH

Investigate the USCG developments in these two areas (accomplished independently by District o.a.n. offices). Review and expand upon the solutions found by the Districts, if any, and develop a uniform approach for modifying the battery pockets in existing buoys and for improving the design of battery vent lines. Prepare budgetary cost estimates for incorporating these two modifications into steel USCG buoys.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            1        IMPROVEMENTS TO EXISTING USCG BUOYS

**TECHNOLOGY NO.**       1.3      BETTER VENTING AND/OR CHANGING SHAPE OF  
BATTERY POCKETS

**A. AREA OF APPLICABILITY**

All USCG steel lighted buoys.

**B. COMPONENTS REPLACED**

No components are replaced; however, existing vent lines and battery pockets are modified.

**C. IMPACT**

C. 1 Operational Effectiveness

- Venting will increase the reliability and longevity of batteries.

C. 2 Servicing and Handling

- Battery pocket change will provide easier battery handling.
- Better venting would increase battery life and thereby improve maintenance frequency and increase relief cycle.

C. 3 Logistics

- The technology is available and can be introduced quickly.

- The changes would be simple and compatible with current systems and operations.
- Applicable to all buoys with battery power sources.

C. 4 Economic Impact

- The changes are not expected to cost any more than current systems.
- Savings in battery costs should be expected in terms of at least a 50% increase in battery life from 2 years to 3 years.
- Savings in battery servicing costs should be expected in terms of a 25% decrease in servicing.

C. 5 Miscellaneous

- Should be perfectly acceptable to user.

C. 6 Special Functions

- No significant impact.



## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.           1       IMPROVEMENTS TO EXISTING BUOYS  
TECHNOLOGY NO.       1.4     QUICK ACTING BUOY HATCH COVERS

### RATIONALE

The USCG has utilized various hatch securing configurations on its buoys including clamps, V-bands and swing bolts. Reportedly each of these has problems with the requirement to seal and prevent leakage.

Quick-acting buoy hatch covers have been developed by the Japanese, presumably in an effort to provide for quicker access to components during maintenance operations. The advantage of faster component access must be weighed against possible problems such as watertight integrity and development costs as well as the USCG's actual need for such hatch covers. Vandalism is probably a greater problem in the U.S. and hence a potential drawback for easier access.

### APPROACH

Determine problems with USCG hatch closures. Obtain additional information on the Japanese designs. Determine cost benefits.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**        1        IMPROVEMENTS TO EXISTING USCG BUOYS  
**TECHNOLOGY NO.**    1.4    QUICK ACTING BUOY HATCH COVERS

**A. AREA OF APPLICABILITY**

All USCG lighted steel buoys with battery pockets.

**B. COMPONENTS REPLACED**

Current hatch covers and securing devices.

**C. IMPACT**

C. 1 Operational Effectiveness

- Reliability increased.

C. 2 Servicing and Handling

- Easier to operate.

C. 3 Logistics

- Technology appears to be available in Japan.

C. 4 Economic Impact

- Assume 25% increase in capital cost over current and this is offset by fewer necessary replacements.
- Maintenance costs reduced due to time saved on buoy tender.

C. 5 Miscellaneous

- Should be perfectly acceptable to user.
- Applicable to all steel buoys having batteries.
- More susceptible to vandalism.

C. 6 Special Functions

- No significant impact.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.	<u>1</u>	<u>IMPROVEMENTS TO EXISTING USCG BUOYS</u>
TECHNOLOGY NO.	<u>1.5</u>	<u>FREE HANGING PIECES OF CHAIN IN TAIL TUBE TO REDUCE FOULING</u>

### RATIONALE

The British have been using freely hanging chain in the counterweight tubes of their large lighted buoys to prevent marine growth accumulation. The application of such an anti-fouling technique requires that the counterweight tube be hollow and open to the sea. The only standard USCG buoys with this type of counterweight configuration are the large sea buoys with wave activated generators and sound buoys.

### APPROACH

Identify the USCG buoys to which this concept might be applicable. Determine the severity of the problem. If advantage appears, develop a prototype design for the installation.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            1        IMPROVEMENTS TO EXISTING USCG BUOYS

**TECHNOLOGY NO.**        1.5      FREE HANGING PIECES OF CHAIN IN TAIL TUBE  
TO REDUCE MARINE FOULING

**A. AREA OF APPLICABILITY**

Tail tube buoys with wave activated generators and tail tube sound buoys.

**B. COMPONENTS REPLACED**

None. The chain would be an addition.

**C. IMPACT**

C. 1 Operational Effectiveness

- Increased reliability.

C. 2 Servicing and Handling

- Decreased maintenance in terms of cleaning the tail tube of marine growth.

C. 3 Logistics

- The technology has been tried and proven in Japan.

- The changes would be simple and compatible with current systems and operations.

**C. 4 Economic Impact**

- The changes are of small cost compared to maintenance savings.

**C. 5 Miscellaneous**

- Should be perfectly acceptable to user.
- Applicable to all steel buoys having open tail tubes.

**C. 6 Special Functions**

- Will increase the effectiveness of sound and wave-powered buoys.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            2        BUOY CONSTRUCTION MATERIALS  
TECHNOLOGY NO.        2.1      FOAM MATERIAL FOR BUOYS

### RATIONALE

The use of ionomer foam or similar substance as a buoy construction material offers several advantages. First, the material exhibits excellent damage resistance characteristics which would improve a buoy's ability to survive collisions. Second, the material is lightweight, which would improve ease of handling and safety during buoy operations. Finally, ionomer foam may be pigmented throughout so that a buoy would retain its color characteristics even when damaged. The USCG has already applied ionomer foams to a family of unlighted buoys, but there are many more design possibilities that may be investigated.

### APPROACH

Study the impact of the use of ionomer foam and its equivalents as a buoy construction material. This study should weigh the benefits listed above against potential problem areas such as development cost, material cost, motion effects, and any other problems revealed by previous USCG experience with the material.

## TECHNOLOGY BACKGROUND FOR EVALUATIONS

CATEGORY NO.           2       BUOY CONSTRUCTION MATERIALS

TECHNOLOGY NO.       2.1   FOAM MATERIAL FOR BUOYS

### A. AREA OF APPLICABILITY

All USCG buoys.

### B. COMPONENTS REPLACED

If foam buoys were determined to be suitable for all applications then in principle they could replace every non-foam buoy.

### C. IMPACT

#### C. 1 Operational Effectiveness

- If a foam buoy is designed to behave like existing non-foam buoys then the principal differences will be those of the construction material itself.
- If the material can be surface hardened to resist damage by ice then it is possible that in all the environmental conditions found in the USCG system foam would result in a buoy that would best survive collisions.
- Foam buoys can easily be configured to demonstrate visual significance.
- If a commercial SR-6 radar reflection is used, effectiveness as a radar target will be increased.

#### C. 2 Servicing and Handling

- As foam buoys for the same application as a steel buoy are known to be much lighter the equipment and facilities to handle, safety in handling, and number of personnel required in servicing might be reduced.



### C. 3 Logistics

- Foam buoy design and construction technology is here.
- All applications of foam buoys to date have indicated that the technology can be implemented and is compatible with existing USCG support systems.

### C. 4 Economic Impact

- The principal capital cost savings will be the difference in cost of steel versus foam buoys. As the USCG has a class of unlighted foam buoys for which purchase prices are known, this difference can be estimated. For smaller buoys foam is currently more expensive while for larger buoys steel is.
- Maintenance cost reductions should accrue as the foam may not require the extensive re-furbishing that must be given to steel buoys every six years. Foam buoys will not sink, even if their shell is damaged.
- Disposal of foam material at the end of the buoy's useful life may prove to be costly.

### C. 5 Miscellaneous

- As the users are currently utilizing foam buoys they should be willing to accept the technology if it is able to properly carry out the intended function.
- It is noted that in some USCG District interviews certain respondents did not believe foam buoys are working as well as steel under certain circumstances.

### C. 6 Special Functions

- Effectiveness as lighted buoys, ice buoys and fastwater buoys has not been exhaustively proven.
- Foam buoys lack ice resistance. To resist ice damage the buoy surface would have to be adequately hardened or protected.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            2        BUOY CONSTRUCTION MATERIALS  
TECHNOLOGY NO.        2.2      ELASTOMER SKIN FOR BUOYS

### RATIONALE

Several U.S. and foreign manufacturers have commercially available buoys constructed of foam and GRP with elastomer skin. In the U.S., Seaward International (SI), Urethane Technologies (UT), and Tideland Signals (TS) are three such manufacturers. SI's "Sea Float" style buoy has a steel core surrounded by rigid closed cell foam covered with a resilient urethane elastomer skin. UT's "Collision Survivable" buoys are constructed of closed cell crosslined poly-ethylene foam with a tough polyurethane skin. TS has a plastic "SB-138 Sentinel" buoy which has a fiberglass core and the outside of buoy body is shielded by a 4" thick elastomer skin. In England, Hippo Marine has a 2.5m. buoy with lightweight foam interior, and polyurethane elastomer exterior. Balmoral's EF20L series buoys are manufactured of foam with elastomer exterior. It has been stated by many during worldwide surveys that foam buoys with elastomer skin hold a great deal of promise for being the navigation buoy of the future. This technology should be investigated to determine the benefit of this type of construction material.

### APPROACH

Review in detail the performance characteristics, construction methods, and costs of elastomer skin buoys. Investigate the applicability of such material for USCG buoy types and sizes. Application to steel buoys should also be considered. Determine the budgetary costs.

## TECHNOLOGY BACKGROUND FOR EVALUATIONS

CATEGORY NO.            2            BUOY CONSTRUCTION MATERIALS

TECHNOLOGY NO.        2.2        ELASTOMER SKINS FOR BUOYS

### A. AREA OF APPLICABILITY

All USCG buoys subject to risk of collision with ships.

### B. COMPONENTS REPLACED

- Steel buoys would be completely replaced with new foam/ elastomer buoys.
- Elastomer skins could be added to existing foam buoys.

### C. IMPACT

#### C. 1 Operational Effectiveness

- Will increase the survivability and reliability of all buoys subjected to collisions due to a reduction in discrepancies. Assume 50% reduction in loss.

#### C. 2 Servicing and Handling

- Maintenance frequency will be affected in terms of reduced visits to repair collision damage. i.e. no on-site welding.

C. 3 Logistics

- The technology is available although not field tested for certain applications like fitting to steel buoys.

C. 4 Economic Impact

- The cost of application should be no more than 25% of the gain (decreased cost) due to the greater survivability to collisions.
- There will be a reduction in lost buoys.

C. 5 Miscellaneous

- No acceptance expected.
- If fewer buoys are lost then there will be a reduction in the need of spares.

C. 6 Special Functions

- Increased resistance to damage in ice and river conditions.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            2        BUOY CONSTRUCTION MATERIALS  
TECHNOLOGY NO.        2.3      FRP & GRP MATERIALS

### RATIONALE

The use of GRP or FRP as a buoy construction material has been avoided in the USCG, mainly due to some bad experiences with these materials during R&D projects in the early and mid 1970's. There are many countries and manufacturers around the world who have been using GRP and FRP for their buoys with quite a bit of success. These include England's "Balmoral Group, Ltd.", "Pharos Marine, Ltd.", and "Reinforced Plastic Structures", Japan's "Ryokuseisha Corp" and "Nippon Kogi Kogyo Co.", France's "Gisman Co.", India's "ANA Navoids, Ltd.", and in the U.S. "Tideland Signal Corp." and "Automatic Power, Inc.". The records and illustrations of FRP/GRP buoys manufactured by these firms are included in the BTIS. It would seem that the technology with regard to GRP and FRP has advanced significantly since the USCG's early efforts and that these materials may now be suitable for consideration as a construction material for future buoys. The use of FRP and/or GRP for buoy construction would result in lighter buoys which may improve buoy handling operations and safety.

### APPROACH

Evaluation of this technology should begin with a review of the strength and durability characteristics of "state-of-the-art" FRP and GRP materials in comparison with those used with earlier USCG designs. The experience of foreign authorities and manufacturers should also be investigated. The handling and safety benefits of this material should be weighed against possible problem areas such as durability, maintenance, material cost and buoy motions.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            **2**        **BUOY CONSTRUCTION MATERIALS**  
**TECHNOLOGY NO.**       **2.3**     **GRP/FRP BUOYS MATERIAL FOR BUOYS**

**A. AREA OF APPLICABILITY**

All USCG buoys except those manufactured of foam.

**B. COMPONENTS REPLACED**

If GRP/FRP buoys were determined to be suitable for all applications then in principle they could replace every non-foam buoy.

**C. IMPACT**

**C. 1 Operational Effectiveness**

- If a GRP/FRP buoy is designed to behave like existing non-GRP/FRP buoys then the principal differences will be those of the construction material itself.
- If the GRP/FRP can be utilized in conjunction with an elastomer skin to help it resist collision/impact damage then it is possible that in all environmental conditions found in the USCG system GRP/FRP would result in a buoy that would better survive collisions/impacts.

