# Shielded from Oversight

***The Disastrous US Approach to Strategic Missile Defense***

*http://www.ucsusa.org/shieldedfromoversight*

## Appendix 2: The Sea Based X-band Radar



Union of Concerned Scientists

The Sea Based X-band (SBX) radar, optimized for long-range precision tracking and discrimination, is the primary discrimination radar of the Ground-based Midcourse Defense (GMD) system. According to the Missile Defense Agency (MDA), the major functions of the SBX radar are "cued search, precision tracking, object discrimination, and providing a missile kill assessment."[1] The SBX radar is currently the world's largest X-band phased array radar.[2] However, while the SBX radar is the most capable discrimination radar in the GMD system, it has a number of serious limitations, including a very limited electronic field of view, issues with reliability and survivability, and limited coverage (the single SBX radar that was built cannot cover both the U.S. east and west coasts).[3]

Discriminating the warhead from other objects that accompany it, whether launch debris or intentional countermeasures, is vital if the GMD system is to be effective. The core radar infrastructure of the current GMD system consists of Upgraded Early Warning Radars (UEWR), which have essentially no discrimination capability.[4] While the Clinton-era plan for national missile defense would have included first one large X-band Ground Based Radar (GBR) (on Shemya Island in the Aleutians) and eventually eight or nine GBRs for the essential precision tracking and discrimination mission, these were never constructed. (See Appendix 1: Development of the Ground-based Midcourse System.)

Instead, a single Sea-Based X-band (SBX) radar was constructed on an ocean-going, self-propelled, semisubmersible platform built for other purposes by Russia.[5] The SBX, essentially a sea-going but smaller version of the planned Shemya GBR, is by default the primary radar tool that the homeland missile defense system has to contribute to any attempt to discriminate between a target warhead and countermeasures.

Originally, the SBX was built primarily for testing purposes although it was described as being able to be used operationally if needed. When the MDA first announced its plans for the SBX, it argued that because of its platform's mobility, the SBX radar could support a much wider range of testing scenarios and geometries than a radar on Shemya Island. It was touted as a faster, easier, and cheaper way to get a discrimination capability, and at the time speed of deployment was deemed to be of the essence. But although it provided an increase in discrimination capability, the lack of a rigorously analyzed concept of operations and the compromises made to build the SBX radar quickly and cheaply have dramatically limited its ability to contribute to the discrimination mission in the longer term.
First, in order to build the SBX quickly and inexpensively, key features, such as fiber optics communications to the GMD command system,

[1] Missile Defense Agency History Office (MDA History). 2008. ***A brief history of the Sea-Based X-Band Radar-1***. Washington, DC. May 1, 4. Online at ***www.mda.mil/global/documents/pdf/sbx_booklet.pdf***. Note: All URLs in footnotes to this appendix were accessed June 3–4, 2016.

[2] Its official designation is SBX-1, since at the time it was named it was anticipated that one or more additional SBX radars would be deployed. "In this budget, beginning with Block 2006 we will … expand our sensor net (with a second sea-based midcourse radar and forward deployable radars)…" Kadish, R. 2004. Testimony before the Defense Subcommittee of the Senate Committee on Appropriations. April 21. Online at ***www.mda.mil/global/documents/pdf/ps_spring04.pdf***.

[3] The SBX radar could move from one coast to the other, but this would be a lengthy trip because of its low speed and inability to pass through the Panama Canal. In 2005–2006, it took about 52 days for the SBX radar to be transported on a heavy lift ship from its construction sites on the east coast of Texas to Hawaii by going around South America.

[4] While other higher frequency radars such as the Cobra Dane radar and the forward-based TPY-2 and Aegis radars have good resolution, they are not suitable for the discrimination function for the GMD for other reasons. See Appendix 10: Sensors.

[5] The semisubmersible platform, originally called Moss Sirius, was constructed at the Vyborg Shipyard, Russia, delivered in May 2002 to Norway, and then sent to the United States to be fitted as the SBX radar. Rach, N. 2005. More than $4 billion committed for new MODUS. ***Oil & Gas Journal.*** July 4. Online at ***www.ogj.com/articles/print/volume-103/issue-25/drilling-production/more-than-4-billion-committed-for-new-modus.html*** (subscription required).

