Agenda Item: 5.4

ANALYSIS OF A 406 MHZ LOCATION PROTOCOL BEACON TEST

1. ACTION REQUIRED

The Joint Committee is invited:

a) to review the following analysis of a 406 MHz location protocol beacon test conducted by the United States.

b) to consider the recommendations provided in section 6.

2. BACKGROUND

Document JC-16/6/23-Rev.1 (USA) provided an analysis of the accuracy, availability and timeliness of operational 406 MHz location protocol beacons. The Joint Committee noted that more study was required to understand the reason(s) why it appeared that only about one third of the beacon messages from operational location protocol beacons contained encoded position. Consequently, JC-16 invited participants to conduct controlled tests with location protocol beacons at known locations, in situations representative of operational beacons (TWG-16/AI.5).

In response to this action item, the United States conducted a test of location protocols beacons, according to the Test Plan at Attachment 2. The test was conducted at the Coast Guard Group in Key West, Florida from March 17 - 20, 2003. A limited retest of one beacon model was performed in Hawaii on May 2, 2003. Four beacon manufacturers participated in the test.

3. TEST METHODOLOGY

The initial Test Plan included 9 phases. These phases tested beacon performance in optimal conditions (Phase 1), when an active beacon is moved (Phases 2 and 3), with limited Global Positioning System (GPS) satellite visibility (Phases 4 and 5), on deck at sea with good GPS satellite visibility (Phase 6), in a life raft at sea (Phase 7), floating at sea (Phase 8), and on deck at sea against the bulkhead (Phase 9). Due to time constraints, the Phase 9 test was not performed.

Four additional 'ad-hoc' tests were performed that were not included in the initial Test Plan. In Phase A, a beacon was submerged in water, set afloat and continually doused while active. In Phase B, the beacon was set afloat but otherwise kept dry while active. These tests addressed concern about the performance of beacons while afloat at sea (Phase 8). In Phase C, a PLB was submerged in water, and then activated out of the water on a life vest. In Phase D, many beacons were activated in close proximity, in order to test if beacon performance was affected by interference from other beacons. The complete Test Plan is contained at Attachment 2. Additions to the initial test plan are indicated in *italics*. All beacons were test encoded.

During the test, hand held GPS units were used to record the location of each active beacon. This information was used to determine location accuracy. In some cases, the beacon location was not recorded, and so location accuracy could not be determined.

This GPS unit was also used to record the number of GPS satellites in view at each beacon location every 10 to 15 minutes, to account for the impact of GPS satellite visibility on beacon performance. Excluding Phases 4 and 5, which intentionally limit satellite visibility, the availability of GPS satellites does not appear to be a factor in the test results, since there were normally 6 to 9 GPS satellites in view for these tests.

The time of beacon activation was recorded, in order to determine the time until a beacon message was transmitted successfully. SarTech portable test kits were used to manually record the time and 30 hexadecimal Id of the first valid beacon message and of the first valid beacon message with encoded location. (In most cases, location data was only recorded if the encoded position recorded by the test kit was confirmed to be within a few minutes of the known location. This effectively eliminated coarse positions.) Every 30 hexadecimal beacon Id recorded manually was later run through beacon decode software, in order to ensure that the correct Beacon Id was recorded.

Once a beacon transmitted encoded location, it was left on for a minimum of 5 additional minutes, to give the GEOLUT some time to acquire a valid beacon message. If a beacon did not transmit a GPS location, it was left on for a maximum of 31 minutes, based on the requirement that the internal navigation device provide valid data within 30 minutes (C/S T.001 section 4.5.5.3). However, a beacon was turned off sooner if the beacon manufacturer's on-site representative decided that the beacon would not transmit encoded location.

Test results recorded during the test were supplemented by beacon message data provided by Canada from Canadian GEOLUTs and LEOLUTs. This supplementary data was only used when it occurred earlier than the data recorded on site or when appropriate data was not recorded on site. GEOLUT data was included only for integrated beacon messages, that is, beacon messages that were eligible for transmission to the MCC. Note that the actual transmission of beacon messages to the MCC was not considered in this test.

Test results exclude activations for beacon models that are not C/S type approved and beacon units that were identified by the manufacturer as "prototype" (not ready for operational use).

4. TEST RESULTS

Test results are provided in Attachment 1, by Test Phase in Table 1, by Encoded Position Resolution Type in Table 2, and by Beacon Model in Table 3. Specific beacon models are not identified in Table 3. However, information identifying the beacon model has been made available to the associated manufacturer.

