KWAJALEIN MISSILE RANGE MODERNIZATION AND SUPPORT OF BMDO TESTING

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Abstract

The Kwajalein Missile Range (KMR) has embarked on a four-year major modernization program in which much of the Range instrumentation will be upgraded. The major benefits to KMR are improved efficiency and reduced cost of operation. High maintenance, unique components will be replaced with commercial off-the-shelf equipment. Sensors are being reconfigured to incorporate common architectures, where practical, resulting in common parts sparing, and reduced maintenance staffing. The new architecture supports a significant degree of automation, enabling instrumentation to be monitored and operated remotely. Sensor control and execution of missions will be from a central location, the Mission Control Center on Kwajalein Island. Much of the telemetry equipment will be consolidated into a new location on Kwajalein. Telemetry and optical assets that remain on outer islands of the Atoll are being upgraded to achieve higher reliability and improved performance. This will either eliminate or drastically reduce the requirement for daily aircraft commuter services to the various equipment sites around the Atoll. The major technical benefits of modernization to the users of KMR are improved sensor capability, flexibility in specifying and satisfying test needs, and more timely data reduction. The enhancement of KMR's instrumentation and the extension of the Range Safety Center's capability to enable it to handle multiple simultaneous engagements increase the diversity and scope of future testing. KMR is uniquely qualified to support full envelope testing of multi-layer TMD and NMD target engagements.

INTRODUCTION

The Kwajalein Missile Range (KMR) is located in the Marshall Islands, approximately 2300 miles southwest of Hawaii (Fig. 1). KMR's near-equatorial location in the mid-Pacific is ideal for supporting all aspects of space, strategic, theater and national ballistic missile testing. Its sparse population and limited land mass amid the broad ocean area allow the full envelope, multiple simultaneous engagement testing mandated by Congress. KMR's location allows critical first orbit observations and tracking of New Foreign Launches from Asia and the Western Pacific nations. Today KMR provides critical data to the Army, the Air Force and other government agencies on ballistic missile testing, and accumulates more than 7000 sensor support hours annually in collecting space control and surveillance data for Space Command and National Intelligence Agencies.

KMR's data collection assets, illustrated in Fig. 2, consist of a broad array of unique sensors distributed throughout the Kwajalein Atoll including signature radars, beacon tracking radars, visible and MWIR optical sensors, and impact scoring assets. KMR's instrumentation is located on eight islands that are part of the world's largest atoll, providing a 770-square mile lagoon with a maximum depth of 200 feet. Immediately surrounding the Kwajalein Atoll is a sparsely populated broad ocean area capable of supporting the full envelope testing of multiple TMD target engagements with minimal environmental impact.

The suite of assets at KMR has evolved through more than 35 years of test support to US offense/defense programs. More recently, since the mid-1980's, KMR has been deeply involved with numerous SDIO/BMDO system development and measurement test activities. Range capabilities have been upgraded specifically to support BMDO requirements. Through a combination of high range resolution radars and optical sensors, KMR provides highly accurate range and angle solutions of target trajectory and body motion. High resolution