**C. 2 Servicing and Handling**

- As GRP/FRP buoys for the same application as steel buoys are known to be somewhat (Note: check Tidelands) lighter, the equipment and facilities and the number of personnel required in servicing might be reduced and as a result safety in handling might be improved.

### **C. 3 Logistics**

- GRP/FRP buoy design and construction technology has developed over the years and is known.
- The reported significant implementation of the technology has occurred mostly overseas and has met with mixed success. The USCG experience has not been successful but the outcome has been identified as most likely being due to a less than optimum utilization of the technology.
- As many of the complaints about GRP/FRP buoys are the damage they can sustain on impact with other objects, the technology should also utilize the elastomer skin technology as a means of protection. This has been accomplished by some, e.g. Tidelands.

### **C. 4 Economic Impact**

- The capital cost of a fiberglass buoy should be about the same as a steel buoy of comparable size and sea-keeping ability (Ref.: Tidelands).
- Maintenance cost reductions should accrue as the GRP/FRP buoys may not require the extensive refurbishment that must be given to steel buoys every six years. Foam-filled GRP/FRP buoys will not sink even if their shell is damaged.

### **C. 5 Miscellaneous**

- As the users are aware, GRP/FRP buoy technology is being utilized around the world they should be willing to try it.
- However, as there have been unsuccessful experiences both by the USCG and others abroad, there may be some resistance to acceptance.
- The ability to mold the material will provide the opportunity to conceal components to reduce theft/or vandalism.

### **C. 6 Special Functions**

- Effectiveness as a lighted buoy, ice buoy and fastwater buoy has not been exhaustively proven.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            2        BUOY CONSTRUCTION MATERIALS  
TECHNOLOGY NO.        2.4      OFF THE SHELF PLASTIC/FOAM BUOYS

### RATIONALE

There are many types of plastic and foam buoys constructed by domestic and foreign manufacturers using the material technologies of 2.1, 2.2 and 2.3, i.e. foam, elastomer skin, and FRP/GRP. When the benefit of the materials are identified, a first step should be to investigate the advantages of the buoys constructed of this material and their transportability into the USCG system.

### APPROACH

From the BTIS database and other sources, the buoys constructed of the most promising materials will be identified. Technical, performance, and cost data will be obtained and the economic viability of introducing the buoy into the USCG system determined. As these buoys are intended for varying conditions and applications, it is not realistic to evaluate them all together; instead they should be evaluated by the environment in which they will be deployed, .i.e., open sea, river, ice, etc.



## **TECHNOLOGY BACKGROUND FOR EVALUATIONS**

**CATEGORY NO.**            **2**        **BUOY CONSTRUCTION MATERIALS**  
**TECHNOLOGY NO.**       **2.4**      **OFF THE SHELF PLASTIC/FOAM BUOYS**

### **A. AREA OF APPLICABILITY**

All USCG buoys except existing foam buoys.

### **B. COMPONENTS REPLACED**

If they were determined to be suitable for all applications then in principle they could completely replace all steel and plastic buoys. The existing foam buoys may be modified to suit the new design (such as adding an elastomer skin).

### **C. IMPACT**

#### **C. 1 Operational Effectiveness**

- Effectiveness as a daytime aid will be improved with those having solid superstructures.
- If an off the shelf plastic/foam buoy behaves like existing buoys then the principal differences will be those of the material of construction itself.
- It is expected that the plastic/foam buoys, when filled with foam or if foam core throughout, will have better survivability in collisions.

## C. 2 Servicing and Handling

- As plastic/foam buoys for the same application as a steel buoy are known to be somewhat lighter, the equipment and facilities to handle and number of personnel required in servicing might be reduced.
- Access to components has been enhanced in some manufacturer buoys.

## C. 3 Logistics

- As the buoys in question have already been implemented by others, logistical impacts/problems are virtually non-existent in the technical context.
- In the policy arena, most of the buoys are of designs proprietary to the manufacturer and therefore it would be difficult at best to have meaningful bid competition. However, a functional type specifications can be prepared.

## C. 4 Economic Impact

- As the buoys in question have already been implemented by others, the cost to design and implement has already been absorbed.
- The capital cost of the unlighted buoys is expected to be nearly equal to steel buoys on the average. USCG unlighted foam buoys have demonstrated this. However, the cost of lighted plastic foam buoys is assumed to be 89% of the steel.
- Maintenance cost reductions should accrue as the plastic/foam buoys may not require the extensive refurbishment that must be given to steel buoys every five years. Assume a 25% reduction in maintenance costs. As long as their core is foam, these buoys should not sink even if their exterior is damaged. Therefore, the buoy losses will be reduced.

## C. 5 Miscellaneous

- Some of the manufacturer buoys have built in provisions for resistance to vandalism and/or theft.
- As the technology is known and the USCG has used buoys constructed of these materials there should be willingness to accept the technology if the buoys are shown to be able to properly carry out the intended function.

- It is noted that in some USCG District interviews certain respondents did have doubts about plastic/foam buoys when it comes to comparisons with steel buoys in certain applications like in ice for example.
- If these buoys survive better than existing buoys then the number of spares necessary could decrease. Assume a 25% reduction in spares.

#### C. 6 Special Functions

- There are off the shelf plastic/foam buoys which are touted as being as effective as those of any material utilized by the USCG; possibly more effective in fastwater and ice; and definitely more effective in river debris conditions during impacts.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            3        BUOY FOR OPEN SEA APPLICATIONS  
TECHNOLOGY NO.        3.1     SEMI-SUBMERSIBLE HULLS

### RATIONALE

Utilization of semi-submersible type hull designs for offshore buoys may provide for a stable buoy platform with superior seakeeping qualities in those cases where a proper relationship can be obtained between wave length and frequency and hull submergence. This is especially advantageous for lighted buoys since there is less probability of the heeling motion exceeding the angle of divergence of the light, and therefore the aid would be more detectable to mariners at night. The possible disadvantages which must be considered are the increase in weight sensitivity resulting in less payload flexibility, and the costs to develop and construct.

### APPROACH

Utilizing data available in the BTIS and other literature, synthesize semi-submersible buoy concepts and evaluate their potential for reduced motion. If promise is identified, develop a prototype for analytical evaluation and testing.

## TECHNOLOGY BACKGROUND FOR EVALUATIONS

CATEGORY NO.           3       BUOYS FOR OPEN SEA APPLICATIONS  
TECHNOLOGY NO.       3.1     SEMI-SUBMERSIBLE HULLS

### A. AREA OF APPLICABILITY

Buoys exposed to significant wave action.

### B. COMPONENTS REPLACED

The entire buoy for sea applications.

### C. IMPACT

#### C. 1 Operational Effectiveness

- It is not expected that there will be any improvements and in fact the payload/support flexibility will be decreased as these types of hulls are very draft sensitive to changes in weight.

#### C. 2 Servicing and Handling

- Handling may become more difficult as the deeper draft required for the buoy hulls may increase overall height. The size of the submerged hulls may also result in a larger overall buoy envelope and weight than currently in use.

### C. 3 Logistics

- The only application of this technology has been in the area of ships and boats.
- Accordingly, it should be possible to draw upon knowledge gained with ships and boats but the result of its applications to buoys is unknown.
- It is possible that adequate immersion of the lower hulls for avoiding oscillating wave pressures will not be practical within height constraints of buoys.

### C. 4 Economic Impact

- The designs will be new and will have to be tested.
- These specialty hulls are expected to have both higher capital and maintenance costs.

### C. 5 Miscellaneous

- There will probably be some negative user acceptance because of the novelty of the concept.

### C. 6 Special Functions

- The entire purpose of this technology is to promote a greater effectiveness as a lighted buoy through increased resistance to the seakeeping motion induced by wave action.

## REVIEW OF BUOY TECHNOLOGIES

**CATEGORY NO.**            **3**        **BUOY FOR OPEN SEA APPLICATIONS**  
**TECHNOLOGY NO.**       **3.2**      **OFF THE SHELF OPEN SEA BUOYS**

### **RATIONALE**

A large number of "off the shelf" buoys have been identified both within the United States and abroad and included in the BTIS database. U.S. buoys are those of manufacturers while foreign buoys consist of both those of manufacturers and designs of national navigation authorities. It is possible that some of these buoys can be directly useable by the USCG.

### **APPROACH**

Firstly, performance criteria for open sea buoys would be developed against which off the shelf buoys could be compared. The extent to which the identified off the shelf buoys meet the performance criteria would be determined. Economic feasibility of incorporating the most promising commercially available off the shelf open sea buoys into the USCG system would be investigated, and recommendations made accordingly.

## TECHNOLOGY BACKGROUND FOR EVALUATIONS

CATEGORY NO.        3        BUOYS FOR OPEN SEA APPLICATIONS  
TECHNOLOGY NO.    3.2    OFF THE SHELF BUOYS

### A. AREA OF APPLICABILITY

All USCG buoys for open sea applications.

### B. COMPONENTS REPLACED

All buoys suffering from excessive wave induced motions which negatively affect the light signal. Also buoys shown to be less cost effective than off the shelf buoys.

### C. IMPACT

#### C. 1 Operational Effectiveness

- An off the shelf buoy could be expected to improve effectiveness as a daytime aid if its superstructure has shape significance.
- Foam filled or compartmented buoys would be expected to increase survivability in collisions.
- Some off the shelf buoys have special treatment of radar capabilities in that commercial radar reflectors are mounted in protected and conspicuous locations. This could be an improvement for radar effectiveness. Examples are the Firdell Blipper 210 Series radar reflectors and Luneburg lenses mounted on some Tideland Signals buoys.
- Some off the shelf buoys can be fitted with varying topmarks and equipment payloads. As an example, Tideland Signals' SB-138 Sentinel buoy has options for Topmarks (any IALA Regions A&B



markings), lantern guards, radar reflectors, photovoltaic modules, batteries, or daymark panels.

C. 2 Servicing and Handling

- In general, as many of the off the shelf buoys are of newer design than most USCG buoys and are sold to countries having less servicing equipment, they should exhibit some advantages.

C. 3 Logistics

- As the buoys in question have already been implemented by others, logistical impacts/problems are virtually non-existent in the technical context.
- In the policy arena, most of the buoys are of designs proprietary to the manufacturer and therefore it would be difficult at best to have meaningful bid competition.

C. 4 Economic Impact

- As the buoys in question have already been implemented by others, the cost to design and implement has already been absorbed.
- The capital cost of the buoys is expected to be approximately equal to current USCG buoys.
- Some maintenance cost reductions should accrue as some of these buoys are of newer design and sold to countries without the maintenance facilities available in the U.S.A.
- Foam and compartmented buoys should have reduced maintenance costs due to better resistance to loss in collisions.

C. 5 Miscellaneous

- As the technology is known and the USCG has previously used commercially available off the shelf buoys, some constructed with materials other than steel, there should be willingness on the part of the users to accept this technology if the buoys are shown to be able to properly carry out the intended functions.

- It is noted that in some USCG District interviews certain respondents did have doubts about plastic/foam buoys when it comes to comparisons with steel buoys. These types of buoys for harsh open sea applications are expected to have somewhat lower user acceptance as steel buoys have proven performance under these conditions.

#### C. 6 Special Functions

- From what has been observed of off the shelf buoys, their performance and effectiveness as a signalling device is expected to be equal to USCG buoys but not superior.
- Some off the shelf buoys may have superior designs for ice, fastwater and debris shedding.

## REVIEW OF BUOY TECHNOLOGIES

**CATEGORY NO.**            **4**        **RIVER BUOYS**  
**TECHNOLOGY NO.**       **4.1**    **DEBRIS SHEDDING BUOY HULLS**

### **RATIONALE**

The U.S. Coast Guard has not yet been able to develop a survivable, low cost, lightweight buoy for fast water environments, capable of shedding debris. The debris shedding capability of the current spherical USCG buoys is considered poor however, it was chosen primarily for its ability to recover from a capsize. Where debris is a problem the USCG uses small foam-filled steel buoys that are considered throw-aways as they are usually damaged and/or lost.

### **APPROACH**

Research in detail past USCG projects and foreign authority/commercial manufacturer literature on the subject of fastwater buoys and debris shedding. Identify the properties that make for good fast water and/or debris shedding buoy design. Design a new buoy system(s) to address the problems of fast water survivability and debris shedding. Study the advantages/ disadvantages of existing USCG and foreign river buoy designs including the following:

- Gilman's Log Shedding Foam Buoy
- Gilman's River Buoy Design for Canada
- Germany's Steel/Foam Inland Waterways Buoy
- Japan's (Zeni Lite) Large Fast Water Discus Buoy
- Boat Hull For High Currents
- India's Catamaran River Buoy
- Canada's (JANKO) Fast Water Buoy

## TECHNOLOGY BACKGROUND FOR EVALUATIONS

CATEGORY NO.           4       RIVER BUOYS  
TECHNOLOGY NO.       4.1     DEBRIS SHEDDING BUOY HULLS

### A. AREA OF APPLICABILITY

All USCG river buoys.