Note that the sample size is not controlled by test phase or beacon model. Some beacon models were activated more often than others for a specific test phase and some beacon models were not activated for every test phase. (For example, PLBs were not activated in tests at sea and some models were not activated for the 'ad-hoc' test phases.) This should be taken into account when considering test results in summary.

4.1 TIMELINESS AND AVAILABILITY

Table 1 provided results on timeliness and availability for 84 beacon activations. For optimal and non-optimal conditions combined, 77.4% (65) of beacons provided encoded location and 71.4% (60) of beacons provided encoded location within 5 minutes of activation. When encoded location was provided, it was available within 5 minutes in 92.3% (60 of 65) of cases. Thus, if encoded location was not provided promptly it was usually not provided. In 3 of 5 cases where encoded locations was only provided more than 5 minutes after activation, GPS satellite visibility was limited (Phases 4 and 5).

Encoded location was not provided in at least one case for 8 of 11 test phases. Location was available for 89.5% (34 of 38) of beacons activated with high GPS satellite visibility (Phases 1, 2, 6, A, B and C). Location was available for only 62.5% (10 of 16) of beacons activated with limited GPS satellite visibility (Phases 4 and 5). Limited GPS satellite visibility is clearly a factor in the acquisition of encoded location.

The unavailability of encoded location in conditions of limited GPS satellite visibility (Phases 4 and 5) is linked to beacon model. In total, 4 beacon models (M2, M3, M4 and M5) provided encoded location in 90.0% (7 of 9) of cases. The other 3 models (M1, M6 and M7) provided encoded location in 28.6% (2 of 7) of cases.

This problem may be related to the fact that some models allocate a short period of time to acquire GPS location (eg., 5 minutes) between long sleep periods (eg., 15 minutes). Beacon manufacturers indicated that interference from the beacon's 121.5 MHz homer may also be a factor.

Location was available for 57.2% (4 of 7) of beacons activated while floating at sea (Phase 8). The three failures occurred for the same beacon model.

When many beacons were activated in close proximity (Phase D), only one beacon failed to provide encoded location, which occurred on three successive activations. However, this beacon did provide encoded location when all other beacons were turned off. This test shows that some beacon models are affected by interference from other signal sources.

Table 3 shows that the availability of encoded location is dependent on beacon model. In total, 4 beacon models (M2, M3, M4 and M5) provided encoded location in 94.9% (37 of 39) of cases. The other 3 models (M1, M6 and M7) provided encoded location in 62.2% (28 of 45) of cases.

4.2 LOCATION ACCURACY

Table 1 provides results on location accuracy for 60 beacon activations. 86.7% (52) of encoded locations were accurate within 1 km, 96.7% (58) within 5 km, and 96.7% (58) within 10 km. C/S T.001 section 4.5.5.3 states that "The distance between the position provided by the navigation device, at the time of the position update, and the true beacon position shall not exceed 5 km."

The long message format for 406 MHz location protocol beacons allows position to be encoded as either coarse or refined. A coarse position occurs when position data is only available in the first protected field of the beacon message (PDF-1), due to a bad BCH or a default value in the second protected field (PDF-2). A coarse position in the standard location protocol is accurate to a resolution of 15 minutes of latitude and longitude, or about (+ or -) 18.8 km at the latitude of the Key West test site. A coarse position in the national location protocol is accurate to a resolution of 2 minutes, or about (+ or -) 2.5 km at the Key West test site.

A refined position occurs when position data is available in both the first and second protected fields of the beacon message. A refined position in the standard or national location protocol is accurate to a resolution of 4 seconds, or about (+ or -) 0.08 km at the Key West site. Given that an accuracy of 0.08 km is possible at the Key West site, the fact that only 86.7% of encoded locations were accurate within 1 km merits further investigation regarding beacon processing..

Table 1 shows that increased GPS satellite visibility does not increase location accuracy. Accuracy was within 1 km for 85.3% (29 of 34) of beacons activated with high GPS satellite visibility (Phases 1, 2, 6, A, B and C). Accuracy was within 1 km for 100.0% (10 of 10) of beacons activated with medium to low satellite visibility (Phases 4 and 5).

Table 2 shows the location accuracy of coarse and refined positions separately. Coarse positions occurred in 8.3% (5 of 60) of cases and were never accurate within 1 km. However 94.5% (52 of 55) of refined positions were accurate within 1 km.

Table 3 summarizes location accuracy by beacon model. The error exceeded 1 km for model M1 in 2 of 4 cases, for model M4 in 2 of 9 cases, and model M5 in 2 of 14 cases.

