REPORT 919-2*

PERFORMANCE OF A LOW-ALTITUDE, POLAR-ORBITING SATELLITE EPIRB SYSTEM

(Question 90/8)

(1982-1986-1990)

1. Introduction

1.1 *Background*

The COSPAS/SARSAT** programme is an international cooperative effort between the United States of America, Canada, France (SARSAT) and the USSR (COSPAS). Norway, the United Kingdom, Finland, Bulgaria and Denmark are also participating in this programme, and discussions are under way for the participation of Brazil and additional countries.

The programme has the following objectives:

- first, to support the existing search and rescue activities by providing position determination for aircraft emergency locator transmitters (ELTs) and maritime emerency position-indicating radio beacons (EPIRBs) transmitting at 121.5 MHz;
- second, to demonstrate the advantages of a new system operating at 406 MHz, which provides better performance and which better satisfies users' requirements of global coverage and identification;
- third, to promote the development of an international operational system as soon as possible.

A summary description of the system is given in Report 761, and details are provided in [USSR, *et al.*, 1984a]; therefore, they are not repeated in this Report.

The Cospas-1 (C1), -2 (C2) and -3 (C3) satellites were launched on 30 June 1982, 25 March 1983, and 21 June 1984, respectively. Sarsat 1 (S1), the first satellite carrying the SARSAT payload, was launched on 28 March 1983. It lost attitude stability and was placed out of operation in June 1984, but it was successfully reactivated in May 1985. Sarsat-2 (S2) was launched in December 1984. Sarsat-3 (S3) is planned to be launched in 1986. The initial launches started an engineering measurement effort and a demonstration and evaluation (D and E) effort. The purpose of the engineering measurements was to determine that the design was functioning as expected. The purpose of the D and E programme was to demonstrate the 406 MHz system performance and the system's capability for providing effective assistance to search and rescue (SAR) operations.

The engineering measurements consisted of well controlled 121.5 MHz and 406 MHz engineering tests and they continue to be performed with each new satellite launched. The D and E programme demonstrated 121.5 MHz and 406 MHz system performance in a more realistic user environment. The D and E programme was concluded in July 1984. However, additional measurement data is being continually acquired. Thereafter, the D and E data will be referred to as the "environmental" data to differentiate it from the engineering data. Preliminary results of the programme have become available in several reports (see References).

It must be noted that the 406 MHz COSPAS/SARSAT sub-system has just entered its operational phase and is continually improving its system performance. On the other hand, the 121.5 MHz sub-system has already demonstrated its operational performance in a number of successfully resolved real distress situations.

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* The Director, CCIR, is requested to bring this Report to the attention of the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT).

** COSPAS: Kosmicheskaya Sistyema Poiska Avariynykh Sudov (Space System for Search of Distressed Vessels); SARSAT: Search And Rescue Satellite-Aided Tracking system.

1.2 *Objective of the Report*

The objective of this Report is to present a consolidation of preliminary results taken from various engineering measurement and D and E reports and papers describing the 406 MHz system performance and environmental tests performed by all the COSPAS/SARSAT participants.

General test results of the 121.5 MHz system are also presented to give the user an idea of COSPAS/SARSAT operational capabilities and a basis from which to compare the effectiveness of the 406 MHz system.

1.3 *Scope of the Report*

In researching the various reports of test results provided by the participating countries, it was found that there were variations in the methods and formats in performing the tests and in recording the results. Accordingly, it was determined necessary to use only those results that were based on performance parameters with similar definitions and where the sample sizes of the collected data were known.

The countries whose data is used in this Report are:

- the COSPAS/SARSAT partners: the United States of America, Canada, France and the USSR; and
- the COSPAS/SARSAT investigators: Bulgaria, Norway, and the United Kingdom.

The reports used are listed in the References. The time period for the reported test results spans from 1 February 1983 to 31 August 1985.

Additional tests are planned for both the floating EPIRBs and the end-to-end performance assessment. The floating EPIRB tests will further investigate location probability for various conditions, including high sea states; the end-to-end tests will continue to investigate system performance using a four-satellite constellation with reduced susceptibility to interference. The results of some of these tests are reported in Annexes II and III and the comparison of this data with similar parameters measured during the D and E phase is presented in Annex IV.

2. Measured performance of the 406 MHz system

This section focuses on the measured performance of the COSPAS/SARSAT system using the 406 MHz experimental beacons.

2.1 *Introduction*

The purpose of the engineering measurements and the environmental tests was to determine the ability of the COSPAS/SARSAT system to detect, identify, and locate 406 MHz experimental beacons operating in maritime and inland environments. This was accomplished mainly by the evaluation of the following parameters for single-pass data:

- beacon-detection probability,
- beacon-location error,
- ambiguity resolution,
- beacon-location probability,
- capacity,
- homing range at 121.5 MHz and at 406 MHz,
- notification time.

During the period reported, the COSPAS/SARSAT system underwent:

- the continuation of ground system development;
- addition of the C3 and S2 satellites to the space segment;
- implementation of new operating procedures; and
- improvements of on-board satellite equipment.

For these reasons, the test results reflect a changing system. They afford a basis for preliminary evaluation of the parameters listed above with continuing improvements expected.

The tests fell into two categories; engineering tests and environmental tests.

Engineering tests are defined as closely controlled technical tests established to evaluate the degree to which the system design goals have been met. Environmental tests are reasonably controlled field tests designed to evaluate the impact of environmental factors (such as sea state, terrain, and weather) in a more operational mode.

Engineering tests were run under very good conditions in which the environment was stable and known. The true location of each beacon was accurately known to within approximately 0.50 km, output power was controlled, and beacon elevation angles to the spacecraft were accurately computed.

Environmental tests, on the other hand, were performed under a wide range of conditions that were not precisely recorded nor controlled. For example, beacon true locations were estimated and frequently fell outside 0.5 km error, output power measurements were not usually taken, and elevation angles were not usually recorded; however, with a sufficient sample size, this data can be expected to characterize the operational system.

2.2 *Description of the tests*

The tests were carried out under conditions and at locations selected by the participating nations. Generally, beacons were activated in sufficient time for them to warm up prior to data being taken to ensure that beacons were operating within specifications. Elevation angles from the beacons to the satellites were selected to allow message locations to be computed. To give a representation of what could occur during a beacon activation under real circumstances, a range of environmental conditions were selected. Such inland environments included flat and mountainous terrain, wet and dry weather, high to low altitudes above mean sea level, varying ambient temperatures, etc. Maritime tests were generally performed at low sea states with the EPIRBs on the decks of ships and/or floating. The beacons employed were newly developed 406 MHz ELTs and EPIRBs designed to meet the international specification for experimental beacons called for in the COSPAS/SARSAT 406 MHz ELT/EPIRB specification [Canada, *et al.*, 1982].

In order to cross-reference the various test results provided in this Report, to the originating country, the following list should be used:

Series	*Country*
A	Bulgaria
B	Canada
C	France
D	Norway
E	USSR
F	United States of America
G	United Kingdom

2.2.1 *Beacon-detection probability*

Beacon-detection probability is defined as the probability of detection by a local user terminal (LUT) (see Note) of at least one beacon message with a correct code protected section for the first tracked satellite.

Note. – A local user terminal is the COSPAS/SARSAT receiving earth station.

2.2.1.1 *Test description*

2.2.1.1.1 *On-land tests*

The C-series engineering test results were obtained in June 1985 by the Toulouse LUT during the Sarsat-1 and Sarsat-2 comparative performance tests. A local orbitography beacon and a reference beacon, placed on the roof of a building, were used during these tests.

The E-series environmental test results were obtained during January-February 1985 tests [CSSC, 1985a]. One test beacon (an industrial prototype) was placed on the roof of the Moscow LUT. The beacon was powered by internal batteries. During the 30-day test period the temperature varied between 0 °C and −24 °C.

The F-series engineering test results were obtained in August 1985 during simultaneous testing of two on-land and one on-deck field test beacons and a number of floating EPIRBs. The on-land test beacons were placed on top of two buildings, one of which was located at the Atlantic Marine Center near Norfolk, Virginia, and the other at NASA/Goddard Space Flight Center in Greenbelt, Maryland. Both of these beacons, as well as the on-deck beacon and the floating EPIRBs, transmitted at full power.

2.2.1.1.2 *On-deck tests*

The F-series engineering test results were obtained in August 1985 as mentioned in the preceding sub-section. A field-test beacon was used with the antenna placed on the bridge of a ship, which was stationed off the coast of Norfolk, Virginia.

2.2.1.1.3 *Floating tests*

The C-series environmental test results were obtained in April and June 1985 during the tests of three tethered and two free-floating EPIRBs, respectively [CSSC, 1985b]. These tests were conducted in the south-western Atlantic Ocean coastal region of France (near Bordeaux) during low sea-state conditions. In these tests, only those satellite passes were tracked whose elevation angles exceeded 5°; also, only the local (regional) mode was used.

The F-series engineering tests for floating EPIRBs were conducted in August 1985 off the coast of Norfolk, Virginia, where wave heights of up to 5 feet (1.5 m) were encountered. The data reported for the 6 EPIRBs were collected simultaneously with the on-land and on-deck engineering tests.

2.2.1.2 *Test results*

The measured beacon-detection probability is shown in Table I. The engineering test results indicate an overall value of this parameter to be 0.999, with somewhat lower results for environmental tests, 0.98; the measured cumulative beacon-detection probability thus being 0.99. These results were achieved with the use of the short message type with a protective BCH code. If the long message had been used, lower results would have been achieved due to the absence of correcting code for the last 32 bits of information.

2.2.1.2.1 *On-land tests*

In the C-series engineering tests, the beacon-detection probability for 66 passes of Sarsat-1 and 67 passes of Sarsat-2 was measured to be 1.0. Likewise, in the F-series engineering tests, it was also measured to be 1.0 for 246 possible detections.

In the E-series environmental tests, the beacon-detection probability for 262 passes of Cospas-2 and 253 passes of Cospas-3 was measured to be 0.98.

2.2.1.2.2 *On-deck tests*

The on-deck F-series engineering tests yielded a 0.99 beacon-detection probability for 130 possible detections and show essentially the same results as the on-land beacon and the floating EPIRB F-series engineering data.

2.2.1.2.3 *Floating tests*

In the F-series engineering tests, the beacon-detection probability was measured to be 1.0 for 260 possible detections.

In the E-series environmental tests, the beacon-detection probability for numerous passes of Cospas-2 and -3, and Sarsat-1 and -2 satellites was measured to be 0.98.

TABLE I – *Beacon-detection probability*

Beacon	Series	Engineering tests		Environmental tests		Cumulative	
		Probability	No. of possible detections	Probability	No. of possible detections	Probability	No. of possible detections
On-land	C E F	1.0 – 1.0	266 – 246	– 0.98 –	– 515 –	1.0 0.98 1.0	266 515 246
Sub-total		1.0	512	0.98	515	0.99	1027
On deck	F	0.99	130	–	–	0.99	130
Floating	C F	– 1.0	– 260	0.98 –	377 –	0.98 1.0	377 260
Sub-total		1.0	260	0.98	377	0.99	637
Total		0.999	902	0.98	892	0.99	1794

2.2.2 *Location error*

Location error is defined as the difference between the location calculated by the system using measured Doppler frequencies and the actual location of the radio beacon as reported by the field personnel.

One should be aware that measurement of location error during engineering tests is expected to be more precise than that during environmental tests because the actual beacon locations could be more accurately determined. The ELT actual locations often are more accurately determined than the actual locations of the EPIRBs. Hence, confidence in the actual beacon positions obtained during environmental on-land ELT tests is generally higher than EPIRB tests run at sea.