FIGURE 1.

***The Sea-Based X-band (SBX) radar is the GMD's primary means of discriminating warheads from decoys. Built primarily as a test asset, it operates out of Honolulu and must propel itself to a different location to be used in defense.*** ***Source: MDA***

electromagnetic pulse hardening and redundant electronics, were omitted. While those omissions might not be a serious problem for test scenarios, such deficiencies would not normally be acceptable in an operational system. The overall reliability and survivability of the SBX radar likely fall short of what would have been required if it had been intended from the beginning to be an operational system.

Second, the original plan was for the SBX radar to be home-ported at Adak Island in the middle of the Aleutian island chain, and a $26 million mooring system was completed there in 2007. The MDA argued that anchoring the SBX radar in Adak would leave the SBX radar both well-positioned to see ICBM trajectories from North Korea towards the West Coast, which pass nearly directly over Adak, and would avoid having to build a ground-based radar in the difficult Arctic construction conditions on Shemya Island. However, the Adak mooring facility has never been used, in part because of the extreme weather, including 30-foot ocean swells, common in Adak.[6] Although the SBX radar no longer has an official home port, in practice it now operates out of

[6] Staff writers. 2007. Boeing announces completion of Sea-Based Radar's mooring system. ***Space Daily***, September 25. Online at ***www.spacedaily.com/reports/Boeing_Announces_Completion_Of_Sea_Based_Radar_Mooring_System_999.html***. Cole, W. 2011. On the ball. ***Honolulu Star-Advisor***, January 23. Online at ***www.staradvertiser.com/hawaii-news/on-the-ball/***.

Honolulu, a far less suitable location for an operational radar. To be used for a missile defense test or as part of an operational defense, the SBX radar must move into place; under its own propulsion, it can travel at about 10 miles per hour.

The most serious deficiency of the SBX is its limited electronic field of view (EFOV): the range of angles over which the radar can electronically position its beam without moving its antenna. A full field-of-view phased array radar, such as the early warning radars that have been incorporated into the GMD system, will have an EFOV of ±60 degrees or even slightly greater. The EFOV of the SBX is only about ±12.5 degrees. While the SBX radar's limited EFOV design significantly reduced its cost by greatly reducing the number of transmit receive modules required to cover its large antenna, it resulted in a radar that is nearly useless as an operational sensor, except for very limited circumstances.

In GMD tests, the small electronic field-of-view of the SBX radar can be worked around; the sets of target objects are well-controlled and in close proximity to one another. However, in an actual attack, the warheads and other objects could be spaced much more widely across the sky, requiring the SBX radar to use time-consuming mechanical rotations to switch among targets.

When interviewed for a ***Los Angeles Times*** article critical of the SBX radar, David Montague, former president of the Missile Systems Division of Lockheed Martin Missile and Space Company and co-chairman of the National Academy of Sciences' missile defense report, said the SBX radar "should never have been built." [7] Its technical limitations render it "irrelevant to ballistic missile defense," according to David Barton, a physicist and radar engineer who also took part in the National Academy review.[8]

A final limitation is that only one SBX radar was ever built, and it cannot be used to defend simultaneously both the U.S. east and west coasts.

Even with all its deficiencies, the SBX radar has ended up being expensive to build and to operate. Its high operating costs led to its being put in a reduced operating status in fiscal year (FY) 2013. Even so, the MDA requested in FY 2016 about $73 million for SBX radar operating costs, with similar annual amounts projected through 2020.[9]

Implicitly acknowledging the shortcomings of the SBX radar, in March 2014 the MDA announced a plan to deploy by 2020 a Long Range Discrimination Radar (LRDR) for the defense of the United States from missiles launched from North Korea. In May 2015, the Department of Defense announced that Clear Air Force Station in central Alaska was its preferred location for the LRDR.[10] (See Appendix 3: Long Range Discrimination Radar.) The MDA has also stated that the deployment of LRDR would give the SBX radar "more geographic deployment flexibility for contingency and test use."[11] This "geographic deployment flexibility" may include moving the SBX radar to the U.S. East Coast or basing it permanently in Hawaii.