### B. COMPONENTS REPLACED

The entire buoy.

### C. IMPACT

#### C. 1 Operational Effectiveness

- As debris accumulation can completely neutralize a buoy, an improvement would increase effectiveness as a daytime visual aid and as a radar target.
- Improved debris shedding would increase survivability, position keeping and reliability.

#### C. 2 Servicing and Handling

- Access would be improved as buoys would be upright and floating properly more often. Handling safety would be improved as well.
- Maintenance frequency would be reduced as a result of reductions in debris accumulation.

#### C. 3 Logistics

- There are a number of off the shelf buoys touted as having demonstrated debris shedding capability, however, the best technology which allows this to be accomplished has not been identified.

- It is anticipated that a short R & D study can be conducted to identify the technology and prepare a prototype design. If this should prove effective, production could begin in a moderate time frame.
- The principal difference between the new and existing river buoy types would be a modification of the buoy hull within current geometric boundaries and probably a re-positioning of the mooring attachment. Accordingly the buoy would be similar to existing types and be adaptable to the system in all respects.

#### C. 4 Economic Impact

- Cost to design and test is expected to be minimal for a new buoy design.
- Cost to manufacture and implement is expected to be identical to current buoys and the capital cost is expected to be nearly identical as well.
- Annual operating and maintenance costs are expected to be significantly reduced as fewer buoys will be required to replace lost buoys and fewer tender trips will be required to replace lost buoys and clear debris from other buoys.

#### C. 5 Miscellaneous

- As these buoys will be similar to existing types the user acceptance should be automatic.
- The USCG currently loses more river buoys than any other types. Accordingly, a significant inventory of the buoys must be maintained. This could be reduced by a buoy better able to survive.

#### C. 6 Special Functions

- Effectiveness in fastwater conditions is expected to increase significantly.
- Effectiveness in river conditions is expected to increase significantly.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.           4       RIVER BUOYS  
TECHNOLOGY NO.       4.2     GIMBALLED LANTERNS

### RATIONALE

The lanterns of current USCG buoys lose some of their visibility/ recognizability in cases where the buoy is heeled. In severely heeled conditions, the lantern may not be visible at all even within reasonably small distances. The effectiveness of the light signal may be much improved by installing gimballed lanterns on the ATON buoys.

### APPROACH

Research foreign navigation authority and commercial manufacturers literature to document commercially available gimbal mechanism suitable for use on buoys to install lanterns. Also establish if any U.S. manufacturers offer such equipment. Study the improvements to be obtained in the effectiveness of buoy light with the use of a gimballed buoy lantern. Determine the cost impact of acquiring such equipment, modifying the installation design, and installing the gimballed lanterns on USCG buoys. Make recommendations for adoption or rejection of this technology.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            **4**        **RIVER BUOYS**

**TECHNOLOGY NO.**       **4.2**     **GIMBALLED LANTERN TO IMPROVE LIGHT  
SIGNAL IN HEELED CONDITION**

**A. AREA OF APPLICABILITY**

Lighted USCG river buoys acted on by strong currents.

**B. COMPONENTS REPLACED**

This would actually be an add-on and not replace any existing components.

**C. IMPACT**

**C. 1 Operational Effectiveness**

- o No significant impact.

**C. 2 Servicing and Handling**

- o Provided a reliable gimbal system is adopted there should not be any increase in maintenance frequency.
- o This will be an additional component to maintain.

**C. 3 Logistics**

- o Although a specific gimbal available for navigation buoys is not known at this time, it is believed that the technology is such that a device could be designed and manufactured in a relatively short period of time.

- The device should be compatible with existing buoys with minor modification and be tible h other parts of the system as well.

C. 4 Economic Impact

- The cost of introducing such a device and maintaining it is anticipated as being moderate.

C. 5 Miscellaneous

- No significant impact.

C. 6 Special Functions

- Will increase the effectiveness of a lighted buoy in fast water.



## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.        4        RIVER BUOYS  
TECHNOLOGY NO.    4.4     OFF THE SHELF RIVER BUOYS

### RATIONALE

A large number of "off the shelf" river buoys have been identified during the worldwide surveys both within the United States and abroad. U.S. buoys are those of manufacturers while foreign buoys consist of both those of manufacturers and designs of navigation authorities. It is possible that some of those buoys can be directly purchased and used by the USCG to replace the existing river buoys which have a very high degree of annual losses.

### APPROACH

Firstly, performance criteria for river buoys would be developed against which off the shelf buoys could be compared. The extent to which the identified off the shelf buoys meet the performance criteria would be determined. Economic feasibility of incorporating the most promising off the shelf river buoy into the USCG system would be investigated and recommendations made accordingly.

## **TECHNOLOGY BACKGROUND FOR EVALUATIONS**

**CATEGORY NO.**            4        RIVER BUOYS  
**TECHNOLOGY NO.**       4.4      OFF THE SHELF BUOYS

### **A. AREA OF APPLICABILITY**

All USCG buoys deployed in rivers/estuarine environments that have experienced damage and/or loss due to current, collisions, debris accumulation, etc.

### **B. COMPONENTS REPLACED**

The complete buoy is replaced.

### **C. IMPACT**

#### **C. 1 Operational Effectiveness**

- Daytime visibility should be improved with the use of buoys better able to negotiate the prevailing conditions. Radar effectiveness should be improved for the same reason.
- As better debris shedding characteristics would be expected for a buoy to be considered, increased survivability in these types of collisions should be a result.

#### **C. 2 Servicing and Handling**

- Equipment, safety, maintenance frequency and personnel requirements should be improved with buoys better able to negotiate the prevailing conditions.

### C. 3 Logistics

- As the buoys in question have already been implemented by others, logistical impacts/problems are virtually non-existent in the technical context.
- In the policy arena, most of the buoys are of designs proprietary to the manufacturer and therefore it would be difficult at best to have meaningful bid competition.

### C. 4 Economic Impact

- As the buoys in question have already been implemented by others, the cost to design and implement has already been absorbed, except for testing.
- The capital cost of the buoys is expected to be approximately equal to current USCG buoys. However, since the losses are reduced, overall system cost is less.
- The operating and maintenance costs are expected to decrease significantly.

### C. 5 Miscellaneous

- As the technology is known and the USCG has used some of these off the shelf buoys constructed of various materials, there should be willingness to accept the technology if the buoys are shown to be able to properly carry out the intended function.
- Fewer aids will be needed if fewer losses take place.

### C. 6 Special Functions

- The effectiveness of these buoys is expected to be superior in fast water and river environments.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            5        BUOYS FOR ICE ENVIRONMENT  
TECHNOLOGY NO.        5.1      COMPARTMENTED ICE BUOYS

### RATIONALE

Loss of buoyage due to damage suffered in collisions is one of the most troublesome problems faced by navigation authorities. This is especially true for buoys operating in ice environments since collisions with ice flows often result in penetration of the buoy hull and sinking of the ATON. Compartmentalizing of the buoy hull would allow an ice buoy to sustain a greater amount of damage in service without being lost entirely. This would allow the USCG to retrieve and repair a larger proportion of their ice buoys than they currently do. For their size, ice buoys tend to be more expensive than buoys built for regular service, so the cost savings that would result from recovering more of them should be significant. Furthermore, the added structural strength afforded by the compartment bulkheads may allow the use of thinner shell plating (to the extent allowable to avoid ice penetration) and therefore offset the added weights of bulkheads.

### APPROACH

The evaluation should start with a review of the Finnish and Norwegian steel ice buoy designs in comparison with current USCG designs. Next, the number of USCG ice buoys lost each season should be determined. This will provide a basis for the evaluation of economic impact.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**        5        BUOYS FOR ICE ENVIRONMENTS  
**TECHNOLOGY NO.**    5.1      COMPARTMENTED ICE BUOYS

**A. AREA OF APPLICABILITY**

All USCG ice buoys of which there are approximately 860.

**B. COMPONENTS REPLACED**

The entire ice buoy would be replaced with the new compartmented design.

**C. IMPACT**

**C. 1 Operational Effectiveness**

- If the compartmented buoys are able to maintain their position more often, the daytime visibility and radar effectiveness will be improved.
- Increased survivability will result.

**C. 2 Servicing and Handling**

- Risks associated with recovery of lost buoys will be decreased since there will be fewer lost buoys.
- On the average an increased relief cycle is expected as these buoys will be better able to survive the effects of ice. Consequently time should be saved in replacing damaged buoys and searching for and replacing lost buoys.

- In all other characteristics they will be identical to existing buoys.

### C. 3 Logistics

- It is believed the technology is available and can be implemented.
- Compartmentation of these buoys is likely to cause a 25% increase in the complexity of a buoy hull.

### C. 4 Economic Impact

- Design and test costs will be small as the technology is available and not complicated.
- Capital costs of buoys are expected to increase 15%.
- Operating and maintenance costs are expected to decrease 10%.
- Assume that 25% of existing.

### C. 5 Miscellaneous

- User acceptance is expected to be good as few people probably enjoy replacing an ice buoy and this technology is expected to reduce losses.
- It is likely that with a lower expectation of buoy loss expected, fewer spares can be stockpiled.

### C. 6 Special Functions

- Effectiveness in ice conditions will improve.
- Therefore effectiveness as a light will also.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.           5       BUOYS FOR ICE ENVIRONMENT  
TECHNOLOGY NO.       5.2     PLASTIC SPAR BUOYS FOR ICE SERVICE

### RATIONALE

The use of plastic for buoys which service harsh environments has historically been avoided by the USCG because the plastic materials just could not endure collisions and high sea loads. The use of plastic spar buoys for ice service in countries such as Finland and Norway indicate that the technology with regard to these materials has advanced to the point where plastics can now be considered a viable option. The advantages of plastic spar buoys include the following:

- a) Lighter weight than steel ice buoys.
- b) Spar design allows the buoy to be pushed under the ice floes without snagging and being dragged off-station.
- c) Since there is no steel to be welded during repairs, there is no problem with filling them with foam to provide added damage survivability.
- d) Since radar attenuation through plastic is relatively small, radar reflectors can be mounted inside the tube where they are less likely to be damaged by contact with ice.

These advantages are tempered by disadvantages in terms of material ruggedness, on-site repairability, and visual perceptibility, however an evaluation of the pro's and con's of this concept seems worthwhile.

### APPROACH

The evaluation should start with a review of the Finnish and Norwegian spar ice buoy designs contained in the BTIS. Then the evaluation of material technology carried out by the USCG in Category 2 should be introduced. Next, an evaluation should be developed for those areas where this technology may prove especially advantageous or deficient.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            5        BUOYS FOR ICE ENVIRONMENT  
**TECHNOLOGY NO.**        5.2      PLASTIC SPAR BUOYS FOR ICE SERVICE

**A. AREA OF APPLICABILITY**

All USCG ice buoys.

**B. COMPONENTS REPLACED**

The entire buoy, both unlighted and lighted.

**C. IMPACT**

**C. 1 Operational Effectiveness**

- Effectiveness as a radar target should increase since radar attenuation through plastic is relatively small and therefore reflector can be mounted inside the tube where they are less likely to be damaged by contact with ice.
- Survivability will be increased as these buoys can be filled with foam.

**C. 2 Servicing and Handling**

- These buoys have become popular in countries such as Finland and Norway so it is believed they provide optimum maintenance and servicing characteristics.



- Equipment, facilities and servicing facilities would be required to handle lighter buoys of plastic material. It is not believed this will have any significant impact.

### C. 3 Logistics

- The technology is available in other countries and appears simple enough that implementation could occur rapidly.
- The buoys should be compatible with the existing system.

### C. 4 Economic Impact

- Design and test costs should be low as the technology is available.
- Capital costs are expected to be 50% less due to simplicity of the buoys.
- Maintenance costs are expected to be 50% less due to greater survivability of the buoy.

### C. 5 Miscellaneous

- User acceptance is not expected to be a problem as long as the buoys perform.
- The impact on the total number of aids would be to reduce stockpiles as these buoys would have a greater survivability and therefore require fewer spaces.

### C. 6 Special Functions

- Effectiveness in ice conditions is expected to show a significant improvement.

## REVIEW OF BUOY TECHNOLOGIES

**CATEGORY NO.**            6        BUOYANT BEACONS (BB)  
**TECHNOLOGY NO.**        6.1      MOORING CONCEPTS

### RATIONALE

Task A study results have indicated that the USCG designed buoyant beacon has experienced problems with damage to the bottom hinge or universal joint. It has been suggested during the interviews that the bottom hinge problem, attributed to high loading, can be alleviated by the use of a taut-moor which has increased flexibility. In any event, a re-evaluation of mooring concepts appears warranted to identify the best concept of the following in service applications.