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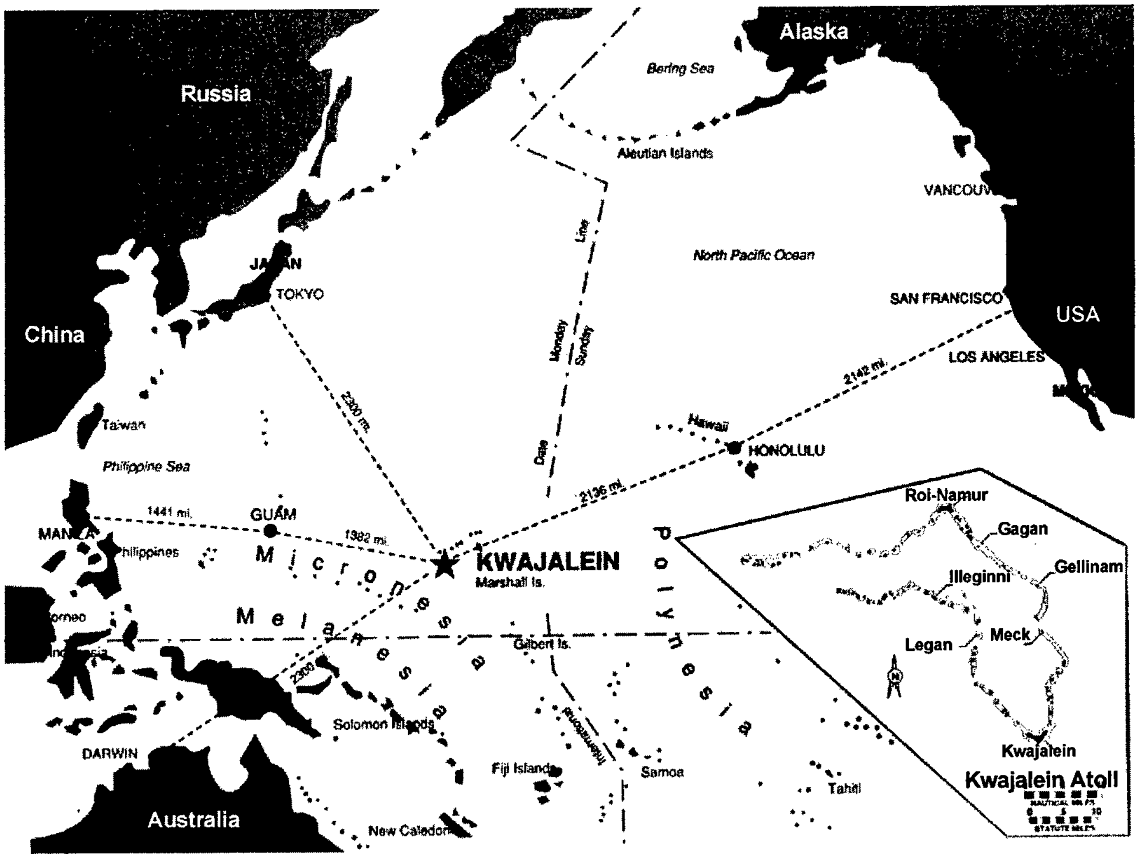


Figure 1. Kwajalein Missile Range – Strategic Location

Doppler processing of radar data allows vehicle intercept and hit-point determination for kill assessment down to centimeter accuracies. Broad-beam and complementary, multiple radar coverage ensures that both metric and signature data are collected on all objects (including interceptors) involved in a test scenario.

KMR's heritage in testing has led to an impressive array of highly sophisticated, unique sensors, each requiring a dedicated, highly educated staff for maintenance, operation and improvement. In the last several years KMR has been investigating ways to maintain its hallmark of technical excellence yet reduce operating costs through the use of modern technology, standardized procedures and remote operation. With the recent advances in high speed computing and I/O bandwidth, it is now possible to replace many of the special, one-of-a-kind components in the radars with commercial-off-the-shelf (COTS) equipment. COTS technology allows a redesign of major portions of KMR's five signature radars, leading to a common set of core components and computers. Large numbers of high-maintenance, unique components will be replaced with COTS components, resulting in a significant reduction in the number of O&M staff and their skill level. Further, a common radar configuration yields the additional benefit of a common data recording format, which allows for more timely post-mission data reduction at lower cost.

KMR MODERNIZATION AND REMOTING ACTIVITIES

In the summer of 1997 KMR initiated an aggressive range-wide modernization program with major upgrades planned for the signature radars, telemetry and optical sensors, and KMR Mission Control Center. The Range Safety Center is also being upgraded to enable Multiple Simultaneous Engagement (MSE) missions to be supported at KMR. This latter upgrade will also utilize similar, modern technology based on COTS.