The rest of this appendix focuses in more detail on the SBX radar's technical characteristics, cost, testing, and operations.

## Technical Characteristics

The SBX radar operates in the X-band (8–12 gigahertz) of radar frequencies. The SBX radar is typically assumed to have a center operating frequency of about 9.5 GHz, corresponding to a wavelength of about 3.16 centimeters (1.2 inches). It has a bandwidth of about 1.0 GHz, and a resulting range resolution of about 25 cm (10 in.) or

[7] Willman, D. 2015. Lawmakers pushed to keep troubled defense programs alive. ***Los Angeles Times***, April 5. Online at ***http://graphics.latimes.com/missile-defense-congress/*** . National Research Council. 2012. ***Making sense of ballistic missile defense.*** Committee on an Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives. Division on Engineering and Physical Sciences. Washington, D.C.: National Academies Press. Online at ***www.nap.edu/catalog.php?record_id=13189***, 277.

[8] Willman, 2015.

[9] Missile Defense Agency (MDA). 2015. PB 2016 summary. February. Online at ***www.mda.mil/global/documents/pdf/budgetfy16_summary.pdf***.

[10] Department of Defense. 2015. Department of Defense identifies planned site of future Long Range Discrimination Radar (LRDR). Press release NR-193-15. May 22. Online at ***www.defense.gov/Releases/Release.aspx?ReleaseID=17294***.

[11] Syring, J. 2014a. Briefing on the Missile Defense Agency's FY 2015 budget in the Pentagon briefing room. News Transcript. Washington, DC: Department of Defense, March 4. Online at ***http://archive.defense.gov/Transcripts/Transcript.aspx?TranscriptID=5388***.

slightly better.[12] The SBX radar's roughly circular antenna has a diameter D of about 17.8 meters.[13] This corresponds to a beamwidth $\theta$ of about $\theta = \lambda/D =$ $0.0316/17.8 = 0.00178$ = 0.1°.

The SBX's antenna face has an active area of 249 $m^2$ which is populated with 45,056 X-band transmit/receive (T/R) modules.[14] The T/R modules used on the SBX radar are part of a "family" of very similar X-band modules that are also used on the Ground-Based Radar-Prototype (GBR-P) at Kwajalein Atoll in the Pacific Ocean and on the smaller TPY-2 X-band radars. According to one estimate, the T/R modules used on the SBX have a peak power of 10 watts and an average power of 2 W.[15] The entire radar would thus have a peak power of 450 kilowatts and an average power of 90 kW. The SBX radar has been officially described has having a detection range of 4,800 kilometers, although the radar cross section (RCS) of the target was not specified.[16] A standard claim on the capability of SBX radar is that it could detect and discriminate a baseball-sized object at a distance of about 4,000 km.[17] A metallic sphere the size of a baseball (diameter = 7.4 cm) would have a RCS of about $\sigma = \pi r^2 = 0.0045$ $m^2$. It has also been claimed by the MDA that the SBX radar could detect a golf ball-sized reflecting object in similar circumstances.[18]

## Limited Electronic Field of View

A major limitation of the SBX radar is that it has a very limited electronic field of view (EFOV). The EFOV is the range of angles over which a phased-array radar can position its beam electronically, and almost instantaneously, without moving its antenna. Phased array radars typically are limited to maximum electronic scan angles of roughly ± 60° because of losses associated with larger scan angles. Phased arrays with maximum scan angles of roughly ±60° are referred to as full field-of-view (FFOV) radars.

FFOV radars typically have antenna module spacing of about 0.6 λ, where λ is the radar wavelength, depending on the arrangement of the modules. If the spacing between antenna elements is greater than d = λ/2, then it is possible for additional main beams, known as grating lobes, to be formed as the main beam scans away from the antenna boresight (the direction perpendicular to the antenna face), severely impairing the performance of the radar. Grating lobes can limit a phased array radar to a maximum off-boresight scan angle that is determined by the spacing of its antenna elements. Phased array radars with significantly reduced scan angles due to wide module spacing are referred to as limited field of view (LFOV) radars.[19]

For radars such as the SBX that have modules arranged on a square array, a module spacing of 0.536 λ or less is needed to obtain a ±60 degrees scan angle

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[12] Ingwersen, P., W. Camp, and A. Fenn. 2002. Radar technology for ballistic missile defense. ***Lincoln Laboratory Journal*** 13(1): 109-148.