2.2.2.1 *Test description*

2.2.2.1.1 *On-land tests*

The B-series results were obtained from a single test in which two experimental beacons were placed on the roof of a building and powered by an external source [Canada, 1985a].

The C-series engineering tests provided a large number of measurements and were taken in an area where there is considerable interference at 406 MHz [USSR *et al.*, 1984b; Castetbert, 1984a; France, 1984a].

The C-series environmental tests were conducted at airports located throughout the world [CSSC, 1985c].

The D-series engineering test results were obtained from a single beacon transmitting via the S1 satellite [Hovmork, 1984a].

The D-series environmental tests included placing 406 MHz beacons at 16 different sites on land and in the water, including former aircraft and ship accident sites [Hovmork, 1984b].

The E-series engineering test results were obtained from two separate tests [USSR, *et al.*, 1984c]. One test used five beacons activated simultaneously with internal lithium batteries; the second test used a single beacon powered from an external source.

The F-series engineering tests were conducted at varying power levels to obtain threshold data concurrent with location accuracy [Westinghouse, 1985].

The F-series environmental tests were conducted over a 1-year period [NASA, 1984a; NASA, 1985a].

The G-series tests were run using three LUTs for data comparison [United Kingdom, 1985].

A joint G-series and C-series engineering test was held [Department of Transport, 1984; USSR *et al.*, 1984b] to allow comparison between the two LUTs.

2.2.2.1.2 *On-deck tests (all environmental)*

A-series tests involved both ship-mounted and floating EPIRBs [USSR *et al.*, 1984d].

B-series tests were quite extensive and were conducted inland and on open ocean [Canada, 1985b].

C-series tests involved stationary and moving vessels [USSR *et al.*, 1984b; CSSC, 1985d].

E-series tests involved several different ships [USSR *et al.*, 1984e].

F-series tests [NASA, 1984b; NASA, 1985b] may have had some procedural problems early in the testing which were corrected during later tests. The effect on the results is unknown.

2.2.2.1.3 *Floating tests (all environmental)*

B-series tests [Canada, 1985b] utilized only tethered EPIRBs.

C-series tests were conducted both inland and in several different sea states [CSSC, 1985d; USSR *et al.*. 1984b].

F-series tests were conducted using both tethered and free-floating EPIRBs [NASA, 1984c; NASA, 1985b].

G-series tests were conducted using data collected from three different LUTs [United Kingdom, 1985].

2.2.2.2 *Test results*

The location-error test results are shown in Table II and are described below. Graphs depicting the data are included in Annex I.

TABLE IIa – *Location error measured during engineering tests of land beacons* *

Series	Average (mean) error (km)	No. of locations	50th percentile (median) error (km)	No. of locations	90th percentile error (km)	No. of locations	95th percentile error (km)	No. of locations
B	2.2	675	1-2	675	2-4	675	2-4	675
C	3.6	3733	0-1	3682	1-2	3682	5-10	3682
D	1.6	23	0-1	23	5-6	23	6-7	23
E	1.8	66	1-2	66	3-4	66	5-6	66
F	3.2	89	2.0	89	6.3	89	7.7	89
G	3.5	136	0-2	136	5-10	136	5-10	136
Sub-total	3.4	4722	0-1	4671	2-3	4671	5-10	4671

* Location error is measured between true location and the correct-side solution.

TABLE IIb – *Location error measured during environmental tests of land beacons* *

Series	Average (mean) error (km)	No. of locations	50th percentile (median) error (km)	No. of data points	90th percentile error (km)	No. of locations	95th percentile error (km)	No. of locations
C	2.5	961	0-1	961	1-5	961	5-10	961
D	3.1	149 (1)	1-2	149 (1)	7-8	149 (1)	10-15	149 (1)
F	5.8	260	–	–	–	–	–	–
Sub-total	3.2	1370	0-1	1110	1-5	1110	5-10	1110

* Location error is measured between true location and the correct-side solution.

(1) Includes data from floating EPIRBs.

TABLE IIc – *Location error measured during environmental tests of on-deck beacons* *

Series	Average (mean) error (km)	No. of locations	50th percentile (median) error (km)	No. of locations	90th percentile error (km)	No. of locations	95th percentile error (km)	No. of locations
A	7.6	38 (1)	1-2	38 (1)	10-20	38 (1)	30-50	38 (1)
B	4.5	92 (2)	2-3	92 (2)	9-10	92 (2)	16-17	92 (2)
C	3.5	327	1-2	146	4-9	146	4-9	146
E	3.5	82 (1)	1-2	82 (1)	4-7	82 (1)	7-11	82 (1)
F	8.5	130	–	–	–	–	–	–
Sub-total	4.8	669	1-2	358	5-10	358	10-20	358

* Location error is measured between true location and the correct-side solution.

(1) Includes data from floating EPIRBs.
(2) Data excludes global mode where both regional and global mode data were available.

TABLE IId – *Location error measured during environmental tests of floating beacons* *

Series	Average (mean) error (km)	No. of locations	50th percentile (median) error (km)	No. of locations	90th percentile error (km)	No. of locations	95th percentile error (km)	No. of locations
B	3.8	258 (1)	1-2	189	7-8	189 (1)	14-15	189 (1)
C	3.0	395	1-2	284	4-5	284	5-10	284
F	8.5	256	–	–	–	–	–	–
G	4.1	90	1-2	90	5-10	90	15-20	90
Sub-total	4.7	999	1-2	563	5-10	563	5-10	563

* Location error is measured between true location and the correct-side solution.

(1) Data excludes global mode where both regional and global mode data were available.

TABLE IIe – *Location error summary*

Test type	Average (mean) error (km)	No. of locations	50th percentile (median) error (km)	No. of locations	90th percentile error (km)	No. of locations	95th percentile error (km)	No. of locations
Engineering tests	3.4	4722	0-1	4671	2-3	4671	5-10	4671
Environmental tests	4.0	3038	1-2	2031	5-10	2031	5-10	2031
Total	3.7	7760	0-1	6702	3-4	6702	5-10	6702

2.2.2.2.1 *On-land results*

The mean-location error measured during the engineering tests was 3.4 km for 4722 locations; the 50th, 90th, and 95th percentile ranges were 0-1 km, 2-3 km, and 5-10 km respectively for 4671 locations.

The mean-location error of the environmental tests was 3.2 km for 1370 locations; the 50th, 90th, and 95th percentile ranges were 0-1 km, 1-5 km, and 5-10 km respectively, for 1110 locations. The environmental tests show similar accuracy to the engineering test results.

2.2.2.2.2 *On-deck results*

The mean-location error for the environmental tests was 4.8 km for 669 locations; the 50th, 90th, and 95th percentile ranges were 1-2 km, 5-10 km, and 10-20 km respectively, for 358 locations. While it is possible that degradation from the on-land result may have occurred, it is more likely that the less accurate knowledge of the ship locations at the time of the satellite passes is the reason for the small discrepancy between the on-deck and the on-land results.

2.2.2.2.3 *Floating results*

The mean-location error for the environmental tests was 4.7 km for 999 locations; the 50th percentile range was 1-2 km, the 90th percentile range was 5-10 km, and the 95th percentile range was 10-20 km for 563 locations. Degradation from the on-land results was expected; however, the lack of knowledge of the true location of the beacons during the time of the satellite passes also had an effect on the result.

2.2.2.2.4 *Other data*

Several sets of on-deck and floating series tests were not included in the evaluation of the mean location error because the conditions of the tests were operationally invalid (e.g. a moving ship or lost floating EPIRBs) and were inappropriate to combine with the other tests.

2.2.3 *Ambiguity resolution*

For each real signal, the Doppler position location estimate generates two solutions that are mirror images about the satellite sub-track. Ambiguity resolution is defined as the ability of the system to select the "true" rather than the "mirror" position location as part of the location determination process. The rotation of the Earth introduces a non-symmetrical effect that provides an indication of the true position location. The system uses the non-symmetrical effect to assign each solution a probability of its being the true solution. Therefore, the performance measure of ambiguity resolution is the percentage of beacon-location messages for which the system correctly assigns the higher probability of the true solution.

2.2.3.1 *Test description*

Ambiguity resolution was generally recorded during the same tests as the location error. With the exception of those tests in which ambiguity resolution was not reported or as listed below, all of the tests are described in § 2.2.2.1.

C-series floating environmental tests [CSSC, 1985e] were conducted in low sea states.

2.2.3.2 *Test results*

Test results are noted in Table III and are described below.

TABLE III – *Ambiguity resolution*

Beacon location	Series	Engineering tests		Environmental tests		Cumulative	
		Probability	No. of locations	Probability	No. of locations	Probability	No. of locations
On-land	B	0.97	675	–	–	0.97	675
	C	0.98	831	–	–	0.98	831
	D	0.87	23	0.84	149 (1)	0.84	172
	E	0.82	66	–	–	0.82	66
	F	0.94	410 (2)	0.92	260	0.94	670
Sub-total		0.96	2005	0.89	409	0.95	2414
On-deck	B	–	–	0.87	92	0.87	92
	C	–	–	0.98	372	0.98	372
	E	–	–	0.95	82 (1)	0.95	82
	F	–	–	0.93	130	0.93	130
Sub-total				0.95	676	0.95	676
Floating	B	–	–	0.91	243 (3)	0.91	243
	C	–	–	0.91	234	0.91	234
	D	–	–	0.89	45	0.89	45
	F	–	–	0.81	256	0.81	256
	G	–	–	0.92	90	0.92	90
Sub-total		–	–	0.88	868	0.88	868
Total		0.96	2005	0.91	1953	0.93	3958

(1) Includes data from floating EPIRBs.

(2) Tests were performed by varying the beacon output from 22 dBm to 37 dBm. The actual number of tests run at nominal beacon e.i.r.p. (37 dBm) is unknown.

(3) When both regional and global mode data were available, the regional mode was used. The B-series on-deck data and the floating data would have been 0.97 for 92 locations and 0.99 for 214 locations, respectively, if the global mode had been used.

2.2.3.2.1 *On-land tests*

The 0.96 probability of correct ambiguity resolution obtained during the engineering tests was very good. In addition, the F-series test results indicated that there was no correlation between ambiguity resolution and either the spacecraft or the satellite pass direction (ascending or descending).

As expected, the environmental ambiguity resolution result (0.89) is degraded relative to the engineering results. Some of the reasons are as follows: the elevation angle for one of the test series was either below 10° or above 82°, which made Doppler detection extremely difficult; and the time of closest approach for another of the test series was of the order of 4 min, which is critical if the signal is partially obstructed. Further testing is required for a full understanding of the degraded performance.

2.2.3.2.2 *On-deck tests*

The 0.95 probability of correct ambiguity resolution obtained during on-deck environmental tests appears to be higher than would be expected when compared to other environmental results.

2.2.3.2.3 *Floating tests*

The probability of correct ambiguity resolution obtained during the floating EPIRB tests was 0.88. The result appears to be comparable to the on-land environmental result.

2.2.4 *Beacon-location probability*

Beacon-location probability is defined as the probability of detecting and decoding at least four individual message bursts during a single satellite pass so that a Doppler curve-set estimate can be generated by the LUT. Location probability, as defined here, is not the end product but results in two ambiguous positions.

2.2.4.1 *Test description*

Most of the beacon-location probability results were generally obtained during the same tests as the location error and ambiguity resolution and are described in § 2.2.2.1. The F-series engineering tests were described under the beacon-detection probability, § 2.2.1.1. The remainder of the tests are noted below.