1.      Tension Leg Mooring to Absorb Shock and Vibration

This type of mooring is comprised of one or more tautflexible lines, i.e. cable or chain. It offers the advantage of being more flexible than the stiff pipe usually used for articulated beacons, particularly with the oscillating forces developed by a seaway acting on the buoy or the shock of a vessel collision.

2.      Resinex Elastic Beacon for 100 Meter Depth

This is a buoyant beacon with a chain or cable substituted for the lower section of the pipe stanchion.

The most significant improvements found in Resinex' Elastic Beacon were those relative to the float configuration to enable it to adapt to and perform well in all environments, as well as those relative to the materials of metallic parts such as the shackle connecting the riser to the sinker.

3.      Resinex' Telescoping Buoyant Beacon for South Africa

In the future, Resinex has said that they will have a buoyant beacon with a telescoping mast to accommodate tide changes.

4. **Automatic Power's BB with Foam Float and Shackled Connection**

Automatic Power manufactures a buoyant beacon constructed of steel with a foam filled steel floating chamber and a shackled connection to the sinker. The deepest water depth for which they have manufactured a beacon is 44 feet but they have designs for water depths to 150 feet.

5. **Ryokuseisha's Universal Joint**

The Ryokuseisha buoyant beacons have both floatation and buoy bodies made of steel. They have a patented universal joint connecting the buoy pipe to the sinker. They can accommodate a 2 meter variation in tide in Tokyo Bay.

6. **Tideland's Taut-Moored BB with Surlyn Foam Float**

Tideland manufactures the SAB-12 Sentinel Buoyant Buoy. This has been a successful design with the use of a taut line moor between the sinker and the hull which avoids the build-up of structural loads that can occur in more rigid connections like a universal joint. The taut moor is pre-tensioned by use of a buoyancy chamber constructed of foam with steel end plates. This taut moor beacon reportedly has had a good service record.

7. **Floatex Elastic Beacons**

A significant advantage of this BB design is the use of an elastic tubular rubber joint connecting the beacon to the sinker which absorbs any vibrations that might arise in the system. Also beneficial with this type of joint is that it is electrically non-conductive, reducing a possible source of corrosion.

8. **Chain Connection of Sinker to Riser**

The benefit to be gained from this type of mooring is the reduction of vibratory stress due to environmental forces acting on the buoy body and universal joint. This technology is similar to those expressed in items 1, 2 and 6 above.

## **APPROACH**

An R & D approach to these technologies would be:

- i. Research in detail the above past or current projects and foreign literature on the subject of taut mooring and tension leg, universal joint designs, and floatation design of buoyant beacons.
- ii. Identify the characteristics that are beneficial and/or detrimental in these designs. For example, by replacing the pipe column and universal joint with a taut mooring, the rotational fixity of the system would be lost. This would be a disadvantage for directed signaling systems and solar collection panels.
- iii. Analyze and quantify the hydrostatic and hydrodynamic properties, including wave excitation forces, of the current and proposed systems.
- iv. Redesign the system hardware to address the problems of weak points in the current buoyant beacon.

## **TECHNOLOGY BACKGROUND FOR EVALUATIONS**

**CATEGORY NO.**            6        BUOYANT BEACONS  
**TECHNOLOGY NO.**       6.1      EVALUATION OF MOORING CONCEPTS

### **A. AREA OF APPLICABILITY**

All USCG buoyant beacons.

### **B. COMPONENTS REPLACED**

Mooring elements and lower section of buoyant beacon if a better mooring concept that the current universal joint is identified.

### **C. IMPACT**

#### **C. 1 Operational Effectiveness**

- Resistance to damage of joint in collisions will be increased.
- Reliability will be increased.

#### **C. 2 Servicing and Handling**

- Maintenance frequency and relief cycle will be reduced.
- All other characteristic functions will be identical.

**C. 3 Logistics**

- The mooring concepts to be evaluated are in service around the world.
- The taut moor system is simpler than the current universal joint design.
- Other requirements are similar.

**C. 4 Economic Impact**

- The technology is known so that the cost to design, test and implement should be minimal.
- If a better joint is identified maintenance costs should be reduced.
- If a taut moor concept is selected capital costs would be reduced as well.

**C. 5 Miscellaneous**

- Any concept should be acceptable as another.

**C. 6 Special Functions**

- The taut moor concept would more easily allow greater depth applications.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.           6       BUOYANT BEACONS  
TECHNOLOGY NO.       6.2   OFF THE SHELF BEACONS

### RATIONALE

A number of "off the shelf" buoyant beacons have been identified both within the United States and abroad and included in the BTIS. It is possible that these can be directly useable by the USCG.

### APPROACH

Firstly, performance criteria for buoyant beacon applications would be developed against which off the shelf beacons could be compared. The available beacons can then be evaluated taking into account the mooring conclusions of Technology No. 6.1 (Buoyant Beacon Mooring Concepts).

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            **6**        **BUOYANT BEACONS**

**TECHNOLOGY NO.**       **6.2**      **OFF THE SHELF BUOYS**

**A. AREA OF APPLICABILITY**

All USCG buoyant beacons.

**B. COMPONENTS REPLACED**

Substitute for current articulated beacons.

**C. IMPACT**

**C. 1 Operational Effectiveness**

- Resistance to damage of point in collisions could be increased.
- Reliability may be increased by a better design.

**C. 2 Servicing and Handling**

- Maintenance frequency and relief cycle should improve if a better design is identified.



### C. 3 Logistics

- As the buoys in question have already been implemented by others, logistical impact/problems are virtually non-existent in the technical context.
- In the policy arena, most of the beacons are of designs proprietary to the manufacturers and therefore it would be difficult at best to have meaningful bid competition.

### C. 4 Economic Impact

- As the beacons in question have already been implemented by others, the cost to design and implement has already been absorbed.
- The capital cost of the beacons is expected to be approximately equal to current USCG units.
- Maintenance cost reduction should accrue in a design that is more reliable.

### C. 5 Miscellaneous

- As the technology is known and the USCG has used similar buoyant beacons, acceptance should be complete.
- If a better beacon is available, the number of spaces could be decreased.

### C. 6 Special Functions

- Currently available BB's are advertised for application at depths greater than those for the USCG beacons.
- Better performance in current may be possible.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            7        BUOYS FOR EMERGENCY MARKING  
TECHNOLOGY NO.        7.1      INFLATABLE BUOYS

### RATIONALE

Inflatable danger buoys for off station marking would be easier to keep on hand as spares on a buoy tender than conventional discrepancy buoys although this would probably be a consideration only on smaller tenders. They would also be useful as helicopter deployed buoys due to their reduced weight and size.

### APPROACH

The only known buoy of this type has been developed by the British. It is a complex design intended for deployment from helicopter to provide temporary marking for exposed offshore buoys when lost and for any new and unexpected obstructions such as a ship sinking. The first step should be to investigate this system, identify its characteristics and determine if its technology is transportable.

## TECHNOLOGY BACKGROUND FOR EVALUATIONS

CATEGORY NO.           7       BUOYS FOR EMERGENCY MARKING  
TECHNOLOGY NO.       7.1     INFLATABLE BUOYS

### A. AREA OF APPLICABILITY

To replace the current USCG discrepancy buoy on small tenders where space is at a premium and to serve as helicopter deployable emergency buoys.

### B. COMPONENTS REPLACED

Some current discrepancy buoys.

### C. IMPACT

#### C. 1 Operational Effectiveness

- No significant impact.

#### C. 2 Servicing and Handling

- The equipment and facilities required to deploy the inflatable buoys will be less than required for the discrepancy buoys.
- The number of servicing personnel should be less for deployment as a result of reduced buoy size when stowed and lower weight.

### C. 3 Logistics

- The technology for constructing inflatables is available, even if a specific buoy application is not.
- Incorporation of the technology into a reliable buoy will take some adaption.
- The extent of application will be very limited.
- Time frame will be moderate.
- Compatibility with buoy tenders will be very good as this type of buoys will require much less space and be much lighter.

### C. 4 Economic Impact

- Cost to design and test is expected to be significant.
- Cost to manufacture and implement is expected to be identical to that of current discrepancy buoys.
- Capital cost is expected to be twice that of current discrepancy buoys.
- Operating costs are expected to decrease as smaller tenders can be utilized for deployment. This should more than offset the increased capital cost.

### C. 5 Miscellaneous

- User acceptance would be expected as the buoy would be smaller and lighter than others.
- The impact on the number of aids will be small but could result in a reduction of discrepancy buoys as these buoys would be easily transportable.

### C. 6 Special Functions

- It is expected that the inflatable buoy can be designed so that it is equivalent in effectiveness to the existing discrepancy buoy.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.	8	<u>POWER SOURCES AND PAYLOAD</u>
TECHNOLOGY NO.	8.1	<u>DECK OR SUPERSTRUCTURE MOUNTED BATTERY BOXES</u>

### RATIONALE

The advent of alternative primary power sources such as solar panels and WATG's has allowed the number of batteries necessary for lighted buoys to shrink, thus reducing the space requirements for battery storage. Consequently, batteries may now be housed in protective cases outside of the buoy hull. Battery boxes mounted on the buoy deck or in the superstructure offer several advantages which make them worth evaluating. First, they allow the elimination of the battery pockets that are prevalent in current USCG buoy designs. This will tend to make the buoy somewhat lighter and allow for more flexibility in the application of foam materials and subdivision. These battery boxes also allow easier access for servicing, thus simplifying buoy maintenance operations. Finally, superstructure mounted battery cases allow for more flexibility in modularization of payload components.

### APPROACH

The evaluation should start with a review of past USCG efforts in this area (i.e. the 4X11 buoy project) and foreign designs incorporating deck-mounted battery compartments.

## TECHNOLOGY BACKGROUND FOR EVALUATIONS

CATEGORY NO.           8       POWER SOURCES AND PAYLOAD  
TECHNOLOGY NO.       8.1     DECK OR SUPERSTRUCTURE MOUNTED  
  BATTERY BOXES

### A. AREA OF APPLICABILITY

All lighted USCG buoys.

### B. COMPONENTS REPLACED

Will replace battery pockets. This will tend to make the buoy somewhat lighter and allow for more flexibility in the application of foam materials and subdivision; provide for easier servicing and maintenance; and provide more flexibility in modularization of payload components.

### C. IMPACT

#### C. 1 Operational Effectiveness

- As this will allow for compartmentation of the buoy it will lead to greater survivability in collisions.
- As the buoy should be lighter as a result of elimination of battery pockets it could sustain more payload weight provided the battery box does not degrade stability.

#### C. 2 Servicing and Handling

- Access to batteries will be greatly improved.

- Handling requirements and safety will be improved.
- Number of required service personnel may be reduced.

### C. 3 Logistics

- All logistic aspects are positive.
- All lighted buoys could be affected and this represents approximately 20% of USCG buoys. The USCG's largest most expensive and operationally intensive buoys are all included in the buoys that would be affected.

### C. 4 Economic Impact

- Cost to design and test should be minimal.
- Cost to manufacture and implement, capital cost and operating and maintenance costs will be 50% of current (as related to battery pockets only).

### C. 5 Miscellaneous

- Resistance to vandalism and/or theft will be decreased as the batteries will be given greater exposure.
- User acceptance is expected as battery pockets and handling batteries within these are acknowledged as being less than optimum by USCG personnel in the field.
- All lighted buoys would be affected.

### C. 6 Special Functions

- No significant impact.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.	8	<u>POWER SOURCES AND PAYLOAD</u>
TECHNOLOGY NO.	8.3	<u>NEW WAVE ACTIVATED GENERATORS (WATG)</u>

The new WATG technology that has been identified is the Flex-Hose of Pharos and the inertial mechanism of Denmark. Although they both utilize wave technology, their principles of operation are quite different and accordingly they should be evaluated separately.

### Flex-Hose WATG

#### RATIONALE

One of the problems with current WATG technology is that the driving fluid is seawater, which tends to corrode and foul parts of the device. The flex-hose type of WATG, developed by Pharos Marine utilizes a closed system with fresh water as the driving fluid, thus avoiding corrosion and fouling problems. The configuration of the flex-hose system may also allow the counterweight to be incorporated into the actuation plate at the end of the hose and provide damping of the buoy motion.

#### APPROACH

The first step in the evaluation should be a review of the Pharos Marine flex-hose design. The state of development of the technology should be assessed and an estimate of the economic impact prepared.

### Inertial WATG

#### RATIONALE

As with the flex-hose WATG system, the inertial WATG design allows wave motion to be converted into electrical power while avoiding fouling and corrosion of the device. The inertial WATG design has been developed by Denmark and utilizes an oscillating spring-mass mechanical system enclosed within the buoy hull. Besides providing a closed system, the device



apparently provides significant power with relatively little wave action. The use of this technology may allow the USCG to apply WATG power generation to buoys stationed in more protected areas rather than only on exposed location buoys, which is the only application of WATGs so far.