[13] See the photograph of the SBX radar's antenna on page 17 of MDA History 2008. Diameter is based on an active area of 249 $m^2$.

[14] Dees, B. 2015. Sea-Based X-Band Radar (SBX). Presented at MDA Small Business Conference at the 2015 Space and Missile Defense Symposium, August. Online at ***www.mda.mil/global/documents/pdf/osbp_15conf_SBX_Dees10.pdf***. Earlier (before the SBX was built) sources gave the number of modules as 45,264.

[15] Lewis, G. 2012. Ballistic missile defense: Power of X-band radars. ***MostlyMissileDefense***. Blog. June 4. Online at ***http://mostlymissiledefense.com/2012/06/04/ballistic-missile-defense-power-of-x-band-radars-june-4-2012/***.

[16] Dees 2015.

[17] According to then MDA Director Henry Obering, "If we place it in Chesapeake Bay, we could actually discriminate and track a baseball-sized object over San Francisco." Obering, H. 2007. Defense Subcommittee. Senate Committee on Appropriations. Testimony. April 25, in response to a question from Senator Byron Dorgan. Online at ***https://www.gpo.gov/fdsys/pkg/CHRG-110shrg69104261/pdf/CHRG-110shrg69104261.pdf***. Depending where this ship is in the bay, this is a distance of about 4,100 km. MDA History 2008, 4, states that the SBX can see a baseball sized object at a range of 2,500 miles, which corresponds to about 4,000 km.

[18] Sirak, M. 2006. Raytheon expands capabilities of ballistic missile defense radars. ***Defense Daily***, March 20. The claim made there is that the SBX off coast of Washington DC could detect a golf ball-sized reflecting object ($\sigma$= 0.0015 $m^2$) over Seattle, which is a range of about 3,900 km.

[19] For the discussion in this and the following paragraph, see section 3.3 "Phased-array antennas" of Curry, G.R. 2005. ***Radar system performance modeling***, second edition. Boston, MA: Artech House. Online at ***http://read.pudn.com/downloads163/ebook/744575/Artech.House.Publishers.Radar.System.Performance.Modeling.Second.Edition.Dec.2004.ISBN1580538169.pdf***.

without producing grating lobes.[20] That module spacing corresponds to a maximum allowable antenna area of $0.287\lambda^2$ per module. (For an antenna with modules arranged on an equilateral triangular array, such as the U.S. early warning radars, this maximum permissible antenna area per module is[21] $0.332\lambda^2$.)

The antenna modules on the SBX radar are spaced much more widely than for a typical phased array radar antenna. The SBX radar has 45,056 modules on a square array with an area of 249 $m^2$. That arrangement corresponds to an area per module of 55.3 $cm^2$ and a spacing between of modules of 7.43 cm = 2.35λ assuming a frequency of 9.5 GHz. For radars with widely spaced elements on a square array, the maximum scan angle $\theta_M$ that can be achieved is approximately given by $\sin\theta_M = \pm(0.5\lambda/d)$, where d is the module spacing.[22] With the SBX radar's module spacing of d = 2.35λ, this relationship gives a maximum electronic scan angle of ±12.3°. The achievement of even this relatively small EFOV was made possible by the large size of the individual elements and through use of such techniques as lattice rotation.[23]

The element spacing of the SBX radar (d = 2.35λ) is slightly smaller than that of the earlier, similar Ground-Based Radar – Prototype (GBR-P) at Kwajalein (d = 2.5λ). According to the MDA, the GBR-P has an electronic field of view of 25 degrees (= ±12.5°).[24] This narrower element spacing suggests that the electronic field of view of the SBX radar could be slightly larger than ±12.5°.

To compensate for this very limited EFOV, the SBX radar's antenna is mounted on a gimbal on a turntable that allows the antenna to be rotated (±178°) and elevated (0-90°). This limited EFOV could severely limit the ability of the SBX radar to deal with target threat clouds that are spaced more than about 25° apart, although it would not be a problem for using the SBX radar in GMD system tests.