The B-series on-land engineering tests [King, 1984] were very extensive and included elevation angles below 10°.

The C-series floating environmental tests [CSSC, 1985e] were conducted using tethered and free-floating EPIRBs.

2.2.4.2 *Test results*

Table IV summarizes the measured beacon-location probabilities determined from engineering and environmental tests. The data in this table refers to the two possible locations due to ambiguity. The August, 1985 F-series engineering tests showed better results. All problems with faulty beacons and operational procedures have been eliminated during these tests.

2.2.4.2.1 *On-land tests*

The beacon-location probability measured during on-land engineering and environmental tests has been found to be 0.86 and 0.90, respectively.

2.2.4.2.2 *On-deck tests*

The on-deck engineering beacon measurements, undertaken during the F-series August 1985 tests, resulted in 0.98 beacon-location probability.

The on-deck environmental beacon-location probability test result was comparable to the on-land environmental test data and was found to be 0.87.

TABLE IV – *Beacon-location probability* *

Beacon location	Series	Engineering tests		Environmental tests		Cumulative	
		Probability	No. of possible locations	Probability	No. of possible locations	Probability	No. of possible locations
On land	B	0.82	822 (1)	–	–	0.82	822
	C	0.84	61	0.94	362	0.92	423
	D	–	–	0.91	164 (2)	0.91	164
	E	0.90	73	–	–	0.90	73
	F	0.95	350	0.86	302	0.91	652
Sub-total		0.86	1306 (1)	0.90	828	0.88	2134
On deck	B	–	–	1.0	25	1.0	25
	C	–	–	0.87	634	0.87	634
	E	–	–	0.80	51	0.80	51
	F	0.98	130	–	–	0.98	130
Sub-total		0.98	130	0.87	710	0.89	840
Floating	B	–	–	0.84	403 (3)	0.84	403
	C	–	–	0.88	377	0.88	377
	D	–	–	0.94	34	0.94	34
	E	–	–	0.76	54	0.76	54
	F	0.99	260	0.77	331 (4)	0.87	591
	G	–	–	1.0	9	1.0	9
Sub-total		0.99	260	0.83	1208	0.86	1468
Total		0.89	1696	0.86	2746	0.87	4442

* This data was obtained without resolving the ambiguity.

(1) If only data above 10° elevation angle is considered, the probability becomes 0.93/617 for B-series and 0.93/1101 sub-total.

(2) Includes data from floating EPIRBs.

(3) When both regional and global mode data were available, the regional mode was chosen. The B-series floating data would have been 0.84/476 if the global mode had been used.

(4) This data includes procedural errors in determining elevation angles and from some faulty beacons.

2.2.4.2.3 *Floating tests*

The engineering measurements for floating EPIRBs, obtained during the August, 1985 F-series tests, resulted in 0.99 beacon-location probability, a similar value to the on-land and on-deck data for that series.

Some degradation in environmental beacon-location probability from the engineering test data was expected. The cause of such a degradation to a value of 0.83 has been determined, at least for the F-series tests, to have been caused by use of some intermittent beacons and from less stringent accounting of data.

2.2.4.3 *Beacon-location probability as a function of beacon output power*

The beacon-location probability reduction is a quantitative measure of the system's ability to process beacon signals at reduced signal levels. The test described below measured that value of the beacon e.i.r.p. at which the beacon-location probability decreases by 10% from its value for a nominal power beacon.

2.2.4.3.1 *Test description*

A B-series engineering test on land was conducted during the September-November, 1983 test period to measure the beacon-location probability as a function of beacon output power [King, 1985]. A total of 482 satellite passes of C2 and S1 satellites were tracked by the Ottawa LUT. The test was conducted by operating two 406 MHz beacons collocated with the Ottawa LUT. One beacon was used as a reference and always operated at the nominal power output of 37 dBm (5 W), while the other beacon had selected fixed attenuators inserted in the antenna cable. Each beacon transmitted from a separate, but similar, quarter-wave monopole antenna (with ground plane) mounted on the roof of a one-storey building. The beacons transmitted at 50 s intervals, but staggered by 25 s so as not to have simultaneous transmissions.

2.2.4.3.2 *Test results*

Table V provides the data obtained during the above B-series tests. The test results indicate that for those satellite passes whose maximum elevation angle exceeded 10° (i.e. passes preferred for optimum system operation), a 13 dB beacon power reduction resulted in a 9% reduction in beacon-location probability. However, when all passes are considered (i.e. including those passes below 10° elevation angle), the equivalent power reduction was measured to be 6 dB.

TABLE V – *Beacon-location probability as a function of beacon output power*

Maximum elevation angle of pass	Attenuation level of nominal e.i.r.p. (dB)	Total No. of locations		Relative location probability (1) (attenuated/nominal)
		Nominal power beacon	Attenuated power beacon	
> 10°	0	51	51	1.00
	3	55	54	0.98
	6	96	91	0.95
	9	100	94	0.94
	13	44	40	0.91
> 0°	0	57	57	1.00
	3	70	63	0.90
	6	116	104	0.90
	9	122	101	0.83
	13	54	41	0.76

(1) Actual beacon-location probability data for this test is not known.

2.2.5 *Capacity*

Capacity is defined as the ability of the system to simultaneously process beacons that are in a common field of view of the spacecraft during a single pass. The 406 MHz system is designed to be capable of processing 90 beacons simultaneously in the field of view of the satellite. Verification of this capability was attempted using Cospas-2, Sarsat-2, and a special test facility located in France. In 1984 and 1985, these tests demonstrated that with interference present, the 406 MHz on-board processor could process more than 90 simulated beacon transmissions simultaneously [Castetbert, 1984b; CSSC, 1985f].

2.2.6 *Homing range*

Homing-range capability is measured in terms of the distance (relative to height) from an airborne homing device to a 406 MHz beacon using the latter's low power 121.5 MHz homing signal. Figure 1a shows the test results in terms of homing range as a function of aircraft height above the beacon's terrain.

Some tests were conducted using an existing aircraft 121.5 MHz homer which was modified to respond directly to the 406 MHz burst signal. Performance data for these flight trials is shown in Fig. 1b.

Figures 1a and 1b illustrate that if search and rescue aircraft are used, the homing range of 10 km is sufficient to find 95% of 406 MHz satellite EPIRBs, as shown in Table IIe.

The maritime homing test results are presented in Report 1036.

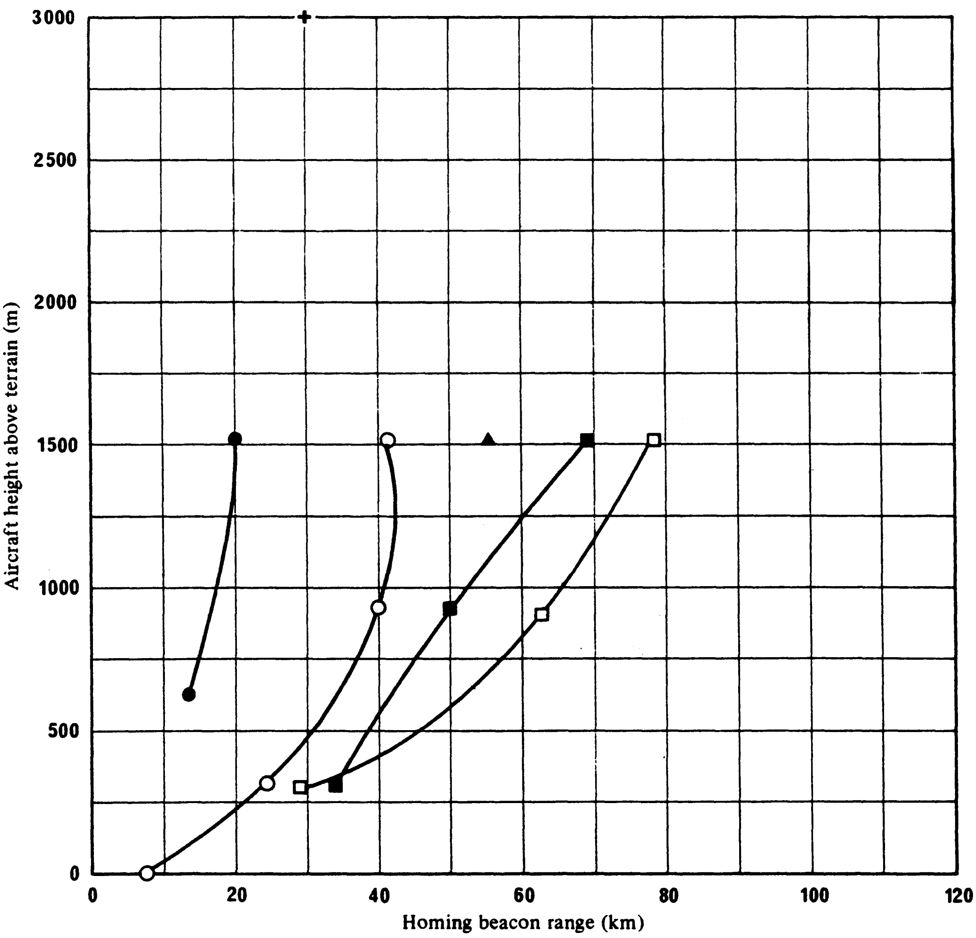

FIGURE 1a – *Homing test results using 121.5 MHz, 20 mW transmitter**

* This was a 20 mW 121.5 MHz homing transmitter placed in a 406 MHz beacon

Sea test data

- ● USCG homer
- ▲ UK/French SAR
- + USSR Black Sea

Land test data

- ○ USAF A homer
- ■ USAF B1 homer
- □ USAF B2 homer

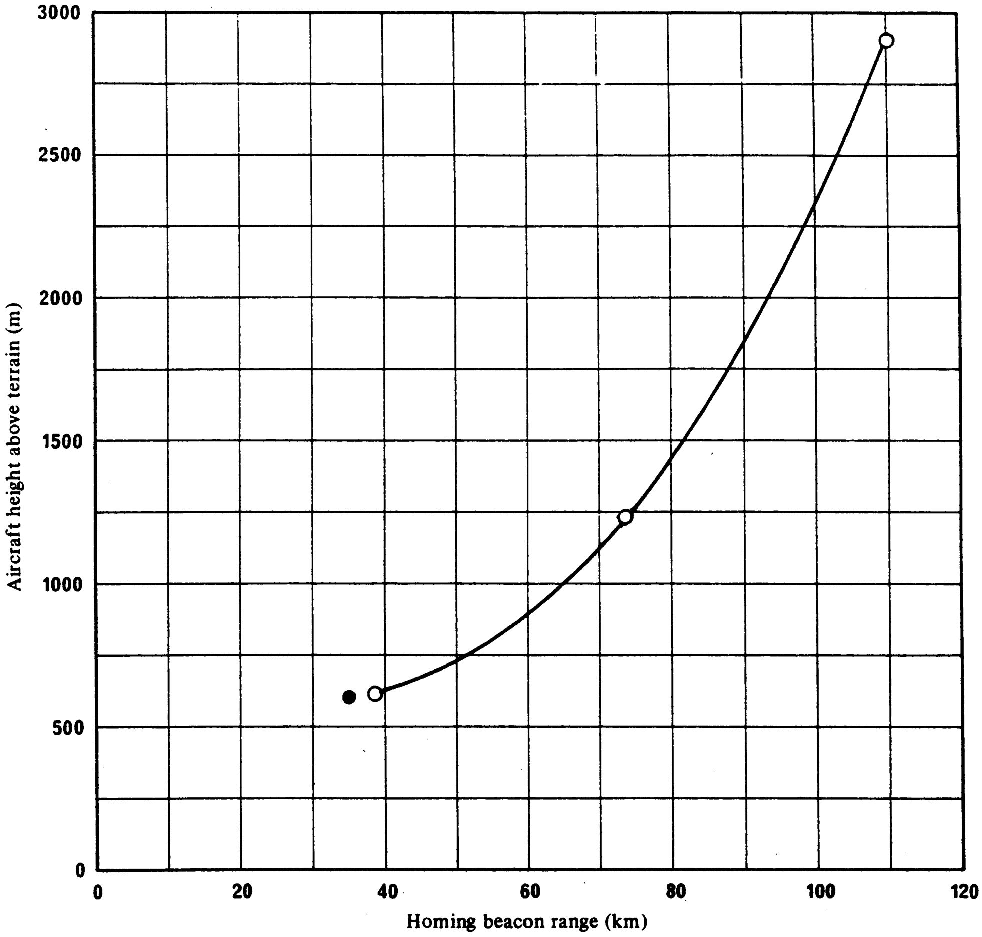

FIGURE 1b – *Homing test results using COSPAS/SARSAT 406 MHz, 5 W/burst signal*

Canadian modified DF 301 E homer

O Land test data

● Sea test data

2.2.7 *Notification time*

For the purpose of this Report, notification time is defined as the time period between activation of a radio beacon and the time when a valid alert message is received by the mission control centre (MCC) responsible for relaying the message to the rescue coordination centre (RCC). In the regional (real-time) mode, notification time includes the time period from beacon activation to the time of the establishment of a common field of view between the beacon and the spacecraft, and the LUT and the spacecraft; all processing time by the LUT; and all communications handling times to receipt of the message by the MCC.