## **APPROACH**

The evaluation of this technology should begin with a review of Denmark's inertial WATG design. The state of development of the technology should be assessed and an estimate of the economic impact prepared.

## TECHNOLOGY BACKGROUND FOR EVALUATIONS

CATEGORY NO.           8       POWER SOURCES AND PAYLOAD

TECHNOLOGY NO.       8.3   NEW WAVE ACTIVATED GENERATORS

### A. AREA OF APPLICABILITY

USCG buoys requiring an onboard power source and located where wave action is present, even small waves.

### B. COMPONENTS REPLACED

Batteries, solar panels and other types of wave activated generators.

### C. IMPACT

#### C. 1 Operational Effectiveness

- More WATG power could result in larger electric load payloads to be installed on these buoys. Reduction in battery weight would provide additional weight for payloads.
- Reliability of WATGs could be increased.

#### C. 2 Servicing and Handling

- Access to components would be more difficult than currently.
- Some special facilities may be required.
- With an increase in components, the maintenance frequency may be increased and relief cycle shortened.
- The servicing would become more complex and the skill level of personnel would have to be expanded.
- Handling safety would be increased with a reduction in batteries.

### C. 3 Logistics

- The technology is available at a prototype stage. It is believed further extensive testing is still necessary.
- The technology will require modification of existing buoys or completely new buoys.
- The time frame to implement will be measured in years.
- The application will be to all buoys having on-board power and being located where at least minimal wave action is present.
- Reduction in the amount of batteries would free up storage and servicing space for these on buoy tenders.

### C. 4 Economic Impact

- Cost to design and test will be measured in several \$100k's of dollars as a minimum.
- Cost to manufacture and implement will be 100% more than battery solar systems. Current WATG's of turbine design are 50% more than battery solar systems.
- Capital cost will be 100% of current.
- Operating and maintenance costs will be 30% less through the savings in the elimination of significant numbers of batteries.

### C. 5 Miscellaneous

- Batteries replaced and the inaccessibility to these WATGs' components will place resistance on vandalism and/or theft.
- User acceptance is not expected to be complete but should increase as the system proves its viability.
- Although the impact on the number of aids will not be great, the impact on the number of batteries could be.

### C. 6 Special Functions

- No significant impact.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.           8       POWER SOURCES AND PAYLOAD  
TECHNOLOGY NO.       8.4     SEAWATER PRIMARY BATTERIES

### RATIONALE

Research into primary batteries which use seawater as the electrolyte has been going on for a fairly long time now, mostly related to large power generation applications for oil well heads and other submerged equipment. The Norwegians appear to have developed this technology to the point where the battery is small enough to install on large ATON buoys. The primary advantage of such a battery is that it can reduce or eliminate the need for traditional primary batteries, which contain materials and chemicals which make them environmentally hazardous and therefore difficult to dispose of. This type of battery also allows power generation to continue regardless of weather or wave conditions, unlike other alternative power-sources such as solar panels and WATGs. For these reasons, it seems that this power source merits some consideration.

### APPROACH

The evaluation should begin with a review of the Norwegian and ALU Power seawater primary battery designs. An assessment of the state of the technology, transportability to navigation buoys and economic impact can then be made.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            8        POWER SOURCES AND PAYLOAD  
**TECHNOLOGY NO.**       8.4      SEAWATER PRIMARY BATTERY

**A. AREA OF APPLICABILITY**

USCG buoys requiring an onboard power source and located in seawater.

**B. COMPONENTS REPLACED**

Other batteries, solar panels and wave activated generators.

**C. IMPACT**

**C. 1 Operational Effectiveness**

- The battery may simultaneously serve as the counterweight and thereby release weight for additional payload.
- Increased reliability due to the simplicity of the system.

**C. 2 Servicing and Handling**

- The servicing to the battery is more difficult as the buoy must be hauled.
- Servicing safety would be increased as these batteries do not contain any noxious or dangerous materials.
- Maintenance frequency should be reduced.

### C. 3 Logistics

- The technology is available however only a Norwegian R&D center has actually applied it to a buoy.
- The technology will require some modifications to buoys or new buoys in order to implement it.
- Application could be to all powered buoys in seawater.
- It will probably take years before a production model will be available.
- The seawater battery system would be compatible with existing buoy tenders and would actually free space and equipment currently needed for other batteries.

### C. 4 Economic Impact

- Cost to design and test will be significant and in the \$100k's as a minimum.
- The cost to manufacture is expected to be low whereas the cost to modify buoys will be additional and significant.
- All considered capital cost is expected to be less than for current power systems.
- Operating and maintenance costs are expected to be significantly less than for current systems.

### C. 5 Miscellaneous

- The battery cannot be vandalized or stolen.
- Although the impact on the number of aids will not be great, the impact on the number of batteries could be.

### C. 6 Special Functions

- No significant impact.

## REVIEW OF BUOY TECHNOLOGIES

**CATEGORY NO.**            9        IDENTIFICATION & REMOTE MONITORING

**TECHNOLOGY NO.**        9.6      SOLID SUPERSTRUCTURE INSTEAD OF LATTICE  
WORK AND TOP MARKS

### RATIONALE

Most existing ocean buoys are made of steel with steel, aluminum or GRP Superstructure. Those with steel and aluminum superstructures have a "cage" (or latticework) which is either bolted or welded to the buoy hull. By making the cage a solid structure and perhaps integral with the buoy, a more rigid platform will have been provided for the installation of lanterns, reflectors and other payload. Also, in accordance with IALA, the solid superstructure will serve for shape significance, eliminating the need for topmarks.

### APPROACH

The feasibility of constructing buoys with solid superstructures will be investigated, advantages/disadvantages will be determined.

## TECHNOLOGY BACKGROUND FOR EVALUATIONS

<b>CATEGORY NO.</b>	<u>9</u>	<u>IDENTIFICATION &amp; REMOTE MONITORING OF BUOYS</u>
<b>TECHNOLOGY NO.</b>	<u>9.6</u>	<u>SOLID SUPERSTRUCTURE INSTEAD OF LATTICEWORK AND TOPMARKS</u>

### **A. AREA OF APPLICABILITY**

USCG cage superstructure buoys.

### **B. COMPONENTS REPLACED**

Superstructure and topmarks.

### **C. IMPACT**

#### **C. 1 Operational Effectiveness**

- Effectiveness as a daytime aid will increase dramatically as the solid superstructure will have much greater visibility.
- The rigidity of the superstructure will provide greater resistance to damage during collisions. This will also increase reliability.

#### **C. 2 Servicing and Handling**

- Access to buoy structure and payload will be more restricted (Unless rung steps are provided to reach the payload. If provided these should be on the inside to preclude vandalism and/or theft).
- Servicing and Handling would be compatible with current equipment and safer than with buoys fitted with topmarks but the same as with slat covered superstructures.



### C. 3 Logistics

- Solid superstructures are within current technology and could be implemented quickly and efficiently.
- Cage type buoys would be affected. The USCG has at least 3500 of these.
- System would have compatibility with buoy tenders.

### C. 4 Economic Impact

- Cost to design and test is low but more than with topmarks and slat coverings.
- Cost to manufacture would be low and implementation would be a phase-in as existing buoys are retired. In some cases it might be adapted to existing buoys. It will be significantly more than utilizing slats and topmarks for existing buoys but not necessarily with new buoys.
- Capital cost will increase slightly over current due to increased material.
- Operating and maintenance costs are expected to decrease slightly due to a reduction in corrosion sources over cages (joints, etc.) and the greater rigidity of the structure offering protection to the payload.

### C. 5 Miscellaneous

- Resistance to vandalism and/or theft will be reduced as access to the payload can be more difficult and batteries and other components can be encased in the solid structure.
- User acceptance should be forthright.
- Buoys or spares would not be reduced in numbers.

### C. 6 Special Functions

- Effectiveness in exposed locations should be increased as the increased rigidity of the superstructure should provide greater resistance to the effects of severe weather.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.        11    PRESERVATION/PROTECTION  
TECHNOLOGY NO.    11.1 COATINGS & PRESERVATION SYSTEMS

### RATIONALE

The floating aids to navigation require periodic and frequent maintenance comprising either of scraping the marine growth and retouching damaged paint areas in the field or a complete repainting at a shore buoy maintenance facility. Problems are also experienced with corrosion from the seawater environment, discoloration of paint, e.g. because of bird droppings, etc. The Worldwide Buoy Technology Survey indicated that studies have been undertaken by some foreign navigation authorities with regard to the development and/or quality testing of new ordinary, fluorescent, or retro-reflecting paint materials. Incorporation of any major improvements to the USCG buoy painting approach may result in better preservation and easier identification of buoys.

### APPROACH

Review the new paint systems and testing procedures used worldwide, including those used in Germany and Canada. Compare the approach to that used by the USCG. Prepare recommendations and cost/benefit analyses for those new paint systems and/or testing procedures that are deemed feasible for adoption by the USCG.

## TECHNOLOGY BACKGROUND FOR EVALUATIONS

CATEGORY NO.        11    PRESERVATION/PROTECTION

TECHNOLOGY NO.    11.1   COATINGS AND PRESERVATION SYSTEMS

### A. AREA OF APPLICABILITY

All USCG buoys where coatings and preservation systems are utilized.

### B. COMPONENTS REPLACED

Existing coating and preservation systems.

### C. IMPACT

#### C. 1 Operational Effectiveness

- Effectiveness as a visual aid could be improved by the use of more visually effective paint systems.
- Reliability will be improved in signaling with better paint color brightness and in buoy longevity with better preservation systems.

#### C. 2 Servicing and Handling

- Maintenance frequency and relief cycles can be improved.

#### C. 3 Logistics

- The technology is available.
- The extent of applicability includes many if not all USCG buoys.
- The time to implement would be immediate.

C. 4 Economic Impact

- As this technology already exists, the only costs leading to implementation would be those of the study to identify beneficial paint and preservation systems.
- Capital cost is expected to be unaffected.
- Operating and maintenance costs could be cut substantially. As an example a 25% increase in relief cycle would probably reduce operating and maintenance costs in the order of 20%.

C. 5 Miscellaneous

- User acceptance should be complete.
- Deployment of this technology should have the effect of reducing the numbers of spares of buoys as they will last longer.

C. 6 Special Functions

- No significant impact.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            11    PRESERVATION/PROTECTION  
TECHNOLOGY NO.        11.2 RUBBER FENDERS ON BUOY HULL

### RATIONALE

The currently used USCG ATON buoys do not have fenders. It was found during the Worldwide Buoy Technology Survey that some foreign navigation authorities as well as some U.S. and foreign buoy manufacturers do have buoys with fenders attached to the upper parts of the buoy hull. It is desirable to establish if the use of such fenders would provide meaningful protection against damage from collisions.

### APPROACH

Review the foreign authority and all manufacturer buoys with fenders including England's 3 meter GRP lighted buoy, India's Medium Size GRP and steel buoys, France's Delphine and Marina buoys, Stromag/Pintsch Bamag's EZ series buoys for shallow waters, Reinforced Plastic Structures' Class II, III, and IV buoys, etc. Conduct a cost/benefit analysis toward incorporation of fenders on applicable USCG buoys and provide recommendations.

## TECHNOLOGY BACKGROUND FOR EVALUATIONS

CATEGORY NO.        11    PRESERVATION/PROTECTION

TECHNOLOGY NO.    11.2   FENDERS ON BUOY HULL

### A. AREA OF APPLICABILITY

All USCG buoys.

### B. COMPONENTS REPLACED

None; new fenders are added.

### C. IMPACT

#### C. 1 Operational Effectiveness

- Survivability in collisions and reliability will both be improved.

#### C. 2 Servicing and Handling

- Reduced visits and maintenance are expected as a result of better survivability in collisions.

#### C. 3 Logistics

- The technology is available and should be easy to implement on all buoys.

C. 4 Economic Impact

- Cost to introduce the technology will be small, while retrofit to existing buoys will be at a moderate cost.
- Capital costs will increase slightly due to the addition of this component.
- Operating and maintenance costs are expected to decrease as the buoys will be better able to survive collisions and will sustain lesser damage.

C. 5 Miscellaneous

- With increased survivability of buoys the required number of spare buoys should be reduced.

C. 6 Special Functions

- Effectiveness in river and exposed locations should be increased as collision and impact damage will be reduced.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            12     STANDARDIZATION OF BUOYS AND BUOY PARTS

TECHNOLOGY NO.        12.1   MODULAR BUOY DESIGNS

### RATIONALE

The use of modular buoys (i.e. those with interchangeable hulls, superstructures, counterweights, etc.) would be expected to provide several advantages to the USCG. First, it would reduce the overall number of ATONS that would need to be purchased by the CG because spare buoys of each individual type would no longer have to be stocked. Second, the USCG districts will be provided with added flexibility in matching the configuration of the ATON to the service environment since they would not then be limited to only the type of buoys that are normally in their inventories. Finally, servicing and repair of the buoys would be more efficient since damaged parts could simply be swapped out and the buoy placed back on station.