The use of wide element spacing on the SBX allows a large aperture—with a correspondingly narrow beam width and long tracking ranges—to be achieved without using a prohibitively large number of T/R modules. To get a FFOV of ±60 degrees on the same size antenna, the SBX radar would have required about $(2.35/0.536)^2$ = 19.2 times more modules, or a total of 45,056 x 19.2 = 864,000 modules. Not only would so many modules have been prohibitively expensive, but it likely would have

[20] For a square array along one the principal axes, grating lobes will occur at θg when

$$(\sin\theta - \sin\theta g) = \pm n\frac{\lambda}{d}$$

where θ = scan angle of main beam and n is an integer, with n = 0 corresponding to the main beam. Skolnik, M. 2001. ***Introduction to radar systems***, third edition. New York, NY: McGraw-Hill, 566. For a scan angle of 60° with no grating lobes in real space (so that θ = ± 60°, θg = ±90°), then λ/d = 1.866, so that d = 0.536λ. For the SBX's spacing of d =2.35λ on a square array, grating lobes occur even with the beam on boresight, with the first grating lobes along its principal axes at θg = ±25.2°.

[21] Joe Frank and John D. Richards. 2008 . Phased array radar antennas. In ***Radar Handbook,*** third edition, edited by M. Skolnik. New York, NY: McGraw-Hill. Online at ***http://airspot.ru/book/file/961/radar_handbook.pdf*** .

[22] Curry 2005, 33. Curry refers to this as the "acceptable element spacing."

[23] The large element sizes result in single element beam widths similar to the angular spacing between the innermost grating lobes, so that the individual elements produce little power in the direction of farther out grating lobes. The rotation of different subsections of the antenna array is evident in the photograph on page 17 of MDA History 2008. In an interview following his retirement, a Redstone Arsenal engineer (Sam Uptain) discussed the use of this technique. "One of my major contributions has been the invention of the antenna lattice rotation technique to greatly reduce the grating lobe radiation intensity of the GBR-X Radar limited field-of-view antenna," he said. This technique was also used on the GBR-P and SBX radars. Uptain explained that without this technique radars with LFOV antennas could not have been based on Kwajalein Atoll or the European Midcourse Radar at the Czech site due to human safety issues. Skarupa, B. 2013. Radar whiz focuses on retirement life. ***The Redstone Rocket***. Redstone Arsenal, AL: Public Affairs Office. Blog, December 20. Online at ***www.theredstonerocket.com/article_7442e193-a969-535d-95c9-c6fc18ef53b0.html?mode=jqm***. A discussion of how a lattice rotation technique works (by rotating subarray grating lobes and their nulls onto each other) is in Agrawal, V. 1978. Grating-lobe suppression in phased arrays by subarray rotation. ***Proceedings of the IEEE*** 66(3):347–349. March. Online at ***http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=1455173&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D1455173*** (subscription required).

[24] Ballistic Missile Defense Organization (BMDO). 1997. ***Report to the Congress on ballistic missile defense***. Washington, DC: The Pentagon. 3-9 (figure 3-5). Online at ***www.dtic.mil/dtic/tr/fulltext/u2/a338606.pdf***. See also Kandebo, S. 1997. NMD system integrates new and updated components. ***Aviation Week & Space Technology***. March 3.

delayed the deployment of the SBX radar by years unless costly new module production lines were opened.[25] In addition, it would also have resulted in a radar with much greater capabilities than would ever be needed in a missile defense role, given the curvature of the earth and the maximum altitude of ballistic missile trajectories.

## SBX Radar Costs

The SBX radar was expensive to build and is expensive to operate. According to the 2012 National Academy of Sciences Report, the SBX radar cost $1.4 billion to develop and procure from 2002 to 2005, with another $300 million spent on enhancements to the system from 2006-2009 (all in 2010 dollars).[26] As of April 2015, the total expenditure on the SBX was $2.2 billion.[27]

Prior to the radar's being put in a reduced operational status in FY 2013, average annual operating costs were expected to be about $162 million per year (in FY 2010 dollars) from 2010 to 2015.[28]

Table 1 below shows the annual spending on the SBX radar from 2008 to 2020.