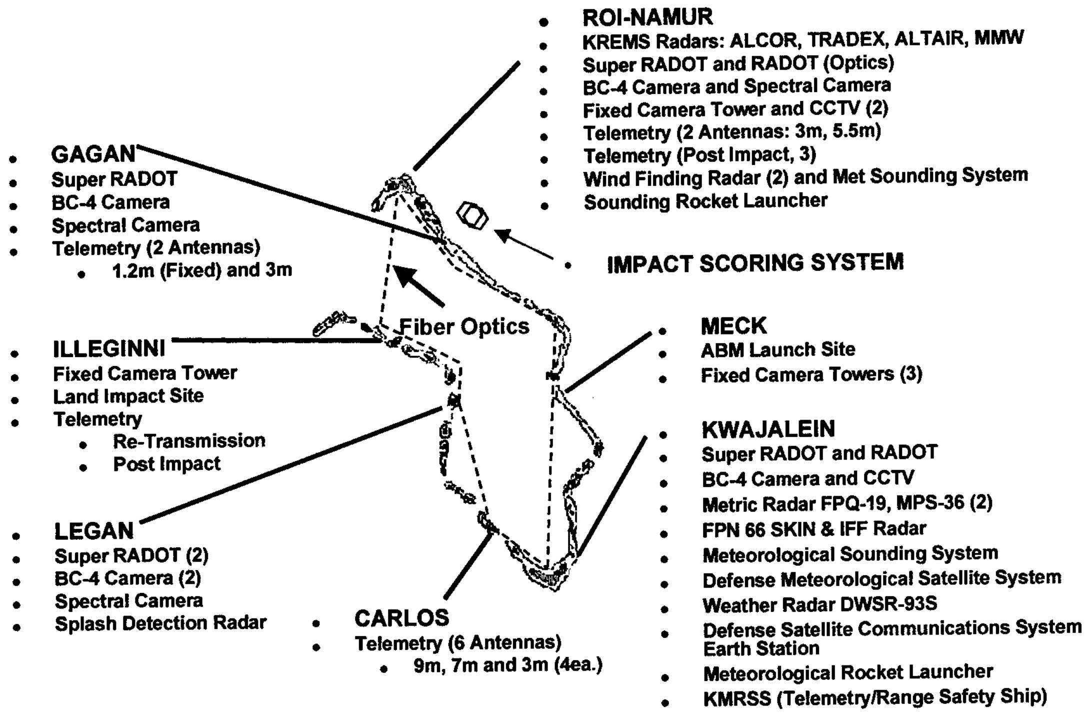


Figure 2. KMR Data Acquisition Sensors

The KMR Modernization and Remoting (KMAR) program has been organized as a joint team effort, with the participation of the US Army sponsorship, MIT Lincoln Laboratory (MIT/LL), and the Range support contractor, Raytheon Range System Engineering (RSE). The project management and execution is consistent with recent DoD Acquisition Reform guidelines, making use of Integrated Product Teams (IPTs) with MIT/LL providing the overall technical leadership.

The primary KMAR objective is to reduce the O&M cost without diminishing the quality of the range instrumentation. To do this the sensors will be modernized, automated, and new diagnostic capabilities added. This will permit troubleshooting and unit replacement at the module and individual board level by technicians. In the case of the radars on Roi-Namur, located 50 miles to the north of Kwajalein Island, system control will be exercised from Kwajalein via a fiber-optic communication link. The radars will be maintained by a resident technician-level workforce living on Roi-Namur. This will eliminate the need for routine daily flights between Kwajalein and Roi-Namur.

For telemetry and optics, the goals are to add automation to the sensors, to remote the operations of some of the sensors, and to relocate and consolidate others. These various changes will enable the remote island instrumentation to support missions on a campaign basis. As a consequence, the daily helicopter flights to these outer islands can be eliminated.

Another major change will be in software and hardware support. With improvements in networking and communications, it is now possible to relocate the majority of KMR's support for these areas to CONUS. In the processing of the data products there will be improvements made to reduce the data delivery time to the user by utilizing more standardized recording formats and more automated data reduction processes.

a. Radar Modernization & Remoting

Modernization of the five KMR signature radars will result in a common system configuration with diverse metric and signature capabilities spanning the frequency band from VHF and UHF at ALTAIR, to L and S bands at TRADEX, to C band (including beacon tracking) at ALCOR and the FPQ-19, to Ka and W bands at MMW. The radar modernization will employ all-digital waveform generation and pulse compression, allowing for virtually any sponsor-desired waveform types and specific characteristics available previously only in custom hardware. Increased computer speed and I/O throughput will allow automatic, off-axis multi-target tracking and signature collection of all objects with high fidelity Kalman filter tracking. Due to the demands of the digital imaging market, COTS recording systems are now available that allow direct digital recording of all radar signature and metric data to computer-based RAID (Redundant Array of Independent Disks) and optical disk recording systems. These components are easily maintained and will provide for extremely quick post-mission data transfer via satellite to the KMR Data Analysis Center in Lexington, MA for both faster Quick-Look and more detailed data processing. Common, Quick-Look data reduction and analysis tools will be available for use both at KMCC and in Lexington. Thus, Range users can get an early view of the mission outcome at either location.