### APPROACH

The evaluation of this technology should begin with a review of the foreign efforts in buoy modularization and standardization, with particular emphasis on the German coastal and inland waterway designs. Next, a scheme for modularization should be prepared to address as many USCG buoys as possible with the lowest number of standard parts. The economic benefit should then be assessed.



## TECHNOLOGY BACKGROUND FOR EVALUATIONS

CATEGORY NO.            12     STANDARDIZATION OF BUOYS & BUOY PARTS  
TECHNOLOGY NO.        12.1   MODULAR BUOY DESIGNS

### A. AREA OF APPLICABILITY

Most USCG buoys.

### B. COMPONENTS REPLACED

None, however buoy inventory will be reduced as the modular components will serve as the building blocks of more than a single buoy type and damage modules can be replaced without replacing the entire buoy.

### C. IMPACT

#### C. 1 Operational Effectiveness

- Payload support/flexibility would be increased as components could be mixed and matched to add alternate buoyancy sections.

#### C. 2 Servicing and Handling

- There would be facility change requirements for this technology but other facilities would be eliminated.
- Personnel skill would have to be altered.

C. 3 Logistics

- The technology tools exist but new buoy designs would require development. The greater the extent of application to the USCG buoy types the greater the effort.
- The time frame to implement would be moderate to long, depending on the extent of the USCG buoyage system to which the concept is applied.

C. 4 Economic Impact

- The cost to design, test, manufacture and implement will be significant.
- Once the system is designed and available the capital cost is expected to be at least reduced by 25% as buoys will have interchangeable components.
- Operating and maintenance costs should be nearly the same as currently.

C. 5 Miscellaneous

- User acceptance would require some familiarization and practice with the concept.
- This system should reduce the number of aids through a reduction in inventory.

C. 6 Special Functions

- No impact.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            13    TECHNOLOGIES AND DESIGN CRITERIA FOR BUOYS

TECHNOLOGY NO.        13.1 SYSTEMS APPROACH TO DESIGN

### RATIONALE

A systems approach to buoy design is one that treats the hull, mooring and payload as an integrated system rather than treating each element as an independent entity. Such a design approach would allow the USCG to identify interdependent areas and optimize their designs with respect to mission, equipment and service environment.

### APPROACH

An evaluation of this design approach must first determine how much, if any, systems-type design methodology is currently in use in the USCG and then determine how much effort would be needed to fully incorporate the technique into the ATON design procedure. The highest costs would be expected to lie in the areas of procedure development and training of personnel, and these would have to be weighed against the expected gains in aid effectiveness both in terms of cost and operation.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            13    TECHNOLOGIES AND DESIGN CRITERIA FOR BUOYS  
**TECHNOLOGY NO.**        13.1 SYSTEMS APPROACH TO DESIGN

**A. AREA OF APPLICABILITY**

All buoy designs.

**B. COMPONENTS REPLACED**

None directly, however the optimization procedure may result in simplification of a design and therefore a reduction in the number of components.

**C. IMPACT**

C. 1 Operational Effectiveness

- Operational effectiveness should be positively affected but there is no clear indication that gains can be achieved.

C. 2 Servicing and Handling

- Access to components should be improved.
- Equipment/facilities required to handle and safety in servicing should be positively affected.

C. 3 Logistics

- This technology can be implemented throughout the system immediately.

C. 4 Economic Impact

- The cost to develop the technology should be minimal.
- The cost to manufacture new buoys developed from this technology will be significant.
- Both capital cost and operating and maintenance costs should be reduced.

C. 5 Miscellaneous

- User acceptance should be high.
- Better buoys should have the effect of reducing the number of buoys in the system.

C. 6 Special Functions

- This type of approach could improve the effectiveness of all aids as much as 20%.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            13    TECHNOLOGIES AND DESIGN CRITERIA FOR BUOYS

TECHNOLOGY NO.        13.2 INCREASED BUOY MOTIONS

### RATIONALE

It has long been known that buoy motion has an effect on the visibility of its light signal. It has further always been believed that the greater the motion of the buoy the worse the visibility due to the small divergence angle of the light's lens. Recent observations on a relatively lively foam buoy fitted with a light suggested that the overall visibility of the light may not be degraded as originally believed. A determination that buoy motion is not as significant to overall visibility of the light as originally thought could have very significant impact on buoy design.

### APPROACH

Develop a means of measuring light visibility on a buoy in terms of availability over a finite period of time. Carry out analytical motion studies of several buoys with very different motion characteristics and determine the availability of the light signal. Confirm with testing. Note that at the 1990 IALA Conference the USCG presented a paper entitled, "Detecting Buoy Lights: Effects of Motion and Lantern Divergence," No. 3.1.7.

## TECHNOLOGY BACKGROUND FOR EVALUATIONS

CATEGORY NO.        13     TECHNOLOGIES AND DESIGN CRITERIA FOR BUOYS

TECHNOLOGY NO.    13.2 INCREASED BUOY MOTIONS

### A. AREA OF APPLICABILITY

All USCG lighted buoys exposed to wave action.

### B. COMPONENTS REPLACED

If this investigation were to show that increased buoy motions are acceptable then the buoys themselves could ultimately be replaced with different and less expensive buoys.

### C. IMPACT

#### C. 1 Operational Effectiveness

- No measurable impact is expected.

#### C. 2 Servicing and Handling

- As livelier buoys are expected to be smaller and lighter equipment to handle, safety, and personnel numbers are expected to be favorably reduced.

#### C. 3 Logistics

- The technology of analyzing buoy motion is available but would have to be assembled and applied.

- The time to implement would be from moderate to long term. First the effects of motion would be determined. Then if more motion is acceptable new buoy designs would be developed, although existing designs of plastic/foam buoys may already be available. These would then have to be manufactured and introduced into the system.
- The extent of application could be all lighted aids.

#### C. 4 Economic Impact

- It is believed that existing foam/plastic buoys could be directly useable as lighted aids if increased motion is found acceptable.
- Cost to implement would be low with existing buoys.
- Capital costs should decrease as buoys with increased motion are likely to be lighter and therefore cheaper.
- Operating and maintenance costs are not expected to be significantly affected.

#### C. 5 Miscellaneous

- No significant impact.

#### C. 6 Special Functions

- Effectiveness as a lighted buoy would have to be at least equal to current levels.



## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            13    TECHNOLOGIES AND DESIGN CRITERIA FOR BUOYS  
TECHNOLOGY NO.        13.3 BUOY MODEL TESTS

### RATIONALE

The use of model testing for buoy design would allow designers to test the performance of a large number of buoy configurations under controlled conditions at relatively low cost. Engineers could also test the mechanics of ice interaction with buoys and fast-water ATON performance without having to resort to expensive and often inconclusive field testing. The use of model tests could also be used to verify and adjust computer models of buoy behavior. All this would result in a faster design process yielding more effective buoys.

### APPROACH

An evaluation of this technology would weigh the costs of developing buoy designs based on full scale prototypes against those of performing model basin tests. The expected gains in buoy effectiveness due to reliable tests should also be considered.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            13    TECHNOLOGIES AND DESIGN CRITERIA FOR BUOYS

**TECHNOLOGY NO.**       13.3 BUOY MODEL TESTS

**A. AREA OF APPLICABILITY**

New buoy designs.

**B. COMPONENTS REPLACED**

None.

**C. IMPACT**

C. 1 Operational Effectiveness

- No significant impact.

C. 2 Servicing and Handling

- No significant impact.

C. 3 Logistics

- The technology is available.
- The extent of application would be to all new buoy designs with performance requirements.

C. 4 Economic Impact

- Would reduce cost to design and carry out prototype testing as smaller scale testing could be accomplished to optimize the design before prototype construction.
- Operating costs would be reduced if better buoys were to be developed.

C. 5 Miscellaneous

- No significant impact.

C. 6 Special Functions

- Testing a series of models should help identify optimum performance. This should improve effectiveness of buoys in all conditions. Assume a 20% improvement.
- Ice tests utilizing paraffin as the ice medium could especially help in the case of these buoy types.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.	13	<u>TECHNOLOGIES AND DESIGN CRITERIA FOR BUOYS</u>
TECHNOLOGY NO.	13.4	<u>EFFECT OF MOORING AND PAYLOAD WEIGHT ON BUOY DESIGN</u>

### RATIONALE

A navigation buoy is sized to support its payload and resist environmental and mooring forces. As payload weight and mooring forces are somewhat under the control of the designer, the impact of these should be assessed to determine sensitivity. Such a study would identify the general cost benefit in utilizing lighter superstructures, equipment and mooring lines. It is expected the mooring system will by far have the greatest impact.

### APPROACH

Select a range of types of USCG buoys and determine their floating characteristics when utilizing first, lighter mooring line elements and second, reduced weight superstructures. Then, consider the size reductions that may be possible.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            13    TECHNOLOGIES AND DESIGN CRITERIA FOR BUOYS

**TECHNOLOGY NO.**       13.4   EFFECT OF MOORING AND PAYLOAD WEIGHT ON BUOY DESIGN

**A. AREA OF APPLICABILITY**

All moored USCG buoys.

**B. COMPONENTS REPLACED**

This technology does not have replacement of components as its goal. However, it is possible that should significant gains be indicated by a variation in mooring components and superstructure this could lead to changes or replacement of these by other types in the future. The principal direct output of this technology could be a reduction in buoy floatation requirements through a better understanding of and optimization of payload and buoy weight.

**C. IMPACT**

**C. 1 Operational Effectiveness**

- o Payload support/flexibility could be improved by optimization of mooring and payload weight.
- o Improved position keeping/watch circle could result from mooring analysis and optimization.

**C. 2 Servicing and Handling**

- o This technology can result in reduction of buoy floatation requirements and therefore a buoy size reduction. Also mooring systems could become lighter.

- Equipment and facilities to handle could be reduced somewhat, say 15%.
- Safety in servicing would be increased somewhat.

### C. 3 Logistics

- Considerations would be based on available technology .
- The technology could be simply applied virtually to all buoys.
- The time frame to implement would be long as probably new buoy designs based on this technology would be phased in over long periods of time.
- The technology would result in buoys that are compatible with existing buoy tenders.

### C. 4 Economic Impact

- Cost to design and test would be moderate to great, depending on the number of buoy types which are determined to benefit from the technology.
- The cost to manufacture and implement would be significant unless new buoys are phased into the system as older buoys are retired. In the latter case the cost should be less than current. Assume buoys will be phased in.
- Capital cost of new buoys is expected to be reduced by 20%.
- Operating and maintenance costs are expected to be identical to the current situation.

### C. 5 Miscellaneous

- Use acceptance of new buoys developed from this technology would be high.

### C. 6 Special Functions

- No significant impact.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.            13    TECHNOLOGIES AND DESIGN CRITERIA FOR BUOYS

TECHNOLOGY NO.        13.5   MEASURE OF EFFECTIVENESS

### RATIONALE

Although studies have been performed to evaluate the effectiveness of buoy systems and positional configurations, no measure of merit has been developed for the buoy platforms themselves. It therefore appears that the USCG still needs to develop a measure of effectiveness which takes into account both aid availability and efficacy, so that new buoy designs may be compared to existing ones.

### APPROACH

An R & D approach would involve research in depth of all current literature and studies on information that could be used to develop measures of buoy effectiveness in terms of signal performance, resistance to environmental forces, availability, reliability, corrosion, etc. The new IALA ATON NAVGUIDE and Reliability Manuals should be considered.

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            13    TECHNOLOGIES AND DESIGN CRITERIA FOR BUOYS  
**TECHNOLOGY NO.**      13.5 MEASURE OF EFFECTIVENESS

**A. AREA OF APPLICABILITY**

All USCG buoys.

**B. COMPONENTS REPLACED**

Although components may be replaced the immediate aim of this technology is to yield more effective buoys.

**C. IMPACT**

C. 1 Operational Effectiveness

- This technology has the potential for a resultant improvement in effectiveness of all buoys. Assume 20% as an upside limit in terms of refinement of existing buoyage.

C. 2 Servicing and Handling

- This technology has the potential for a resultant improvement in servicing and handling of all buoys provided this aspect is included in the measure of merit. Assume 20% as an upside limit in terms of refinement of existing buoyage.

C. 3 Logistics

- This technology is available and could be immediately implementable to all buoys.



- It would be applicable to new and existing buoys and compatible with buoy tenders.
- Implementation for improvement would probably require replacing buoys with new design and would take a long period of time.