## Reduced Operational Status

In February 2012, the MDA announced that the funding for the SBX radar would be drastically cut and that the radar would be placed into a "limited test support" role starting at the beginning of FY 2013.[29] The MDA justified this plan by arguing that it would save at least $500 million over five years, and forward-based TPY-2 X-band radars could replace the SBX radar in future tests, while the SBX radar could be recalled to "active operational status if and when it is needed."[30]

As Table 1 shows, under this plan, SBX funding would have been cut from its average of $159 million over the previous five years to $9.7 million per year. Thus, this plan would have essentially mothballed the radar. However, this plan never went fully into effect. Congress increased the SBX radar's FY 2013 funding

TABLE 1. SBX Budget in Millions of $, **Bold** = actual, ***Italics*** = planned.

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Before 2/2012 Reductions | **155** | **144** | **167** | **153** | **177** | **173** | | | | | | | |
| After 2/2012 Reductions | **155** | **144** | **167** | **153** | **177** | ***9.7*** | ***9.7*** | ***9.7*** | ***9.7*** | ***9.7*** | | | |
| As of 2/2015 | **155** | **144** | **167** | **153** | **177** | 23.7 | 70.3 | ***64.4*** | ***57.1*** | ***71.3*** | ***75.8*** | ***72.3*** | ***87.1*** |

Source: MDA budget documents

[25] For comparison, the thirteen X-band missile defense radars (one GBR-P, one SBX, and eleven TPY-2s, not including the two sold to the United Arab Emirates) delivered as of April 2016, use a total of only about 341,000 T/R modules. Given that the T/R modules are the largest component of such an X-band radar's cost, the cost of such a densely populated radar would likely have been many times the actual cost of the SBX radar.

[26] National Research Council 2012.

[27] Willman 2015.

[28] National Research Council 2012, 278. Almost 70 percent of this cost was for operating the SBX radar's platform and a supporting ship, with the rest being for actual radar operations.

[29] Butler, A. 2012. MDA budget slashed nearly $1 billion; SBX radar shelved. ***Aerospace Daily and Defense Report***, February 14. Online at ***http://aviationweek.com/awin/mda-budget-slashed-nearly-1-billion-sbx-radar-shelved*** (subscription required).

[30] Butler 2012.

from $9.7 to $23.2 million; the MDA further increased it to $70.3 million in FY 2014, and expects to maintain it at about that level through FY 2020. According to MDA Director Vice Admiral James Syring, in 2013 the SBX radar spent 110 days at sea, including 49 days supporting real world operations.[31] As discussed below, since being placed in limited operational status, the SBX radar has participated in every GMD intercept test and has also been deployed for contingency operations. Starting in FY 2016, the MDA plans for "…increased manning for improved readiness and shorter time from notification to underway, and increase in planned underway days from 60 to 120 days per year," noting that "This is an improvement in operational readiness over the Limited Test Support Status that was established in FY 2013."[32]

## SBX Radar Testing and Operations

The SBX radar first participated in a GMD intercept test in September 2006 (FTG-02) in which it observed the test offline in a shadow mode in which it collected data but did not communicate the data back to the GMD system in real time. In a subsequent test involving a target missile but no interceptor (FTX-02 in March 2007) the SBX radar "exhibited some anomalous behavior."[33] After changes were made to its software and operating parameters, the SBX radar reportedly performed well in a shadow mode in the next GMD intercept test in September 2007 (FTG-03a). The SBX radar has been an active participant in all subsequent GMD intercept tests.

The SBX radar suffered a significant failure in the FTG-06 intercept test in January 2010 in which it was the only midcourse sensor. According to the Director for Operational Test and Evaluation, "Undesirable SBX performances occurred that contributed to a failed intercept."[34] The failure was attributed to the presence of unburned chunks of solid rocket fuel that were emitted from the rocket booster towards the end of or after the booster burnout, a phenomenon known as chuffing.[35] Although chuffing is a common phenomenon with large solid rocket boosters, the SBX radar had not been programmed to expect chuffing, and it was unable to cope with the unexpected appearance of the target threat cloud.