The modernized KMR radars will utilize the distributed subsystem architecture shown in Fig. 3. This architecture replaces the historical, custom hardware that has been used at KMR. Maximum use will be made of legacy systems, drawing heavily on the architecture and technology employed in a recently completed dual frequency radar, Cobra Gemini. This distributed, COTS-based architecture allows the radar processing and control to be functionally decomposed into the main computer and a number of separate radar subsystems.

Figure 4 shows the standard block diagram that describes any of the modernized signature radars. With the exception of the antenna, transmitter, microwave hardware, and a portion of the receiver, everything is being replaced with modern components.

Common software will be used for each of the five radars. A common real-time program (RTP) incorporating all of the features of each radar will be utilized. The RTP will be designed by function as if a single radar existed with the combined capabilities of all five radars. Subsystem software will also follow this methodology. The main frame computer will also contain processors that are dedicated to simulating the radar performance. The simulator will execute in real time, provide signature and system status data at pulse repetition rates and will be used to verify real time operation, system maintenance and for operator training.

The radars will be controlled from consoles to be located in the KMR Mission Control Center (KMCC) on Kwajalein Island. The remotely operated signature radars will utilize mission profiles generated in CONUS prior to each mission. These will provide automatic scheduling of radar functions, waveforms, objects to be tracked, data sampling windows, etc. Mission profiles will also allow for contingencies in the event of non-nominal situations, such as anomalous placement of targets. Heavy reliance will be placed on automatic classification and identification of objects, and realistic simulation for mission rehearsal.