In the global (stored) mode, notification time includes the time period from beacon activation to the time of line-of-sight contact with the spacecraft; the time period between receipt of the alert message by the spacecraft (including storage and processing) and its dump to the ground station; and all LUT communications handling/processing times from beacon activation to receipt of the alert message by the MCC.

The limited results presented in Table VI were obtained by B-, C-, and E-series tests [Canada, 1985b; USSR *et al.*, 1984f; France, 1984b; CSSC, 1985e]. Notification times depend on the number of satellites, the latitude of distress locations, the distribution of LUTs over the world, and the varying satellite positions with time. All of the above tests were performed with beacons and LUTs at northern mid-latitudes of about 45° N, and the results presented are mean values of both regional and global modes. In the future, additional computer simulations and tests to verify the simulations may be performed to determine notification time as a function of additional latitudes, global and regional modes, and varying beacon-LUT-spacecraft geometries. The results of this additional effort will be reported in detail and will not be averaged.

TABLE VI – *Mean notification time**

Beacon location	Series	Time (min)	No. of locations
On land	B C E	77 114 90	2 51 44
Sub-total		102	97
On deck	C	87	279
Floating	C	98	89
Total		92	465

* From one to three satellites were used with beacons and LUTs located at an approximate latitude of 45° N.

3. 406 MHz interference

Figure 2 shows the areas over which the COSPAS/SARSAT satellites are affected by interfering signals at 406 MHz [USSR *et al.*, 1984b]. The interference situation was raised during the 1983 World Administrative Radio Conference for Mobile Services (WARC MOB-83), and a Resolution to protect the 406.0-406.1 MHz frequency band was included in the Final Acts of the Conference (Resolution No. 205). With this Resolution, the WARC MOB-83 requested the International Frequency Registration Board (IFRB) to organize a monitoring programme in this frequency band and requested administrations to take all necessary actions to eliminate unauthorized transmissions.

In addition, using both Cospas-I and the SAR repeater (SARR), the SARSAT partners developed specific analysis programmes for locating interfering signals. Some interfering signals have well-characterized spectral components where the frequency variation due to the Doppler shift can be identified. It is therefore possible to determine the position of the interfering source using a positioning technique similar to the technique used for ELT/EPIRBs. A description of this method was submitted to Study Group 1 (see Report 979).

So far, several unauthorized transmission sources have been located and were removed from the SAR frequency band. Other sources are being pursued through bilateral contacts. Most of the interfering transmitters were found to be used for low-rate data links. Such use of the 406 MHz band was authorized prior to the WARC-79. The signal levels received by the satellites from these unauthorized transmissions are comparable to the signal levels from 406 MHz EPIRBs. It is expected that the IFRB actions and the bilateral actions will, in the near future, allow the elimination of most of the interfering signal sources.

4. Measured performance at 121.5 MHz

Although this Report is intended to show the results of the D and E phase at 406 MHz, it is important to mention the results of the concurrent and related D and E tests at 121.5 MHz. The primary relevance of these results is the fact that the 121.5 MHz is presently the most commonly used frequency world-wide for the support of search and rescue operations and is used in distress beacons of general aviation and maritime communities world-wide. Although the capabilities of the 121.5 MHz beacons are not expected to be nearly as good as the new experimental 406 MHz beacons undergoing development, the results of the D and E phase have already shown that the use of low Earth-orbiting satellites in conjunction with a distress beacon system does substantially improve SAR capabilities. As of 31 August 1985, the 121.5 MHz system has provided position locations and alert notifications that contributed to the rescue of 474 distress victims (238 aviation, 217 maritime, and 19 terrestrial) involved in real distress cases. In some of these cases, the 121.5 MHz COSPAS/SARSAT system was the only notification source; and, in more cases, the COSPAS/SARSAT system was the first notification source.

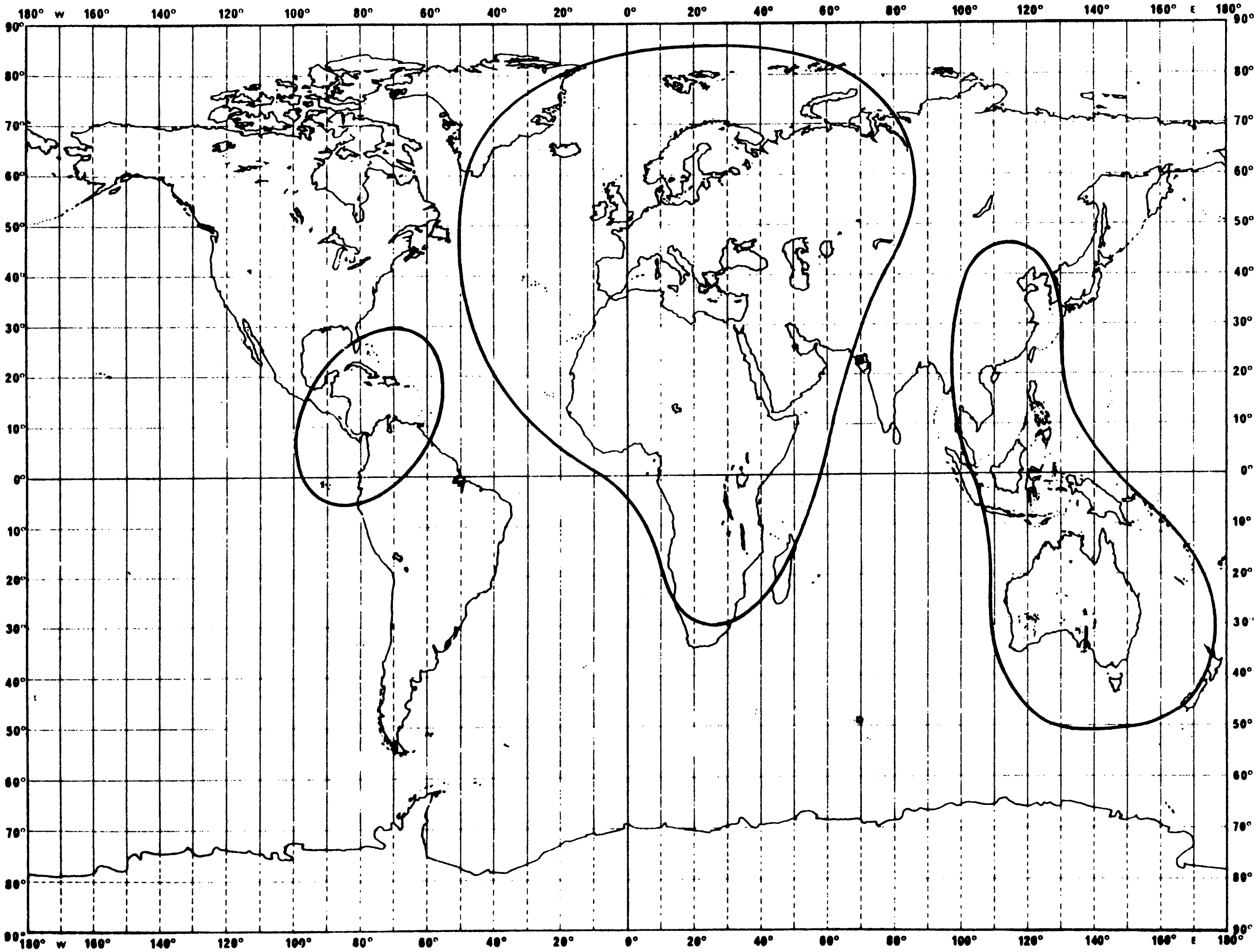

FIGURE 2 – *Areas affected by interference*

It is generally accepted by participants in the COSPAS/SARSAT project that the 406 MHz system is expected to provide to the SAR community, support that is far superior to that of the current 121.5 MHz system. To give the user an understanding of the performance of the 121.5 MHz system, the general SARSAT participants' results of environmental tests performed at this frequecy during the period of February, 1983 to February, 1984 inclusive are presented in Table VII. The results are shown for tests on land and at sea. The tests on land were performed by the participating countries in nearly all possible environmental conditions. (These conditions ranged from desert to mountains, to dense forest from −40 °C to +55 °C from clear weather to thunderstorms, to blizzards and various combinations of other extremes. It must be noted that these tests used known, good ELT configurations, i.e. coherent signal (see Note), nominal signal strength, good power source, good antenna, and compatible geometry. The environmental sea tests were performed in much the same manner as the land tests. The primary variable in the sea tests was the sea state. There also existed the inherent problem of not knowing the exact location while at sea. These two conditions may explain the reasons why the sea-test results do not compare well with the land tests.

Note. – In this context, the definition given to a coherent signal is one with a spectrum containing a clearly identifiable constant frequency component; an incoherent signal has no predominant carrier component in its spectrum.

TABLE VII – *Measured performance of the 121.5 MHz system*

Performance parameter	Measured performance
Mean location error (1)	
Sea tests (km)	23.4
Land tests (km)	17.2
Location probability	
Sea tests (%)	76
Land tests (%)	91
Ambiguity resolution	
Sea tests (%)	72
Land tests (%)	73
Number of orbits	
Sea tests	174
Land tests	139
Number of locations	
Sea tests	189
Land tests	166

(1) Location error is measured between true location and the correct-side solution, i.e. disregarding ambiguity.

By comparing the results of 121.5 MHz tests shown in Table VII with the results of 406 MHz tests shown in Tables II to IV, one can see that performance of the 406 MHz system exceeds that of the 121.5 MHz system in location error and in ambiguity resolution, though there appears to be no significant improvement in performance in location probability over the coherent 121.5 MHz beacons used in the test.

The contributions already made by the 121.5 MHz system in supporting SAR operations are significant, even using distress beacons of unknown operating condition, many of which have neither coherent nor stable frequency characteristics. One should expect greatly improved support of SAR operations using the 406 MHz system with its improved performance and additional message information and identification.

A major improvement expected of the 406 MHz system over the 121.5 MHz system is the reduction of false alarms. This subject is addressed in § 5 below.