#### C. 4 Economic Impact

- The measure of merit can include cost constraints and optimization under these constraints. However, the emphasis will be on buoy performance.
- It is expected that cost savings and increases in the interest of significantly increased effectiveness will balance and that in general the overall economic impact will be small provided that new buoys are phased in over a longer period of time.
- Even phasing in buoys over a longer period of time should increase capital spending.

#### C. 5 Miscellaneous

- Resistance to vandalism and/or theft could be improved to 20%.
- User acceptance should be high.

#### C. 6 Special Functions

- This technology's principal aim is to improve buoy effectiveness.
- Assume 20% as an upside limit in terms of refinement of existing buoyage.

## REVIEW OF BUOY TECHNOLOGIES

CATEGORY NO.	13	<u>TECHNOLOGIES AND DESIGN CRITERIA FOR BUOYS</u>
TECHNOLOGY NO.	13.6	<u>IMPROVED DAMAGE STABILITY BY INCREASED COMPARTMENTATION</u>

### RATIONALE

The current steel USCG buoys all have only one WT compartment, i.e. the buoy hull. The cylindrical battery pockets are also watertight but not large enough to provide added damage stability. By incorporating additional compartmentation and providing at least two-compartment damage stability to steel buoys, the number of buoy losses due to damage from collisions may be considerably reduced and important cost savings realized.

### APPROACH

Study the most effective and economical methods of providing additional subdivision of the buoy hull and at least two compartment damage stability for large steel USCG buoys. Develop recommendations and budgetary cost estimates for the incorporation of same.

### Sources:

Canada - Prescott Base  
Finland - Auth.  
Allmarine - Hol.  
Seaward - US (unsinkable - foam)  
South Africa - double hull buoy  
Japan - double hull buoy

**TECHNOLOGY BACKGROUND  
FOR EVALUATIONS**

**CATEGORY NO.**            13    TECHNOLOGIES AND DESIGN CRITERIA FOR  
BUOYS

**TECHNOLOGY NO.**       13.6   IMPROVED DAMAGE STABILITY BY INCREASED  
COMPARTMENTATION

**A. AREA OF APPLICABILITY**

All steel buoys without internal floatation.

**B. COMPONENTS REPLACED**

None; but bulkheads or other structure to increase compartmentation added.

**C. IMPACT**

C. 1 Operational Effectiveness

- Survivability and reliability will be increased.

C. 2 Servicing and Handling

- Maintenance frequency will be reduced through improved resistance to sinking.

C. 3 Logistics

- The technology is available.
- The complexity of the buoy construction will be increased somewhat in providing increased compartmentation.

- The extent of application would be all steel buoys without internal floatation. This represents all USCG buoys except river buoys.
- The implementation could be over time where existing buoys are replaced by the new compartmented designs.

#### C. 4 Economic Impact

- Cost to design and test will be small as the technology is known. The new buoys would supply replaced lost or retired buoys and would be implemented in this fashion to keep costs down.
- Capital cost is expected to increase as the compartmented buoys will be more expensive by about 15%.
- Operating and maintenance cost will be reduced as fewer buoys will be lost. Assume 50% reduction in losses.

#### C. 5 Miscellaneous

- User acceptance is expected to be high.
- Fewer spare buoys would be required as the survivability of buoys would be increased.

#### C. 6 Special Functions

- As loss of a buoy in exposed locations will require significant time for replacement, the effectiveness of these buoys is expected to be somewhat improved. Assume 15%.

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**APPENDIX C**  
**ECONOMIC ANALYSES**  
**FOR**  
**RECOMMENDED TECHNOLOGIES**

<u>Technology No</u>	<u>Description</u>	<u>Page</u>
1.1	Slat Covered Frame Superstructure Shape Significance Versus Topmarks	C-1
2.1	Foam Material For Buoys	C-2
2.2	Elastomer Skin For Buoys	C-3
2.3	FRP and GRP Materials	C-4
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6.1	Mooring Concepts for Articulated Beacons	C-11
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8.1	Deck or Superstructure Mounted Battery Boxes (for New Construction)	C-13
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9.6	Solid Superstructure	C-15
11.1	Coatings and Preservation Systems	C-16

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13.3	Buoy Model Tests	C-19
13.6	Improved Damage Stability by Increased Compartmentation	C-20

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 1.1 Service Life, Years: 30

Technology Description: Slat Covered Frame Superstructure Total No. of Buoys: 6,032

Items	Modified Slat Frame Buoys (\$K)	Adding Topmarks to Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	82	55
(2) Investment	3,016	2,413
<b>Total Nonrecurring</b>	<b>3,098</b>	<b>2,468</b>
<b>Annual Recurring:</b>		
(3) Servicing	5,088	4,846
(4) 6 Year Rehabilitation (Annualized)	4,880	4,880
(5) Replacement of Losses (Annual)	302	483
<b>Total Recurring (Annual)</b>	<b>10,270</b>	<b>10,209</b>
<b>Discount Factor for Service Life, fb</b>	<b>9.42691</b>	<b>9.42691</b>
<b>PV of Recurring Life Cost</b>	<b>96,813</b>	<b>96,235</b>
<b>Discounted Total Life Cost</b>	<b>99,911</b>	<b>98,703</b>
<b>Terminal Value</b>	<b>0</b>	<b>0</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.05731</b>	<b>0.05731</b>
<b>Discounted Terminal Value</b>	<b>0</b>	<b>0</b>
<b>Net Total Discounted Cost</b>	<b>99,911</b>	<b>98,703</b>



**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 2.1

Service Life, Years: 30

Technology Description: Foam Material for Buoys

Total No. of Buoys: 40,381

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	500	0
(2) Investment	107,772	110,181
<b>Total Nonrecurring</b>	<b>108,272</b>	<b>110,181</b>
<b>Annual Recurring:</b>		
(3) Servicing	5,566	7,421
(4) 6 Year Rehabilitation (Annualized)	4,373	5,830
(5) Replacement of Losses (Annual)	17,062	15,447
<b>Total Recurring (Annual)</b>	<b>27,000</b>	<b>28,699</b>
<b>Discount Factor for Service Life, fb</b>	<b>9.42691</b>	<b>9.42691</b>
<b>PV of Recurring Life Cost</b>	<b>254,530</b>	<b>270,539</b>
<b>Discounted Total Life Cost</b>	<b>362,801</b>	<b>380,721</b>
<b>Terminal Value</b>	<b>(1,284)</b>	<b>800</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.05731</b>	<b>0.05731</b>
<b>Discounted Terminal Value</b>	<b>(74)</b>	<b>46</b>
<b>Net Total Discounted Cost</b>	<b>362,875</b>	<b>380,675</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 2.2

Service Life, Years: 30

Technology Description: Elastomer Skins for Buoys

Total No. of Buoys: 40,381

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	240	0
(2) Investment	118,430	110,181
<b>Total Nonrecurring</b>	<b>118,670</b>	<b>110,181</b>
<b>Annual Recurring:</b>		
(3) Servicing	6,308	7,421
(4) 6 Year Rehabilitation (Annualized)	4,956	5,830
(5) Replacement of Losses (Annual)	13,432	15,447
<b>Total Recurring (Annual)</b>	<b>24,695</b>	<b>28,699</b>
<b>Discount Factor for Service Life, fb</b>	<b>9.42691</b>	<b>9.42691</b>
<b>PV of Recurring Life Cost</b>	<b>232,801</b>	<b>270,539</b>
<b>Discounted Total Life Cost</b>	<b>351,471</b>	<b>380,721</b>
<b>Terminal Value</b>	<b>800</b>	<b>800</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.05731</b>	<b>0.05731</b>
<b>Discounted Terminal Value</b>	<b>46</b>	<b>46</b>
<b>Net Total Discounted Cost</b>	<b>351,425</b>	<b>380,675</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 2.3 Service Life, Years: 30

Technology Description: FRP & GRP Materials for Buoys Total No. of Buoys: 40,381

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	330	0
(2) Investment	90,477	110,181
<b>Total Nonrecurring</b>	<b>90,807</b>	<b>110,181</b>
<b>Annual Recurring:</b>		
(3) Servicing	6,308	7,421
(4) 6 Year Rehabilitation (Annualized)	4,956	5,830
(5) Replacement of Losses (Annual)	12,781	15,447
<b>Total Recurring (Annual)</b>	<b>24,044</b>	<b>28,699</b>
<b>Discount Factor for Service Life, fb</b>	<b>9.42691</b>	<b>9.42691</b>
<b>PV of Recurring Life Cost</b>	<b>226,663</b>	<b>270,539</b>
<b>Discounted Total Life Cost</b>	<b>317,470</b>	<b>380,721</b>
<b>Terminal Value</b>	<b>(1,346)</b>	<b>800</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.05731</b>	<b>0.05731</b>
<b>Discounted Terminal Value</b>	<b>(77)</b>	<b>46</b>
<b>Net Total Discounted Cost</b>	<b>317,547</b>	<b>380,675</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 2.4 Service Life, Years: 30

Technology Description: Off-The-Shelf Plastic/Foam Buoys Total No. of Buoys: 40,381

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	198	0
(2) Investment	107,772	110,181
<b>Total Nonrecurring</b>	<b>107,970</b>	<b>110,181</b>
<b>Annual Recurring:</b>		
(3) Servicing	5,566	7,421
(4) 6 Year Rehabilitation (Annualized)	4,373	5,830
(5) Replacement of Losses (Annual)	17,062	15,447
<b>Total Recurring (Annual)</b>	<b>27,000</b>	<b>28,699</b>
Discount Factor for Service Life, fb	9.42691	9.42691
PV of Recurring Life Cost	254,530	270,539
<b>Discounted Total Life Cost</b>	<b>362,499</b>	<b>380,721</b>
Terminal Value	(1,284)	800
Discount Factor, fa at End of Terminal Life	0.05731	0.05731
Discounted Terminal Value	(74)	46
<b>Net Total Discounted Cost</b>	<b>362,573</b>	<b>380,675</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 3.2 Service Life, Years: 30

Technology Description: Off-The-Shelf Open Sea Buoys Total No. of Buoys: 2,083

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	149	0
(2) Investment	37,782	37,782
<b>Total Nonrecurring</b>	<b>37,931</b>	<b>37,782</b>
<b>Annual Recurring:</b>		
(3) Servicing	1,932	2,147
(4) 6 Year Rehabilitation (Annualized)	1,949	2,294
(5) Replacement of Losses (Annual)	3778	3778
<b>Total Recurring (Annual)</b>	<b>7,660</b>	<b>8,219</b>
<b>Discount Factor for Service Life, fb</b>	<b>9.42691</b>	<b>9.42691</b>
<b>PV of Recurring Life Cost</b>	<b>72,209</b>	<b>77,476</b>
<b>Discounted Total Life Cost</b>	<b>110,141</b>	<b>115,259</b>
<b>Terminal Value</b>	<b>340</b>	<b>340</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.05731</b>	<b>0.05731</b>
<b>Discounted Terminal Value</b>	<b>20</b>	<b>20</b>
<b>Net Total Discounted Cost</b>	<b>110,121</b>	<b>115,239</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 4.1

Service Life, Years: 15

Technology Description: Debris Shedding Buoy

Total No. of Buoys: 25,605

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	158	0
(2) Investment	8,614	5,534
<b>Total Nonrecurring</b>	<b>8,772</b>	<b>5,534</b>
<b>Annual Recurring:</b>		
(3) Servicing	813	1,084
(4) 6 Year Rehabilitation (Annualized)	503	0
(5) Replacement of Losses (Annual)	1723	3874
<b>Total Recurring (Annual)</b>	<b>3,039</b>	<b>4,958</b>
<b>Discount Factor for Service Life, fb</b>	<b>7.60608</b>	<b>7.60608</b>
<b>PV of Recurring Life Cost</b>	<b>23,116</b>	<b>37,714</b>
<b>Discounted Total Life Cost</b>	<b>31,888</b>	<b>43,248</b>
<b>Terminal Value</b>	<b>0</b>	<b>0</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.23939</b>	<b>0.23939</b>
<b>Discounted Terminal Value</b>	<b>0</b>	<b>0</b>
<b>Net Total Discounted Cost</b>	<b>31,888</b>	<b>43,248</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 4.4 Service Life, Years: 15

Technology Description: Off-The-Shelf River Buoys Total No. of Buoys: 25,605

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	130	0
(2) Investment	4,395	5,534
<b>Total Nonrecurring</b>	<b>4,525</b>	<b>5,534</b>
<b>Annual Recurring:</b>		
(3) Servicing	813	1,084
(4) 6 Year Rehabilitation (Annualized)	403	0
(5) Replacement of Losses (Annual)	1318	3874
<b>Total Recurring (Annual)</b>	<b>2,534</b>	<b>4,958</b>
<b>Discount Factor for Service Life, fb</b>	<b>7.60608</b>	<b>7.60608</b>
<b>PV of Recurring Life Cost</b>	<b>19,276</b>	<b>37,714</b>
<b>Discounted Total Life Cost</b>	<b>23,801</b>	<b>43,248</b>
<b>Terminal Value</b>	<b>0</b>	<b>0</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.23939</b>	<b>0.23939</b>
<b>Discounted Terminal Value</b>	<b>0</b>	<b>0</b>
<b>Net Total Discounted Cost</b>	<b>23,801</b>	<b>43,248</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 5.1 Service Life, Years: 30