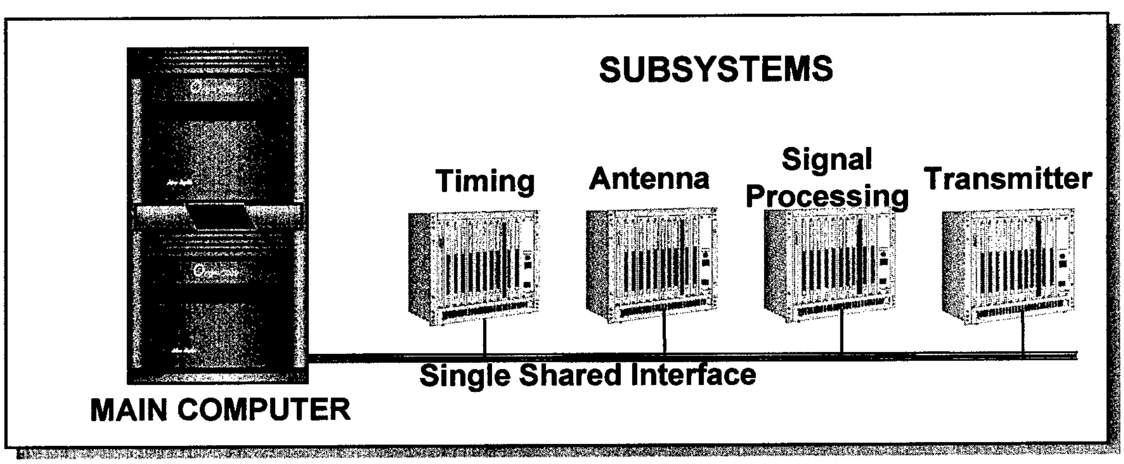


Figure 3. Signature Radars – COTS Distributed Architecture

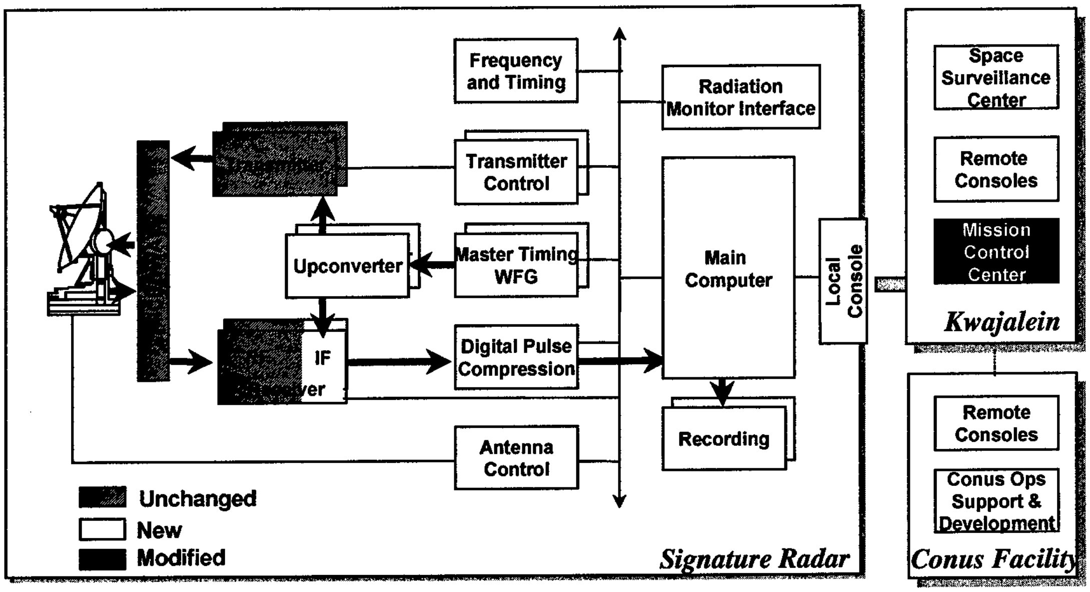


Figure 4. Signature Radar Sensor Block Diagram

b. <u>Optics Modernization</u>

The current optic suite consists of seven tracking telescopes (five SuperRADOT and two RADOT) and a larger number of fixed ballistic and documentary cameras systems located on five islands of the Kwajalein Atoll. Figure 5 illustrates the major upgrades to the optical tracking systems. MWIR telescopes have been added to the mounts, high frame-rate (1KHz) CCD cameras with improved resolution are replacing the older image intensifiers, and direct digital recording of optical intensity data has been implemented. Eventually, it is anticipated that film will be replaced with high-speed electronic recording as technology becomes available.