4.2.1 Encoded Locations with Large Errors

The two largest location errors occurred for model M5. In both cases, the first valid message with location was received from a GEOLUT, contained coarse location in the standard protocol, and should have been transmitted by the GEOLUT to the MCC, based on section 4.2.5.1 of C/S T.009.

In the first case, the first encoded location was 24.0, -82.0, an error of 55.5 km. The associated message had a default location in PDF-2. All subsequent messages for the beacon had a refined position 0.1 km from the actual location.

In the second case, the first encoded location was 25.0, -82.0, an error of 52.6 km. The associated message had uncorrectable errors in BCH-2. All subsequent messages for the beacon except one had a refined position 0.1 km from the actual location.

These two location errors lead to questions concerning beacon performance. First, is it possible to improve the processing of GPS location so that the refined position is provided more often? A second issue is that the position encoded in the first protected field (PDF-1) contained no fraction of degrees, even though the PDF-1 format in the standard location protocol allows a resolution of 15 minutes, or 4 times the resolution that was set. In the first case, a coarse position of 24.5, - 81.75 could have been set (compared to the true location of 24.484, -81.866), with a resulting location error of only 12 km.

Another issue concerns the LUT specification for transmitting valid beacon messages to the MCC. Given that all subsequent messages (except one) for these two beacons contained accurate refined positions, it may be prudent to enhance the confirmation of valid beacon messages to wait for the refined position. Further study would be required to determine if this change is warranted.

5. SUMMARY

In a test of 406 MHz location protocol beacons conducted by the United States, encoded location was provided for 77.4% of activations. The availability of encoded location varied significantly by beacon model. While 4 beacon models provided encoded location for 94.9% of activations, the other 3 models provided encoded location for only 62.2% of activations.

The availability of encoded location was significantly effected by GPS satellite visibility. With high GPS satellite visibility, 89.5% of activations provided encoded location. With low GPS satellite visibility, 62.5% of activations provided encoded location.

Encoded location was available within 5 minutes for 71.4% of activations. When encoded location was provided, it was available within 5 minutes for 92.3% of activations.

Encoded location was accurate within 1 km for 86.7% of activations and within 5 km for 96.7% of activations. Coarse positions occurred in 8.3% (5 of 60) of activations, and accounted for 62.5% (5 of 8) of locations with an error exceeding 1 km.

A brief analysis of issues effecting the performance of 406 MHz location protocol beacons is provided below.

a) Some beacon models may fail to provide encoded location because they are designed to try to acquire GPS location for a short time period between long sleep periods. A long acquisition period is especially important when GPS satellite visibility is restricted. It is suggested that beacons be designed to try to acquire GPS locations for time periods of at least [15] minutes.

b) Some beacon models may fail to provide encoded location because of interference from the beacon's 121.5 MHz homer. It is suggested that beacons be designed to ensure that the 121.5 MHz homer does not interfere with the acquisition of GPS location.

c) Some beacon models produce coarse positions unnecessarily, given that an accurate refined position was available soon after the coarse position was produced.

d) Some beacon models may not be designed to use all the precision available in the first protected field of the beacon message. As a result, when coarse positions are produced, they are much less accurate than is necessary.

6. RECOMMENDATIONS

In respect of the availability, timeliness and location accuracy of 406 MHz location protocol beacons, the Joint Committee is invited to:

a) Encourage beacon manufacturers to take appropriate steps to improve the performance of their 406 MHz location protocol beacons, taking into account the comments and test results provided above; and

b) Encourage beacon manufacturers and National Administrations to inform operators of 406 MHz location protocol beacons that the beacon should be activated in an unobstructed area to aid the acquisition of GPS location;

c) Confirm as appropriate the GEOLUT specification for sending confirmed 406 MHz beacon messages as soon as possible, noting that this may delay (or prevent) the processing of accurate refined position at some MCCs;

d) Consider if the 406 MHz Beacon Specification (C/S T.001) for the location accuracy of the internal navigation device should be changed from 5 km to 1 km, noting that refined encoded position offers resolution well within 1 km; and

e) Consider whether the 406 MHz Beacon Type Approval Standard (C/S T.007) adequately tests the acquisition of GPS location in operational conditions, noting the test results provided above.