5. Problem areas at 121.5 MHz

5.1 *False alarm resolution*

False distress alarms have existed since emergency beacons came into use. False alarms are defined here as the transmission of a signal by an emergency beacon when it is not in a distress situation. (Short test transmissions following specified procedures are allowed and do not cause false alarms.) With the advent of satellite-aided detection of operational 121.5 MHz beacons, many previously undetected false alarms began to be detected because of the COSPAS/SARSAT demonstrated ability to detect very weak distress beacons. The SAR forces have always adopted procedures to continue their effectiveness in spite of false alarm problems, both before and after satellite support. The demonstrated extraordinary ability of the COSPAS/SARSAT satellites to detect even very weak beacons has the unfortunate consequence of capturing, in addition to distress signals, all the false alarms. Despite this present situation of intensity of false alarms at 121.5 MHz, the SAR forces remain responsive to the distress cases. Clearly, future operational systems require improvements for minimizing the false alarm rate.

One of the most positive steps in eliminating false alarms can come from the implementation of 406 MHz beacons that have unique identification, specifications for satellite compatibility, and elimination of 121.5 MHz beacon weaknesses. The 406 MHz beacon unique identification code will eliminate unnecessary searches for many false alarms by allowing communication checks based on data derived from the ID code. The satellite compatibility improvement of the 406 MHz beacon will eliminate falsely generated alerts in the ground system that were due to noise and modulation peculiarities that cause problems in the current 121.5 MHz system. The 406 MHz specifications and the voluntary 121.5 MHz specification for the ELT crash sensor will provide a more reliable system than currently provided by the 121.5 MHz beacons and will also reduce the false alarms. In the United States of America, changes to 121.5 MHz beacon specifications, and pilot and mariner education programmes are under way to reduce the false alarm problem with the present beacons.

6. Preliminary conclusions

The COSPAS/SARSAT system is an excellent example of international cooperation to establish technical and operational compatibility between two completely independent space systems. The project, a synthesis of the Soviet COSPAS and the Canada/France/United States SARSAT project activities, joined because of common technical and humanitarian objectives, has been successful despite its short period of existence. While the detailed evaluation of the performance of the COSPAS/SARSAT search and rescue satellite system continues, some of the following anticipated benefits of the system are being realized:

- saving of lives;
- improved response to distress calls from maritime, aeronautical, and land-mobile stations;
- more efficient use of SAR resources.

In summary, the COSPAS/SARSAT demonstration and evaluation phase indicates the following:

- COSPAS/SARSAT is contributing to quicker detection and location of people in distress, thus relieving human suffering and enhancing the protection of property;
- the SARSAT and COSPAS systems have demonstrated that all inter-operability requirements were achieved;
- experimentation and operational use at 121.5 MHz have been successful. As of 31 August 1985, the system has provided alert and location data in 194 distress incidents world-wide, in which 474 survivors were rescued;
- experimentation at 406 MHz has demonstrated the benefits of using beacons designed for satellite detection. Benefits include global coverage (in the global mode), beacon identification, and improved location probability and improved accuracy over the present 121.5 MHz beacon performance.

7. Summary and outlook

The environmental and engineering test data presented in this Report demonstrate that the COSPAS/SARSAT system has successfully met all its objectives. It has been used operationally at 121.5 MHz since 1982, and additional operations at 406 MHz were initiated in July 1985. The successful demonstration was accomplished even though during much of the demonstration and evaluation phase fewer than the specified four satellites were in orbit. In addition, other portions of the system, such as signal processing techniques and algorithms, continued to undergo improvements.

The in-orbit satellite configuration is now as intended. More LUTs are being added, including the first one in South America. A plan for a system of regional data distribution centres for the world-wide distribution of distress data has been developed and will be implemented over the next few years.

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ANNEX I

COSPAS/SARSAT SYSTEM
LOCATION-ERROR HISTOGRAMS

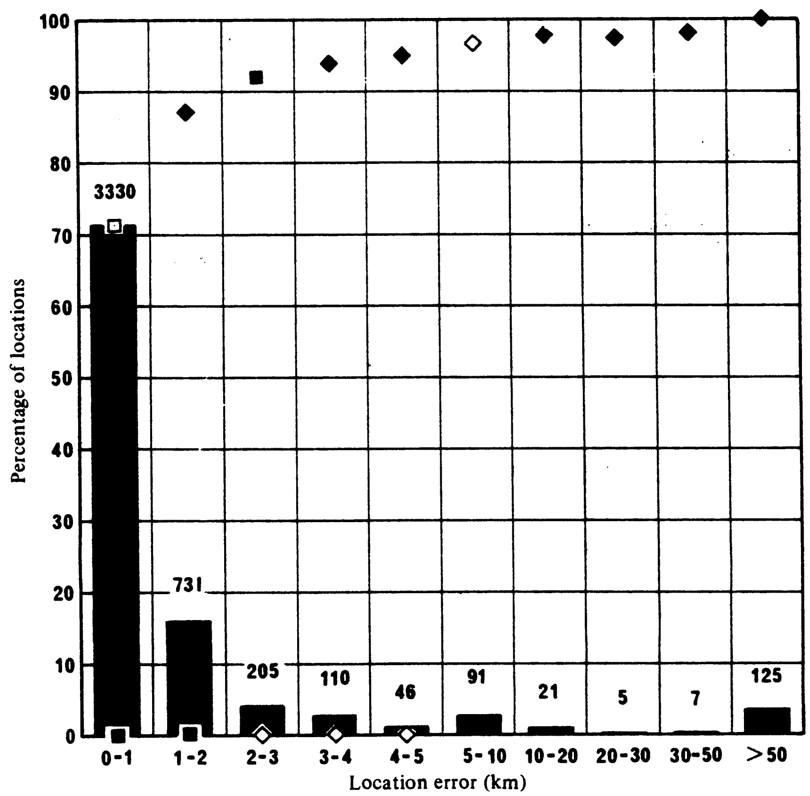


FIGURE 3 – *Location error measured during engineering tests of land beacons as a function of percentage of locations*

(Total of all data where the distributions were reported: 4671 locations)

■ Group percentage

□ 50% mark

■ 90% mark

◇ 95% mark

◆ Cumulative percentage

The number of locations per group is indicated above each column.

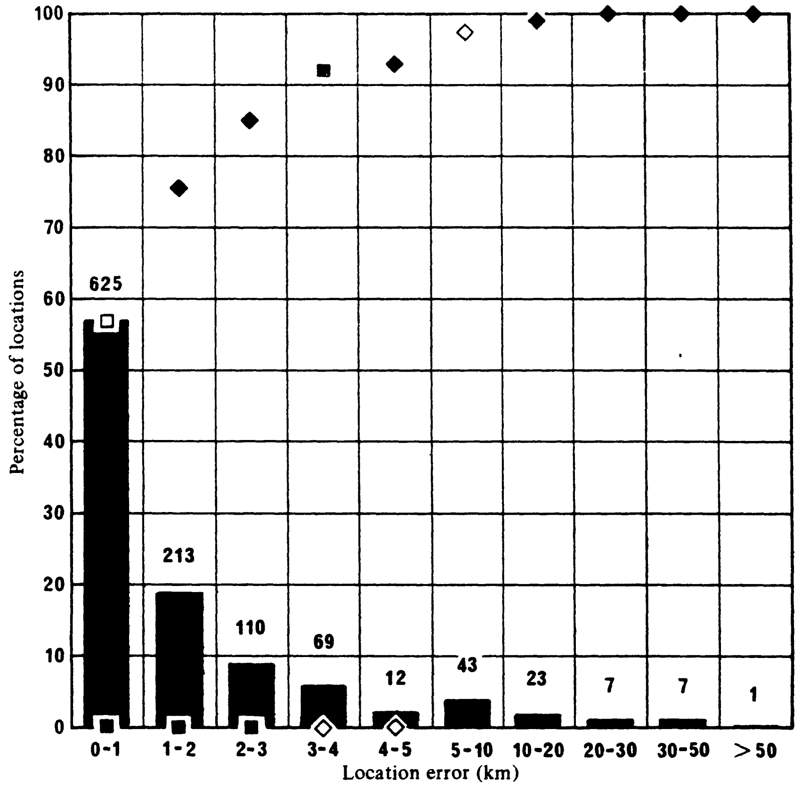


FIGURE 4 – *Location error measured during environmental tests of land beacons as a function of percentage of locations*

(Total of all data where the distributions were reported: 1110 locations)

The number of locations per group is indicated above each column.

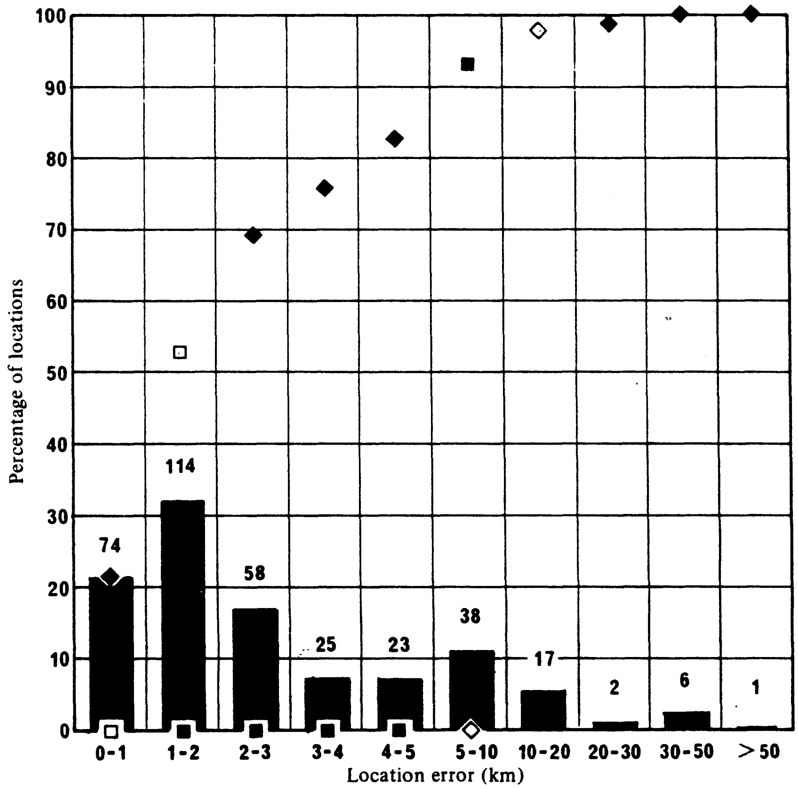


FIGURE 5 – *Location error measured during environmental tests of on-deck beacons as a function of percentage of locations*

(Total of all data where the distributions were reported: 358 locations)

Group percentage

50% mark

90% mark

95% mark

Cumulative percentage

The number of locations per group is indicated above each column.