In the successful FTG-06b intercept test in June 2014, the MDA's Command and Control, Battle Management, and Communications (C2BMC) system did not receive the expected report from the SBX radar about whether or not a hit had been achieved.[36] From the publicly available information, it is unclear if this problem originated with the SBX radar or somewhere else in the C2BMC system.

In addition to its testing role, the SBX radar has been deployed several times for contingency operations. In June 2009, following North Korean nuclear weapons and ballistic missile tests, the SBX radar was deployed off Hawaii.[37] (For safety reasons, the SBX radar cannot be operated while in port.) In April 2013, after being put in limited operational status at the beginning of the year, the SBX radar was deployed to the "central Pacific

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[31] Syring, J. 2014b. Statement before the Defense Subcommittee of the Senate Appropriations Committee. June 11. Online at *www.mda.mil/global/documents/pdf/ps_syring_061114_sacd.pdf*.

[32] Missile Defense Agency (MDA). 2015. ***Research, development, test & evaluation, defense wide***. Defense wide justification book volume 2a of 2 of ***Fiscal Year (FY) 2016 president's budget submission***. Washington, DC: Department of Defense. February. February. 2a-673. Online at *http://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2016/budget_justification/pdfs/03_RDT_and_E/MDA_RDTE_MasterJustificationBook_Missile_Defense_Agency_PB_2016_1.pdf*

[33] Director, Operational Test and Evaluation (DOT&E). 2007. Sensors. In ***FY 2007 Annual Report***. Washington, DC: The Pentagon. December. 229. Online at *http://www.dtic.mil/dtic/tr/fulltext/u2/a482396.pdf* .

[34] Director, Operational Test and Evaluation (DOT&E). 2010. Sensors. In ***FY 2010 Annual Report.*** Washington, DC: The Pentagon. December. 240. Online at *www.dote.osd.mil/pub/reports/FY2010/pdf/bmds/2010sensors.pdf*.

[35] Butler, A. 2010. Diverted attention. ***Aviation Week and Space Technology.*** April 12.

[36] Director, Operational Test and Evaluation (DOT&E). 2015. Command and control, battle management, and communications (C2BMC) system. In ***FY 2014 Annual Report***. Washington, DC: The Pentagon. January. 308. Online at *www.dote.osd.mil/pub/reports/FY2014/pdf/bmds/2014c2bmc.pdf*.

[37] Department of State. 2009. Defense Secretary Gates, Admiral Mullen press conference; Officials discuss Afghanistan, North Korea, Iran, Pakistan. Texts and Transcripts. June 18. Online at *http://iipdigital.usembassy.gov/st/english/texttrans/2009/06/20090622085357eaifas0.20068.html#axzz4AdZDJEMF.*

Ocean," once again over concern about North Korean missile and nuclear tests.[38]

The MDA's March 2014 announcement of its plan to deploy a Long Range Discrimination Radar (LRDR) in Alaska or elsewhere in the western United States by 2020 also stated that the deployment of LRDR would give the SBX radar "more geographic deployment flexibility for contingency and test use."[39] This "geographic deployment flexibility" likely includes moving the SBX radar to cover the U.S. East Coast, as Vice Admiral Syring indicated in a Senate Hearing the next month: "…discrimination capability to the east is equally important and long-term we're going to be looking to address that gap. Right now the strategy would be to move the sea-based X-band to the east as the long-range radar is built to the west."[40] Another alternative would be to deploy the radar permanently in Hawaii, possibly by removing it from its platform and placing it on land.

[38] PACNEWS. 2013. US missile destroyers, anti-ballistic missile system in position. Toorak, Suva, Fiji Islands: Pacific Islands News Association. April 15. Online at ***http://www.pina.com.fj/index.php?p=pacnews&m=read&o=742388146516b5ad84c99e06c056d6***.

[39] Syring 2014a.

[40] Syring, J. 2014. Testimony before the Strategic Forces Subcommittee of the Senate Armed Services Committee. April 2. Online at ***https://www.gpo.gov/fdsys/pkg/CHRG-113shrg91192/pdf/CHRG-113shrg91192.pdf***.