Technology Description: Compartmented Ice Buoys Total No. of Buoys: 2,405

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	57	0
(2) Investment	8,475	7,405
<b>Total Nonrecurring</b>	<b>8,532</b>	<b>7,405</b>
<b>Annual Recurring:</b>		
(3) Servicing	110	122
(4) 6 Year Rehabilitation (Annualized)	108	108
(5) Replacement of Losses (Annual)	1271	1851
<b>Total Recurring (Annual)</b>	<b>1,489</b>	<b>2,081</b>
<b>Discount Factor for Service Life, fb</b>	<b>9.42691</b>	<b>9.42691</b>
<b>PV of Recurring Life Cost</b>	<b>14,034</b>	<b>19,617</b>
<b>Discounted Total Life Cost</b>	<b>22,566</b>	<b>27,022</b>
<b>Terminal Value</b>	<b>35</b>	<b>35</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.05731</b>	<b>0.05731</b>
<b>Discounted Terminal Value</b>	<b>2</b>	<b>2</b>
<b>Net Total Discounted Cost</b>	<b>22,564</b>	<b>27,020</b>



**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 5.2 Service Life, Years: 30

Technology Description: Plastic Spar Buoys for Ice Service Total No. of Buoys: 2,405

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	59	0
(2) Investment	1,985	7,405
<b>Total Nonrecurring</b>	<b>2,044</b>	<b>7,405</b>
<b>Annual Recurring:</b>		
(3) Servicing	61	122
(4) 6 Year Rehabilitation (Annualized)	54	108
(5) Replacement of Losses (Annual)	298	1851
<b>Total Recurring (Annual)</b>	<b>413</b>	<b>2,081</b>
<b>Discount Factor for Service Life, fb</b>	<b>9.42691</b>	<b>9.42691</b>
<b>PV of Recurring Life Cost</b>	<b>3,890</b>	<b>19,617</b>
<b>Discounted Total Life Cost</b>	<b>5,934</b>	<b>27,022</b>
<b>Terminal Value</b>	<b>0</b>	<b>35</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.05731</b>	<b>0.05731</b>
<b>Discounted Terminal Value</b>	<b>0</b>	<b>2</b>
<b>Net Total Discounted Cost</b>	<b>5,934</b>	<b>27,020</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.:	6.1	Service Life, Years:	30
Technology Description:	Buoyant Beacon Mooring Improvements	Total No. of Buoys:	8,612

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	105	0
(2) Investment	58,717	58,717
<b>Total Nonrecurring</b>	<b>58,822</b>	<b>58,717</b>
<b>Annual Recurring:</b>		
(3) Servicing	1,982	3,303
(4) 6 Year Rehabilitation (Annualized)	1,931	3,218
(5) Replacement of Losses (Annual)	5,872	5,872
<b>Total Recurring (Annual)</b>	<b>9,784</b>	<b>12,393</b>
<b>Discount Factor for Service Life, fb</b>	<b>9.42691</b>	<b>9.42691</b>
<b>PV of Recurring Life Cost</b>	<b>92,236</b>	<b>116,825</b>
<b>Discounted Total Life Cost</b>	<b>151,058</b>	<b>175,542</b>
<b>Terminal Value</b>	<b>324</b>	<b>324</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.05731</b>	<b>0.05731</b>
<b>Discounted Terminal Value</b>	<b>19</b>	<b>19</b>
<b>Net Total Discounted Cost</b>	<b>151,039</b>	<b>175,524</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 6.2 Service Life, Years: 30

Technology Description: Off-The-Shelf Buoyant Beacons Total No. of Buoys: 8,612

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	140	0
(2) Investment	58,717	58,717
<b>Total Nonrecurring</b>	<b>58,857</b>	<b>58,717</b>
<b>Annual Recurring:</b>		
(3) Servicing	1,982	3,303
(4) 6 Year Rehabilitation (Annualized)	1,931	3,218
(5) Replacement of Losses (Annual)	5,872	5,872
<b>Total Recurring (Annual)</b>	<b>9,784</b>	<b>12,393</b>
<b>Discount Factor for Service Life, fb</b>	<b>9.42691</b>	<b>9.42691</b>
<b>PV of Recurring Life Cost</b>	<b>92,236</b>	<b>116,825</b>
<b>Discounted Total Life Cost</b>	<b>151,093</b>	<b>175,542</b>
<b>Terminal Value</b>	<b>324</b>	<b>324</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.05731</b>	<b>0.05731</b>
<b>Discounted Terminal Value</b>	<b>19</b>	<b>19</b>
<b>Net Total Discounted Cost</b>	<b>151,074</b>	<b>175,524</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 8.1 Service Life, Years: 30  
 Technology Description: Deck or Superstructure Mounted Battery Box Total No. of Buoys: 5,838

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	87	0
(2) Investment	72,895	80,515
<b>Total Nonrecurring</b>	<b>72,982</b>	<b>80,515</b>
<b>Annual Recurring:</b>		
(3) Servicing	2,339	4,678
(4) 6 Year Rehabilitation (Annualized)	4,267	4,741
(5) Replacement of Losses (Annual)	7,290	8,052
<b>Total Recurring (Annual)</b>	<b>13,895</b>	<b>17,470</b>
Discount Factor for Service Life, fb	9.42691	9.42691
PV of Recurring Life Cost	130,989	164,692
<b>Discounted Total Life Cost</b>	<b>203,971</b>	<b>245,207</b>
Terminal Value	582	582
Discount Factor, fa at End of Terminal Life	0.05731	0.05731
Discounted Terminal Value	33	33
<b>Net Total Discounted Cost</b>	<b>203,938</b>	<b>245,174</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 8.1a Service Life, Years: 30  
 Technology Description: Retrofitted Deck or Superstructure Mounted Battery Box Total No. of Buoys: 5,838

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	87	0
(2) Investment	11,676	0
<b>Total Nonrecurring</b>	<b>11,763</b>	<b>0</b>
<b>Annual Recurring:</b>		
(3) Servicing	2,339	4,678
(4) 6 Year Rehabilitation (Annualized)	4,267	4,741
(5) Replacement of Losses (Annual)	7,290	8,052
<b>Total Recurring (Annual)</b>	<b>13,895</b>	<b>17,470</b>
<b>Discount Factor for Service Life, fb</b>	<b>9.42691</b>	<b>9.42691</b>
<b>PV of Recurring Life Cost</b>	<b>130,989</b>	<b>164,692</b>
<b>Discounted Total Life Cost</b>	<b>142,752</b>	<b>164,692</b>
<b>Terminal Value</b>	<b>582</b>	<b>582</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.05731</b>	<b>0.05731</b>
<b>Discounted Terminal Value</b>	<b>33</b>	<b>33</b>
<b>Net Total Discounted Cost</b>	<b>142,719</b>	<b>164,659</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.:	9.6	Service Life, Years:	30
Technology Description:	Solid Superstructure, Instead of Latticework or Topmark	Total No. of Buoys:	4,077

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	155	0
(2) Investment	74,904	65,633
<b>Total Nonrecurring</b>	<b>75,059</b>	<b>65,633</b>
<b>Annual Recurring:</b>		
(3) Servicing	3,333	3,703
(4) 6 Year Rehabilitation (Annualized)	3,440	3,822
(5) Replacement of Losses (Annual)	7,490	6,563
<b>Total Recurring (Annual)</b>	<b>14,263</b>	<b>14,089</b>
Discount Factor for Service Life, fb	9.42691	9.42691
PV of Recurring Life Cost	134,458	132,812
<b>Discounted Total Life Cost</b>	<b>209,517</b>	<b>198,445</b>
Terminal Value	519	519
Discount Factor, fa at End of Terminal Life	0.05731	0.05731
Discounted Terminal Value	30	30
<b>Net Total Discounted Cost</b>	<b>209,488</b>	<b>198,415</b>



**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 11.2

Service Life, Years: 30

Technology Description: Fenders on Buoy Hull

Total No. of Buoys: 40,381

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	53	0
(2) Investment	151,137	110,181
<b>Total Nonrecurring</b>	<b>151,190</b>	<b>110,181</b>
<b>Annual Recurring:</b>		
(3) Servicing	5,937	7,421
(4) 6 Year Rehabilitation (Annualized)	4,373	5,830
(5) Replacement of Losses (Annual)	9,068	11,018
<b>Total Recurring (Annual)</b>	<b>19,378</b>	<b>24,269</b>
Discount Factor for Service Life, fb	9.42691	9.42691
<b>PV of Recurring Life Cost</b>	<b>182,673</b>	<b>228,786</b>
<b>Discounted Total Life Cost</b>	<b>333,864</b>	<b>338,968</b>
<b>Terminal Value</b>	<b>780</b>	<b>780</b>
Discount Factor, fa at End of Terminal Life	0.05731	0.05731
<b>Discounted Terminal Value</b>	<b>45</b>	<b>45</b>
<b>Net Total Discounted Cost</b>	<b>333,819</b>	<b>338,923</b>



**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 13.1 Service Life, Years: 30

Technology Description: Systems Approach to Buoy Design Total No. of Buoys: 42,216

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	241	0
(2) Investment	100,206	110,759
<b>Total Nonrecurring</b>	<b>100,447</b>	<b>110,759</b>
<b>Annual Recurring:</b>		
(3) Servicing	5,577	7,436
(4) 6 Year Rehabilitation (Annualized)	4,081	5,830
(5) Replacement of Losses (Annual)	10,021	11,076
<b>Total Recurring (Annual)</b>	<b>19,679</b>	<b>24,342</b>
Discount Factor for Service Life, fb	9.42691	9.42691
PV of Recurring Life Cost	185,508	229,469
<b>Discounted Total Life Cost</b>	<b>285,955</b>	<b>340,228</b>
<b>Terminal Value</b>	<b>780</b>	<b>780</b>
Discount Factor, fa at End of Terminal Life	0.05731	0.05731
<b>Discounted Terminal Value</b>	<b>45</b>	<b>45</b>
<b>Net Total Discounted Cost</b>	<b>285,910</b>	<b>340,184</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 13.3

Service Life, Years: 30

Technology Description: Buoy Model Tests

Total No. of Buoys: 42,216

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	365	0
(2) Investment	110,759	110,759
<b>Total Nonrecurring</b>	<b>111,124</b>	<b>110,759</b>
<b>Annual Recurring:</b>		
(3) Servicing	6,320	7,436
(4) 6 Year Rehabilitation (Annualized)	4,956	5,830
(5) Replacement of Losses (Annual)	11,076	11,076
<b>Total Recurring (Annual)</b>	<b>22,352</b>	<b>24,342</b>
<b>Discount Factor for Service Life, fb</b>	<b>9.42691</b>	<b>9.42691</b>
<b>PV of Recurring Life Cost</b>	<b>210,710</b>	<b>229,469</b>
<b>Discounted Total Life Cost</b>	<b>321,835</b>	<b>340,228</b>
<b>Terminal Value</b>	<b>780</b>	<b>780</b>
<b>Discount Factor, fa at End of Terminal Life</b>	<b>0.05731</b>	<b>0.05731</b>
<b>Discounted Terminal Value</b>	<b>45</b>	<b>45</b>
<b>Net Total Discounted Cost</b>	<b>321,790</b>	<b>340,184</b>

**\*\* ECONOMIC ANALYSIS \*\***

Buoy Technology No.: 13.6 Service Life, Years: 30  
 Technology Description: Improved Damaged Stability Through Subdivision Total No. of Buoys: 11,756

Items	New Construction Buoys (\$K)	Existing Buoys (\$K)
<b>Capital Costs:</b>		
(1) R & D	100	0
(2) Investment	118,597	103,809
<b>Total Nonrecurring</b>	<b>118,697</b>	<b>103,809</b>
<b>Annual Recurring:</b>		
(3) Servicing	5,152	5,725
(4) 6 Year Rehabilitation (Annualized)	5,247	5,830
(5) Replacement of Losses (Annual)	4,744	10,381
<b>Total Recurring (Annual)</b>	<b>15,143</b>	<b>21,936</b>
Discount Factor for Service Life, fb	9.42691	9.42691
PV of Recurring Life Cost	142,754	206,786
<b>Discounted Total Life Cost</b>	<b>261,450</b>	<b>310,595</b>
Terminal Value	699	699
Discount Factor, fa at End of Terminal Life	0.05731	0.05731
Discounted Terminal Value	40	40
<b>Net Total Discounted Cost</b>	<b>261,410</b>	<b>310,555</b>