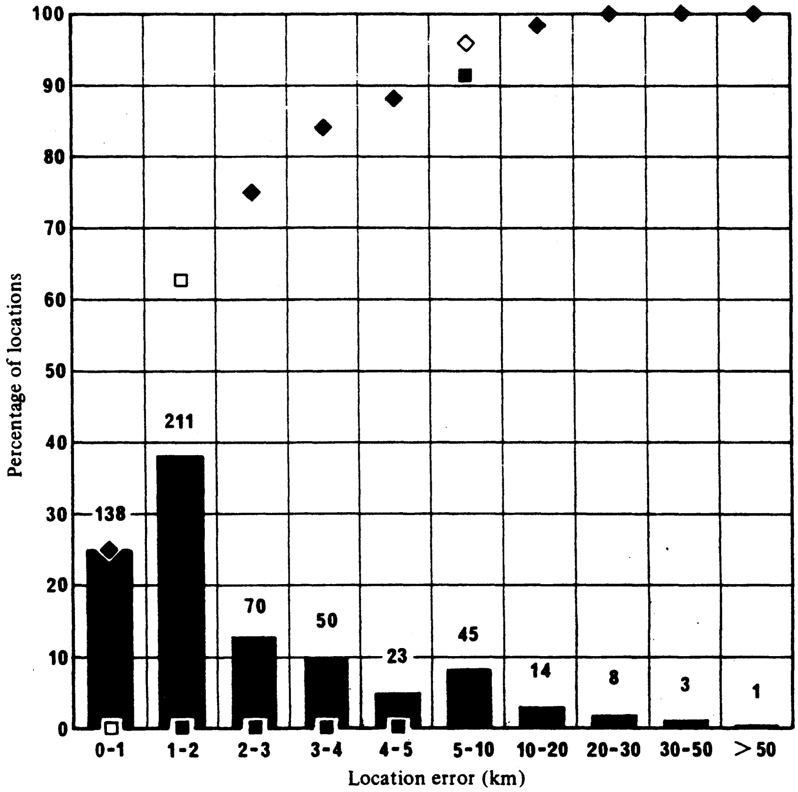


FIGURE 6 – *Location error measured during environmental tests of floating beacons as a function of percentage of locations*

(Total of all data where the distributions were reported: 563 locations)

Group percentage

50% mark

90% mark

95% mark

Cumulative percentage

The number of locations per group is indicated above each column.

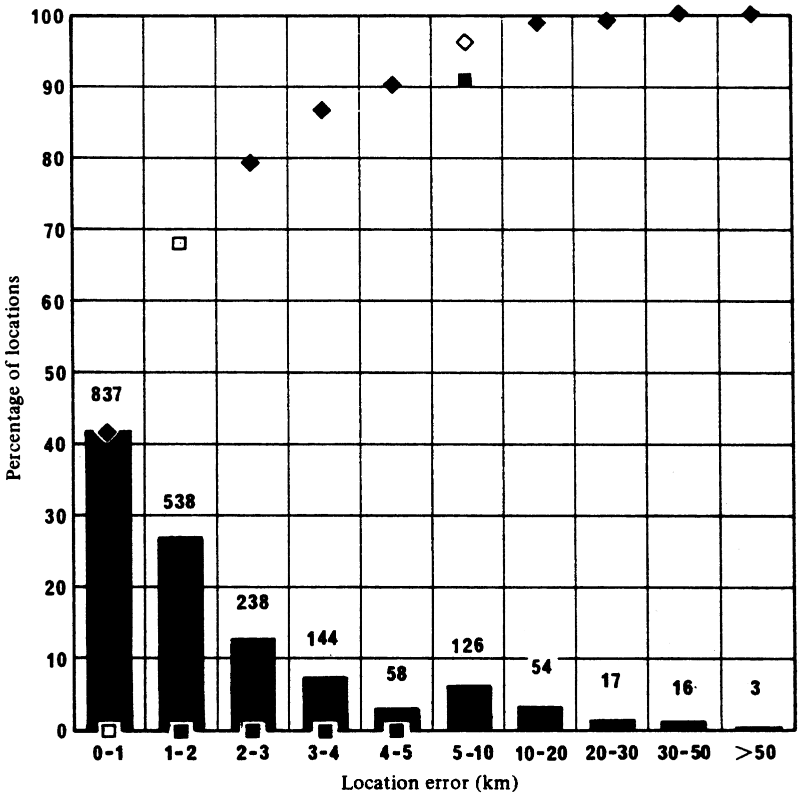


FIGURE 7 – *Location error measured during environmental tests of all beacons as a function of percentage of locations*

(Total of all data where the distributions were reported: 2031 locations)

■ Group percentage

□ 50% mark

■ 90% mark

◇ 95% mark

◆ Cumulative percentage

The number of locations per group is indicated above each column.

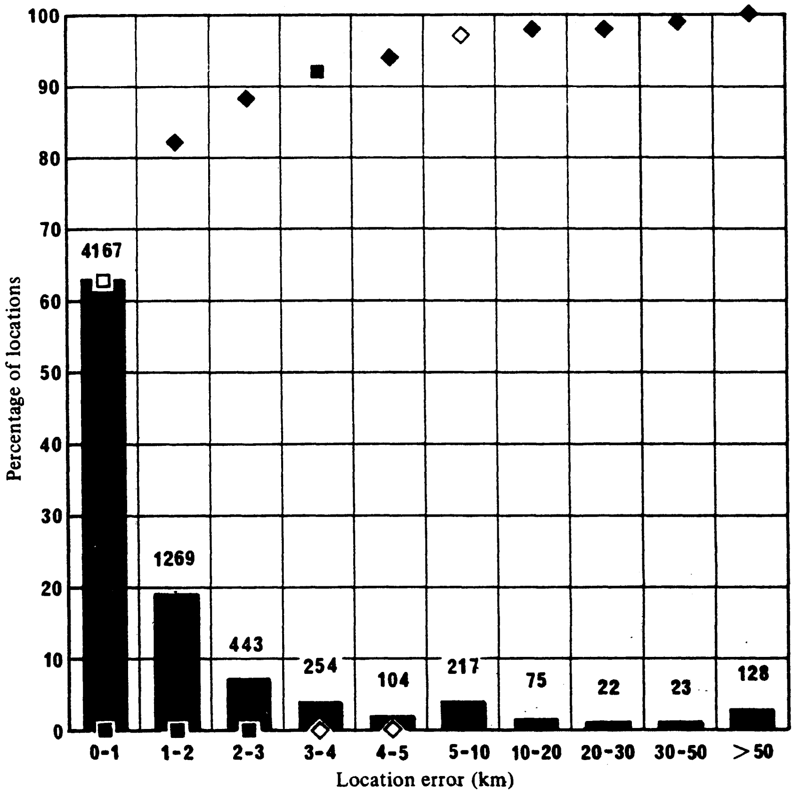


FIGURE 8 – *Location error measured during all tests of beacons as a function of percentage of locations*

(Total of all data where the distributions were reported: 6702 locations)

■ Group percentage

□ 50% mark

■ 90% mark

◇ 95% mark

◆ Cumulative percentage

The number of locations per group is indicated above each column.

ANNEX II

RESULTS OF HIGH SEA STATE TEST CONDUCTED BY FRANCE

1. Introduction

Because the information on high sea state performance was limited, the French Administration decided to conduct a test off the shore of Brittany during a severe storm. This annex describes the results of this test.

2. Description of the test

The test started on 29 January 1988, when a large tug boat deployed two satellite EPIRBs at an initial position of 48.43°N, 6.15°E. The test ended on 1 February 1988, when the satellite EPIRBs drifted ashore.

The first location was obtained on 29 January at 18:10 UTC; the last location was obtained on 1 February at 14:18 UTC.

Two different types of float-free satellite EPIRBs were used. Both of them were commercial units, COSPAS-SARSAT type approved. They were left to drift freely. Their shapes and hydrodynamic characteristics were quite different: one was a 30 cm sphere and the other was a 30 x 10 cm cylinder.

Toulouse Local User Terminal (LUT) obtained most of the locations as the satellite EPIRBs were in its coverage. However, the COSPAS-SARSAT global network was partially used and other LUTs provided some locations.

The purpose of the test was to investigate the impact of the sea state on system performance. The test programme and the results presented take into account the fact that this impact affects only the EPIRB-to-satellite link.

Table VIII describes the sea state and the wind conditions during the test.

TABLE VIII - Brittany test sea state and wind conditions

Date	29 Jan.	30 Jan.	31 Jan.	1 Feb.
Wave height (m)	4 to 5	8 to 10	5 to 6	8 to 10
Wind force (Beaufort scale)	8	10	9	9 to 10

3. Test results

Table IX provides a synthesis of the results obtained for the detection, location and ambiguity resolution probabilities and for the waiting time. The waiting time results were obtained, not only by the use of beacon activation time, but also by the use of the series of intervals between two consecutive locations obtained during the full period of beacon transmissions. Review of this data indicates that system performance did not change due to high sea state condition.

In order to have a comparison between the accurate position of the ship, as calculated by navigation aids, and the location of the satellite EPIRBs, as calculated by the COSPAS-SARSAT system, two satellite EPIRBs were activated on board the ship during the satellite pass, and then dropped into the sea. After this, comparison between the ship and the beacon location was not possible due to heavy sea state (force 10 on the Beaufort scale), as the satellite EPIRBs drifted freely during the test.

It was impossible to determine precisely the location error as the satellite EPIRBs drifted freely during the test. However, a close examination of the plot of the locations shows that for each satellite EPIRB the distance between two adjacent locations (measured on the average more than one hour apart) rarely exceeded 5 km (that distance being the sum of the two location errors and the drift of the satellite EPIRB). A qualitative assessment of this observation shows that the location error is apparently unaffected by the sea state.

Table X describes more precisely the separation distance between the two satellite EPIRBs as the test progressed. Location No. 1 was performed on the deck of the tug boat. Locations 2* to 10 allow a relative assessment of the location accuracy, with locations 8 to 10 showing the gradual increase in the distance between the two satellite EPIRBs as a result of different drifts.

TABLE X - Satellite EPIRB separation distance for the coast of Brittany test

Location No.	1	2	3	4	5	6	7	8	9	10
Time (UTC)	15:45	18:10	18:25	20:05	21:34	21:46	23:20	1:05	1:29	3:15
Separation distance (km)	0.7	2.16	2.86	0.41	0.83	5.9	3.2	4.81	5.4	6.9

* Location No. 2 was performed 10 to 20 minutes after the deployment of the satellite EPIRBs. Absolute error, including the drift, was 1.3 km for satellite EPIRB No. 1 and 3.4 km for satellite EPIRB No. 2.

TABLE IX High sea state system performance results for the coast of Brittany test 29 January - 1 February 1988*

Max. elevation angle to satellite (°)	> 8°									> 0°								
Wave Height (m)	4-6			8-10			Σ = 4-10			4-6			8-10			Σ = 4-10		
Beacon / Performance Parameter	1	2	Σ	1	2	Σ	1	2	Σ	1	2	Σ	1	2	Σ	1	2	Σ
. No, of satellite passes	27	27	54	36	36	72	63	63	126	39	39	78	50	50	100	89	89	178
. No, of beacons detected	26	26	52	36	33	69	62	59	121	31	33	64	41	41	82	72	74	146
. Beacon-detection probability (%)	96.3	96.3	96.3	100	91.7	95.8	98.4	93.6	96	19.5	84.6	82	82	82	82	80.9	83	82
. No, of beacons located	25	24	49	35	33	68	60	57	117	26	30	56	40	37	77	66	67	133
. Beacon-location probability (%)**	92.6	88.9	90.7	97.2	91.6	94.4	95.2	90.5	92.8	66.6	76.9	71.8	80	74	77	74.1	75.3	74.7
. No, of correct beacon location solutions	25	23	48	34	33	67	59	56	115	26	29	55	38	37	75	65	65	130
. Probability of ambiguity resolution on the first pass	100	95.8	97.9	97.1	100	98.5	98.3	98.2	98.3	100	96.6	98.2	95	100	97.4	98.5	95	97.7
. Waiting time (min): Minimum																10	10	
. Waiting time (min): Median 50%																51	45	
. Waiting time (min): 90%																92	82	
. Waiting time (min): Maximum																240	225	

* 68 hour test duration.