Attachment 1

406 MHz LOCATION PROTOCOL BEACON TEST RESULTS - SUMMARY TABLES

Test Phase - Description	**Valid Message Availability**			**Location Availability**			**Location Accuracy**			
	Pop Size	**In 5 Min**	**Yes**	**Pop Size**	**In 5 Min**	**Yes**	**Pop Size**	**< 1 Km**	**< 5 Km**	**<10 Km**
1 Land, 1 bcn, high vis.	14	14	14	14	10	11	9	9	9	9
2 Land, high vis.	11	10	11	11	10	11	11	10	11	11
3 Land, beacon moved *	n/a	n/a	n/a	8	7	7	7	4	7	7
4 Tree canopy, med. vis.	14	13	13	14	7	9	9	9	9	9
5 Tree canopy, low vis.	2	1	2	2	0	1	1	1	1	1
6 On deck, high vis.	8	8	8	8	7	7	7	5	7	7
7 Raft, canopy	8	8	8	8	6	6	4	4	4	4
8 Sea, floating	7	6	6	7	4	4	4	3	3	3
A Float, wet, high vis.	2	2	2	2	2	2	2	2	2	2
B Float, dry, high vis.	2	2	2	2	2	2	2	2	2	2
C On vest, high vis.	1	1	1	1	1	1	1	1	1	1
D Many beacons close	7	7	7	7	4	4	3	2	2	2
Totals	**76**	**72**	**74**	**84**	**60**	**65**	**60**	**52**	**58**	**58**
Total %	**100**	**94.7**	**97.4**	**100**	**71.4**	**77.4**	**100**	**86.7**	**96.7**	**96.7**

Table 1 - Location Protocol Beacon Performance by Test Phase

***** For the moved beacon test (Phase 3), Valid Message Availability is not applicable, since a valid message was already acquired in Phase 2. The start time for a moved beacon is 20 minutes after encoded location is acquired, and an updated location is treated as location available. The beacons were moved about 0.38 km at the Key West site.

Position Type	**Total**		**< 1 Km**		**< 5 Km**		**< 10 Km**	
	Num	**%**	**Num**	**%**	**Num**	**%**	**Num**	**%**
Coarse	5	100	0	0.0	3	60.0	3	60.0
Refined	55	100	52	94.5	55	100.0	55	100.0
Total	**60**	**100**	**52**	**86.7**	**58**	**96.7**	**58**	**96.7**

Table 2 - Location Accuracy by Encoded Position Type

Model	**Valid Message Availability**			**Location Availability**			**Location Accuracy**			
	Pop. Size	**In 5 Min.**	**Yes**	**Pop. Size**	**In 5 Min.**	**Yes**	**Pop Size**	**< 1 Km**	**< 5 Km**	**< 10 Km**
M1	6	6	6	8	6	6	4	2	4	4
M2	7	5	6	7	5	6	6	6	6	6
M3	7	7	7	7	7	7	6	6	6	6
M4	9	9	9	11	7	10	9	7	9	9
M5	13	12	13	14	13	14	14	12	12	12
M6	16	15	15	17	11	11	10	9	10	10
M7	18	18	18	20	11	11	11	10	11	11
Totals	**76**	**72**	**74**	**84**	**60**	**65**	**60**	**52**	**58**	**58**
Total %	**100**	**94.7**	**97.4**	**100**	**71.4**	**77.4**	**100**	**86.7**	**96.7**	**96.7**

Table 3 - Location Protocol Beacon Performance by Beacon Model

ATTACHMENT 2

TEST PLAN FOR 406 MHz LOCATION PROTOCOL BEACONS

The following plan was developed to test 406 MHz location protocol beacons. Additional comments and modifications to the plan occurring after the test commenced on March 17, 2003 are indicated in *italics*.

TEST METHODOLOGY:

General: The test will take place over a three-day period. Retesting and additional testing will be performed on the fourth day as required. All beacons (units) will be test coded to minimize operational impact on the Cospas-Sarsat system.

Given that location protocol beacons are currently available for both land use (PLBs) and maritime use (EPIRBs), testing will take place in both inland and maritime environments.

As described below, each test scenario requires a minimum of two beacons of each model in order to provide a reasonable data sample without placing a burden on the Cospas-Sarsat System or on the beacon manufacturers. Each beacon will be used only once during testing to simulate a "cold start" activation, except where a "warm start" capability is the purpose of the test, or where the beacon can be reset to a "cold start" activation. Prior to each activation, the beacon self-test function will be performed. Each beacon will be activated for a minimum period of 31 minutes during each test scenario. To ensure that beacons that are active simultaneously do not interfere with each other, beacons will be located a minimum of 100 feet apart and activated to transmit at least 5 seconds apart. The activation of different beacon models will be alternated, so that system anomalies (such as a failure of the GPS satellite system) are not attributed as a failure of a specific model. No more than six beacons will be activated at the same time.