** Beacon-location is defined in § 2.2.4 of the main body of Report 919.

ANNEX III

RESULTS OF ON-LAND AND AT-SEA TESTS CONDUCTED IN JAPAN

1. Introduction

The acceptance of the COSPAS-SARSAT System as an essential element of the Global Maritime Distress and Safety System (GMDSS) and the active participation of Japan in the International Maritime Organization (IMO) lead quite naturally to the interest of the Japanese Government in the COSPAS-SARSAT System. Japan, with the approval of the COSPAS-SARSAT Council (CSC), conducted early in 1988 an independent evaluation of the 406 MHz message detection and location capabilities of the COSPAS-SARSAT System [Green, 1989].

The Japanese evaluation of the COSPAS-SARSAT System was accomplished through an operational system test in which 406 MHz satellite EPIRBs were activated, the associated location messages were received and processed, and the results were evaluated by the appropriate testing administration. The test was designed and implemented in Japan with the full cooperation of the CSC.

The test was conducted in five phases: an interference screening phase, two on-shore phases in which satellite EPIRBs were deployed on land, and two off-shore phases in which satellite EPIRBs were deployed at sea. The test was conducted between mid-December 1987 and early July 1988.

1.1 Test objective

The primary objective of the Japanese test was to evaluate quantitatively the capabilities of the COSPAS-SARSAT System in acquiring and processing available 406 MHz transmissions from production quality satellite EPIRBs located on land in Japan and at sea in Japanese territorial waters.

To satisfy this objective, 406 MHz satellite EPIRBs were deployed as shown in Figure 9, relevant data was collected from the operational COSPAS-SARSAT ground network, and appropriate analyses were conducted.

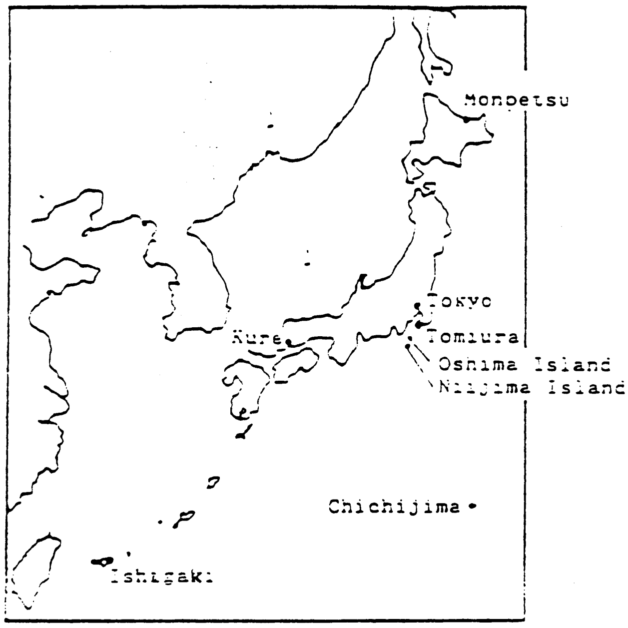


FIGURE 9 - Location of satellite EPIRBs during Japanese test

1.2 Test structure

The five-phase structure of the Japanese test is illustrated in Figure 10. It is to be noted that there were no significant obstructions above 5° of elevation at any of the installation sites.

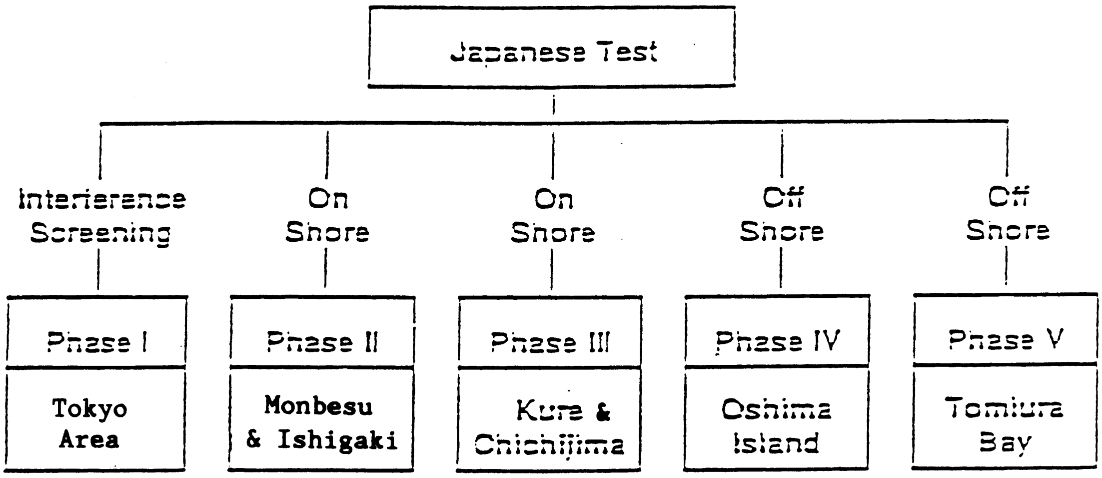


FIGURE 10 - Test structure of the Japanese test

Phase I of the test, conducted between mid-December 1987 and mid-January 1988, was designed to search for possible 406 MHz interference in the Tokyo area and to confirm the reliability of the operational interface between the COSPAS-

SARSAT ground network and the Japanese Search and Rescue Point of Contact (JSPOC). In this phase, four land-based satellite EPIRBs were activated concurrently at Higashimurayama City in suburban Tokyo, as shown on the map in Figure 9.

Phase II of the test, conducted in early February 1988, was designed to evaluate the response of the COSPAS-SARSAT System to 406 MHz satellite EPIRBs located on-shore. In this phase, four satellite EPIRBs were activated concurrently on-shore, two near the coast of Monbetsu and two on Ishigaki Island, as shown on the map in Figure 9.

Phase III of the test, conducted in late February 1988, was designed to continue the evaluation of the response of the COSPAS-SARSAT System to satellite EPIRBs located on-shore. In this phase, four satellite EPIRBs were activated concurrently on-shore, two in Kure City and two on Chichijima Island, as shown on the map in Figure 9.

Phase IV of the test, conducted in mid-March 1988, was designed to evaluate the response of the COSPAS-SARSAT System to satellite EPIRBs located off-shore. In this phase, four satellite EPIRBs were activated concurrently at sea, south of Tokyo between Oshima Island and Niijima Island, as shown on the map in Figure 9. The satellite EPIRBs were free-floating on the surface of the sea and were deployed in two configurations. Initially, each satellite EPIRB was tethered to an inflatable life raft with a nylon cord approximately 4 mm in diameter and 10 m long, and a sea anchor was attached to the life raft to prevent excessive wind-induced drift. Later in this phase, the satellite EPIRBs were redeployed on the surface of the sea, east of Niijima Island. At this location, the free-floating satellite EPIRBs were tethered to the stern of a stationary patrol vessel with a 100 m nylon cord.

Phase V of the test, conducted in early July 1988, was designed to continue the evaluation of the response of the COSPAS-SARSAT System to satellite EPIRBs located off-shore. In this phase, three satellite EPIRBs were activated concurrently at sea, near Tokyo at Tomiura Bay, as shown on the map in Figure 9. The satellite EPIRBs were free-floating on the surface of the sea and were tethered by cords to a small buoy that was anchored to the sea bed.

1.3 Environmental conditions

The environmental conditions at each test site at the time of satellite EPIRB activation are summarized in Table XI.

TABLE XI - Environmental conditions

Test phase	II	II	III	III	IV	V
Location / Environment	Monbetsu	Ishigaki	Kure	Chichijima	Niijima (sea)	Tomiura (sea)
Air temperature (°C)	-18 to -2	18 to 26	4 to 15	17 to 23	8 to 17	21 to 28
Water temperature (°C)	-	-	-	-	18	22
Wind speed (m/s)	-	-	-	-	5 to 15	0 to 5
Wave height (m)	-	-	-	-	3 to 5	0 to 0.5
Weather	Fine	Fine, Clear	Rain, Cloudy	Cloudy, Fine	Stormy	Cloudy, Fine

1.4 Data acquisition network

The locations of the satellite EPIRBs activated during this test were calculated by the COSPAS-SARSAT System, and these calculated locations were transmitted to the JSPOC in Tokyo.

1.5 Satellite EPIRBs

Four operationally-coded 406 MHz satellite EPIRBs used in the five phases of this test were COSPAS-SARSAT type approved and their physical characteristics are described in Table XII.

All satellite EPIRBs were designed for free-floating applications but also function on land when properly installed. No test phase exceeded the 48-hour battery life of these satellite EPIRBs, and all batteries were changed between test phases.

TABLE XII - Physical characteristics of satellite EPIRBs used in Japanese test

Designation	Country of manufacture	Mass (kg)	Total height (mm)	Center of gravity* (mm)
EPIRB A	Japan	12.410	990	250
EPIRB B	Japan	6.650	883	203
EPIRB C	France	6.215	310	125
EPIRB D	Norway	3.515	570	191

* Measured from the bottom of the satellite EPIRB.

2.0 Data evaluation

The data analysis associated with this test considered four primary system characteristics defined below:

1. **Beacon - location probability**: the percentage of the predicted spacecraft passes over active satellite EPIRBs that resulted in a *beacon-location* message being generated and transmitted to the JSPOC.

2. **Beacon - detection probability**: the percentage of the predicted spacecraft passes over active satellite EPIRBs that resulted in a *beacon location* or *beacon-detection* message being generated and transmitted to the JSPOC.

3. **Ambiguity resolution**: the ability of the system to select the correct (rather than the mirror image) satellite EPIRB location from the calculated location pair.

4. **Location error**: the distance between the actual and the calculated satellite EPIRB locations.

It is to be noted that only spacecraft passes over active satellite EPIRBs in which the maximum beacon-to-spacecraft elevation angle was equal to or greater than 8 degrees were included in the pass-prediction schedule. This eliminated any system low-angle characteristics from the analysis results. Waiting time was not measured during this test.

3.0 Evaluation results

The results of the data analysis are presented in this section by primary system characteristics.

It is to be noted that one MCC was unable to transmit data during one test phase to the JSPOC because of conflicts between test and operational activities. Therefore, that data is not included in these results.

3.1 Beacon-location probability

A satellite EPIRB location is calculated and a satellite EPIRB-location message is generated at a LUT (or MCC) for each spacecraft pass over an active satellite EPIRB in which the minimum required number of satellite EPIRB transmissions is received (i.e., three or four satellite EPIRB transmissions, depending on the LUT).

Of the total 366 predicted spacecraft passes over active satellite EPIRBs at all sites in this test, 348 passes resulted in the calculation of locations and the generation of satellite EPIRB-location messages; i.e., 95.1 percent of the available passes resulted in location messages. When considering separately the on-land and at-sea data, the beacon-location probabilities achieved were as follows: 94.6 percent for on-land (244/258) and 96.3 percent for at-sea (104/108).

3.2 Beacon-detection probability

A satellite EPIRB detection message is generated at a LUT for each spacecraft passage over an active satellite EPIRB in which at least one satellite EPIRB transmission is received but less than the minimum number required to determine the satellite EPIRB location.

Of the total 366 predicted spacecraft passes over active satellite EPIRBs at all sites in this test, 350 passes resulted in the generation of satellite EPIRB detection or location messages; i.e., 95.6 % of the available passes resulted in detection or location messages. When considering separately the on-land and at-sea data, the beacon-detection probabilities achieved were as follows: 95.3 % for on-land (246/258) and 96.3% for at-sea (104/108).

3.3 Ambiguity resolution

Each satellite EPIRB location calculation results in two locations, one being the correct location of the beacon and one a *mirror image*. The location algorithms use various techniques to resolve the ambiguity and to select the correct location.

Of the 718 satellite EPIRB location pairs that were provided by two COSPAS-SARSAT MCCs, the location ambiguity was correctly resolved in 710 cases; i.e., the ambiguity resolution was correct for 98.9 per cent of the locations calculated. When considering separately the on-land and the at-sea data, the following ambiguity resolutions were achieved: 99.2% for on-land (487/491) and 98.2% for at-sea (223/227).

3.4 Location error

The error in the calculated satellite EPIRB locations is described qualitatively by the histograms in Figures 11 and 12 and is given quantitatively in Table XIII.

The composite distribution of calculated satellite EPIRB locations about the actual beacon locations is illustrated by the scatter plot in Figure 13. All calculated locations within ±10 km in latitude and ±10 km in longitude of the actual locations are included in this figure.

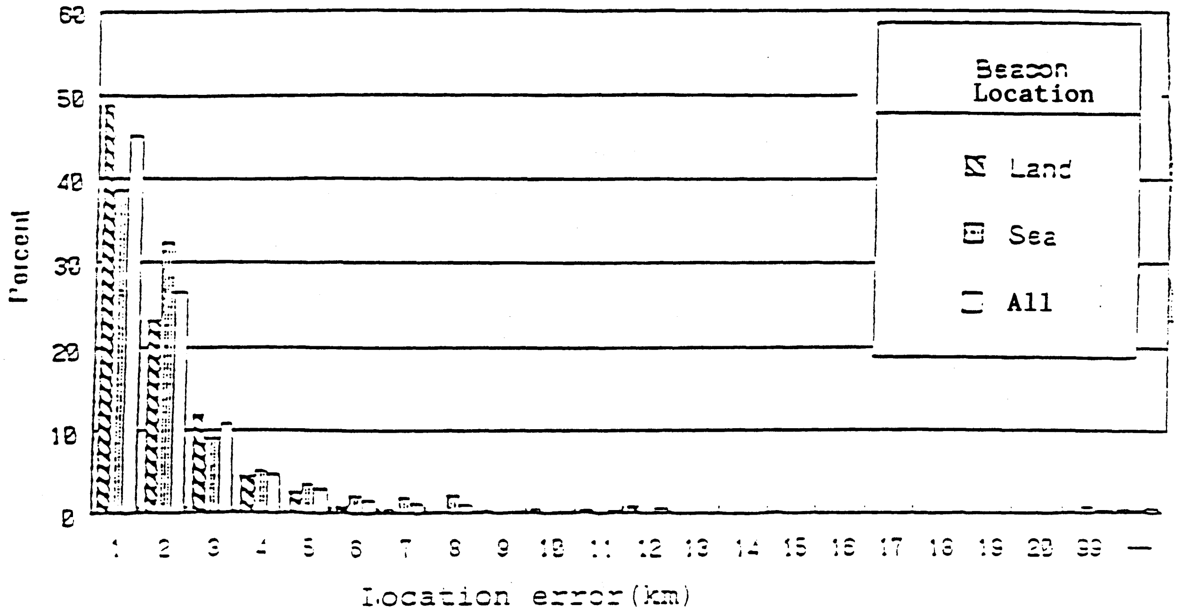


FIGURE 11 - Distribution of location error

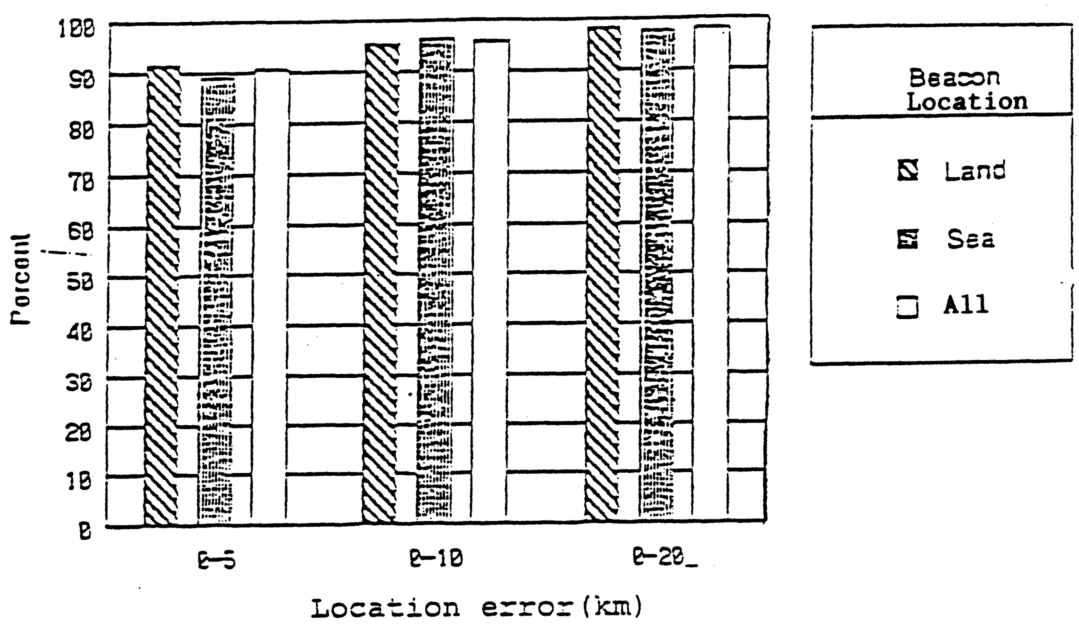
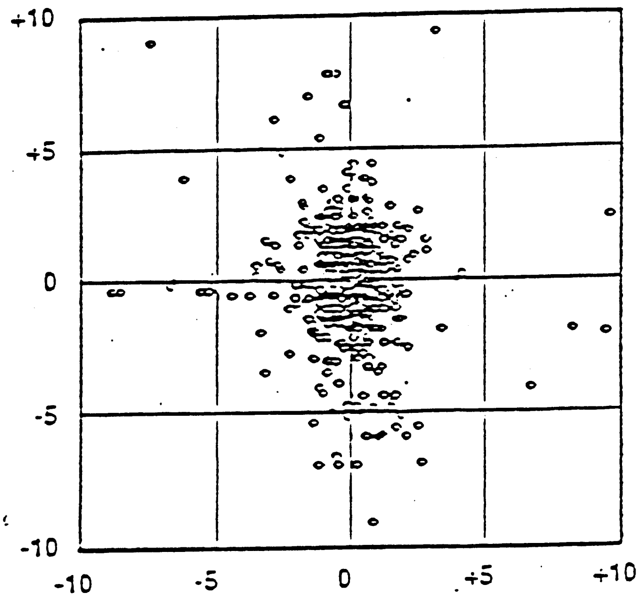


FIGURE 12 - Cumulative location error

TABLE XIII - Distribution of location error

Location error (km)	Satellite EPIRB locations (%)					
	On land		At sea		All	
		cumulative		cumulative		cumulative
0-1	48.9	48.9	38.8	38.8	45.2	45.2
1-2	23.5	72.4	32.5	71.3	26.8	72.0
2-3	12.2	84.6	9.1	80.4	11.0	83.0
3-4	4.7	89.3	5.2	85.6	4.9	87.9
4-5	2.8	92.1	3.8	89.4	3.2	91.1
5-6	1.2	93.3	2.4	91.8	1.7	92.8
6-7	0.8	94.1	2.1	93.9	1.3	94.1
7-8	0.4	94.5	2.4	96.3	1.2	95.3
8-9	0.6	95.1	0.3	96.6	0.5	95.8
9-10	0.8	95.9	0.0	96.6	0.5	96.3
10-11	0.8	96.7	0.3	96.9	0.6	96.9
11-12	1.2	97.9	0.0	96.9	0.8	97.7
12-13	0.2	98.1	0.0	96.9	0.1	97.8
13-14	0.2	98.3	0.0	96.9	0.1	97.9
14-15	0.4	98.7	0.0	96.9	0.3	98.2
15-16	0.0	98.7	0.0	96.9	0.0	98.2
16-17	0.0	98.7	0.3	97.2	0.1	98.3
17-18	0.0	98.7	0.3	97.5	0.1	98.4
18-19	0.0	98.7	0.3	97.8	0.1	98.5
19-20	0.0	98.7	0.0	97.8	0.0	98.5
>20	1.3	100.0	2.2	100.0	1.5	100.0



Location error (km)

FIGURE 13 - Scatter plot of location errors

It is to be noted that:

1. 91.1 percent of all calculated locations are within 5 km of the true location.

2. 96.3 percent of all calculated locations are within 10 km of the true locations.

3. 98.5 percent of all calculated locations are within 20 km of the true locations.

4. There appear to be no significant differences in location errors between satellite EPIRBs deployed on land or at sea.

5. There appears to be no significant bias in the distribution of calculated satellite EPIRB locations about corresponding actual locations.

4.0 Summary and conclusions

In summary, four type-approved operational 406 MHz satellite EPIRBs were deployed and activated at seven locations in Japan and in Japanese territorial waters over a 7-month period, and it was determined that:

1. 95.1 percent of the available satellite EPIRB transmissions resulted in the generation of beacon-location messages.

2. 95.6 percent of the available satellite EPIRB transmissions resulted in the generation of beacon-location or detection messages.

3. 98.9 percent of the location ambiguities were resolved correctly.

4. 91.1 percent, 96.3 percent, and 98.5 percent of the calculated locations were correct to within 5 km, 10 km, and 20 km, respectively, of the actual locations.

5. Measured system performance during this test indicated considerable improvement as compared to the D and E phase data in beacon-location probability and ambiguity resolution and was about the same for beacon-detection probability and location error. This comparative data is presented in Table XIV.

Based on these results, it can be concluded that the COSPAS-SARSAT system is effective in accurately locating 406 MHz satellite EPIRBs and transmitting those locations to the existing SAR community.

ANNEX IV

Comparative system performance data

The comparison of the 406 MHz satellite EPIRB system performance obtained during the environmental tests of the demonstration and evaluation (D & E) phase (Tables I, IIb, IId, IIe, III and IV), the French high sea state tests (Table IX), and the Japanese COSPAS-SARSAT system evaluation tests (Annex III: sections 3.1, 3.2, 3.3 and Table XIII) is summarized in Table XIV. Inspection of that data indicates that better peformance was achieved (about 10%) during the French and Japanese tests as compared to the D & E phase for beacon-location probability and ambiguity resolution and it remained about the same for beacon-detection probability and location error.

TABLE XIV - Comparative system performance data

Test Type	D&E Environmental Tests			French High Sea State Tests	Japanese Tests		
Beacon location / System parameter	on-land	at-sea (floating)	all locations	at-sea (floating)	on-land	at-sea (floating)	all locations
Beacon-location probability (%)*	90	83	85.9	92.8	94.6	96.3	95.1
Beacon-detection probability (%)	98	98	98	96.0	95.3	96.3	95.6
Ambiguity resolution (%)	89	88	88.3	98.3	99.2	98.2	98.9
Location error (km)							
50th percentile	0-1	1-2	1-2	-	1-2	1-2	1-2
90th percentile	1-5	5-10	5-10	-	4-5	5-6	4-5
95th percentile	5-10	5-10	5-10	-	8-9	7-8	7-8

* Beacon-location probability is defined in § 2.2.4 of the main body of Report 919.

REFERENCES

GREEN, L.G. and YOSHIDA, K. [April, 1989] Japan evaluates the COSPAS-SARSAT system. Proc. of the 1989 Radio Technical Commission for Maritime Services (RTCM) Annual Assembly Meeting, Seattle, U.S.A.