TEST PHASES:

Prior to commencing the below test phases, verify and record the ID of every beacon to be used in the testing; pre-designate beacons for use in each test scenario.

For Test Phases 1-9 below, the following procedures apply, unless alternate procedures are specified for a given phase:

1. Record GPS hand-held derived position of testing site (using both GPS units) for each set of beacons
2. Record number of GPS satellites "in-view" as indicated by GPS units (prior to the first beacon activation and every 15 minutes until the last beacon deactivation)

3. Record each beacon ID
4. Perform beacon self-test
5. Activate beacons (stagger activation by 5-7 seconds)
6. Record time of beacon activation
7. Use the beacon test kit to determine which beacon ID is transmitted (if the test kit is available)
8. Deactivate beacons after 31 minutes
9. Photograph test site / beacon deployment

Phase 1: Individual Beacon Test. Activate one beacon of each model sequentially in an open area at the test site, ensuring a clear line-of-sight to GOES East / West and available GPS satellites. Use the beacon test handset to determine the beacon IDs and other transmitted information, including transmitted GPS position.

Phase 2: Baseline Test. Activate two beacons of each model in an open area at the test site, ensuring a clear line-of-sight to GOES East / West and available GPS satellites. Use the beacon test handset to determine the beacon IDs and other transmitted information, including transmitted GPS position. No more than four beacons will be activated at any time during this phase.

Phase 3: Updated Position Test. Beacons activated in Phase 2 will be transported while still active to an open area that is at least 1 km from site in Phase 1, to check the "update" capability. The beacons will remain active until the updated position is observed to be transmitted, or 31 minutes has elapsed once the beacon is at the new site. The beacon test handset will be used to determine the beacon IDs that are transmitted.

Phase 4: Inland Scenario Alpha. Activate two units of each PLB model in an area with minimal obstructions (e.g., a sparsely treed area), so that there is not a significant obstruction to the GPS satellites. All beacons will be placed in the same relative positions. *During the test, the amount of obstruction was defined to be medium GPS satellite visibility, meaning that 1 to 4 satellites were always visible, 4 satellites were occasionally visible, and more than 4 satellites were never visible.*

Phase 5: Inland Scenario Bravo. Activate two units of each PLB model in an area with significant obstructions/canopy (e.g., a heavily treed area). All beacons will be placed in the same relative positions. *During the test, the amount of obstruction was defined to be low GPS satellite visibility, meaning that 1 to 3 satellites were always visible, and more than 3 satellites were never visible.*

Phase 6: Maritime Scenario Alpha. USCG small boat will proceed offshore, to simulate conditions on open seas. Activate two units of each EPIRB model in an upright position on deck on the boat.

Phase 7: Maritime Scenario Bravo. USCG small boat will proceed offshore, to simulate conditions on open seas. Two units of each EPIRB model will be used in this phase. Each beacon used will be secured inside a life raft and activated. For this scenario, only one beacon will be active at a time per life raft. *Beacons were activated under the life raft's canopy, but 7 GPS satellites were usually available.*

Phase 8: Maritime Scenario Charlie. USCG small boat will proceed offshore, to simulate conditions on open seas. Two units of each EPIRB model will be activated and set afloat.

Phase 9: Maritime Scenario Delta: USCG small boat will proceed offshore, to simulate conditions on open seas. The boat will position itself on a North-South heading making no headway. One of each EPIRB model will be secured against the port and another of the same model against the starboard bulkhead of the small boat and activated to simulate activation while in the bracket. This will be repeated with the small boat oriented in the East-West direction. (**NOTE**: This scenario may require up to four units of each EPIRB model) *This phase was not conducted.*

Phase A: Maritime Scenario Echo: near the shore, in an area of open visibility, a beacon is submerged in water, then activated and set afloat in calm water, and continually doused with water, so that its antenna is kept wet.

Phase B: Maritime Scenario Foxtrot: near the shore, in an area of open visibility, a beacon is activated and set afloat in calm water, so that its antenna is kept dry.

Phase C: Land/Maritime Scenario: near the shore, in an area of open visibility, a beacon (PLB) is submerged in water, then activated and set on someone's life vest above the calm water, so that its antenna has a clear view of the sky. This test was designed to simulate activation for U.S. Coast Guard PEPIRBs (personal EPIRBs).

Phase D: Inland Interference: on land, in an area of open visibility, activate many (5) beacons in close proximity. The beacons were set in a circle about 1 - 2 feet apart, with a delay of 5 - 7 seconds between activations. The test was repeated with 5 beacons, then 4 beacons active simultaneously.