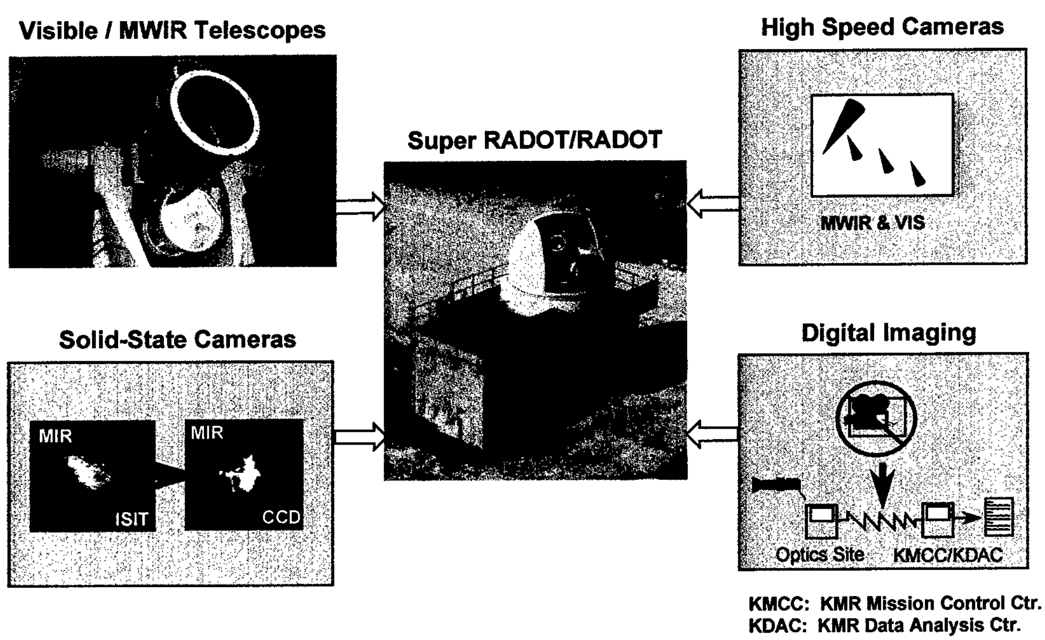


Figure 5. KMR Optics Instrumentation: Example Upgrades

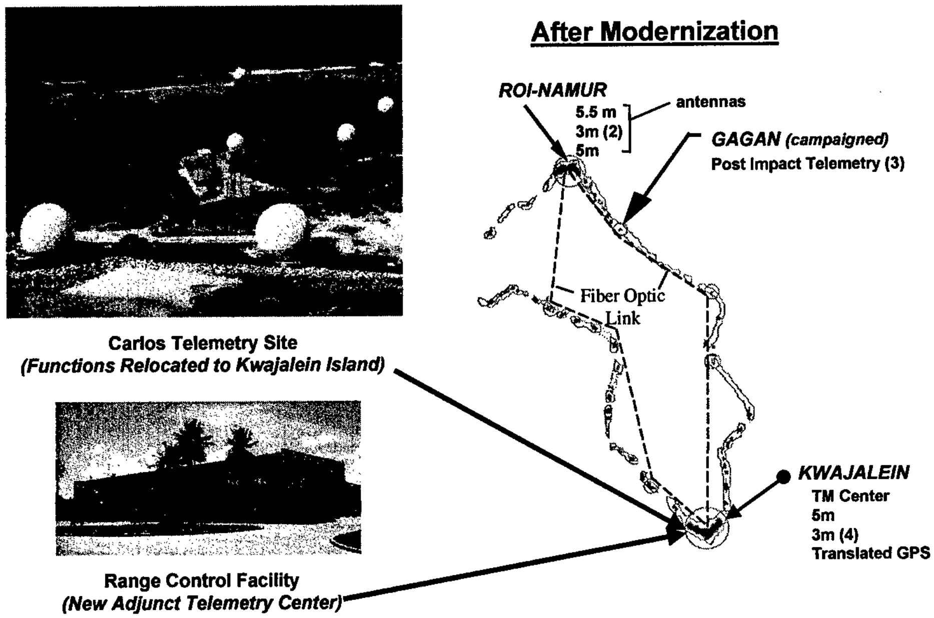


Figure 6. KMR Telemetry Modernization

c. Telemetry Modernization

The modernization of KMR's telemetry systems is illustrated in Fig 6. The telemetry sensors will gain by the addition of real-time decommutation of their data stream to allow for real-time metric tracking solutions. The telemetry data will also be upgraded to permit digital recording of the post-detected data. This will allow much faster data reduction and at lower cost through elimination of analog recording on 14 track tape. Another aspect of the KMR modernization is the ability to utilize telemetry-derived data, such as from the payload Inertial Measurement Unit, in real-time state vector estimation. In particular, data from the new Translated GPS Ranging System (TGRS) will yield highly accurate metric solutions on maneuvering vehicles.

Historically, the majority of the Range telemetry assets have been located on Carlos Island, with some additional systems on Roi-Namur. Post-impact TM antennas were located on Gellinam and Gagan Islands. In the future, the tracking TM assets will be consolidated primarily on Kwajalein Island, with some remaining on Roi-Namur. Post-impact equipment has already been consolidated onto Gagan.

A new Telemetry Center will be constructed on Kwajalein to house the relocated and new equipment. During operations, the S-Band TM analog signals will be transmitted over fiber optics cables to the Center for decommutation and recording. In addition, the tracking antennas will be controlled from the Center. The upgraded TM will provide improved data collection and faster data delivery to the customer, as well as increased efficiency of operation.

d. Mission Control & Data Products

The KMR Mission Control Center, KMCC, is the focal point for sensor coordination during the execution of a mission (Fig. 7). It provides state vectors for sensor directing and target acquisition. KMCC performs ballistic smoothing, coordinate transformation, and time alignment of sensor-to-sensor data. Best Estimate of Trajectory information is developed in real time from fusion of multiple-sensor target tracks.

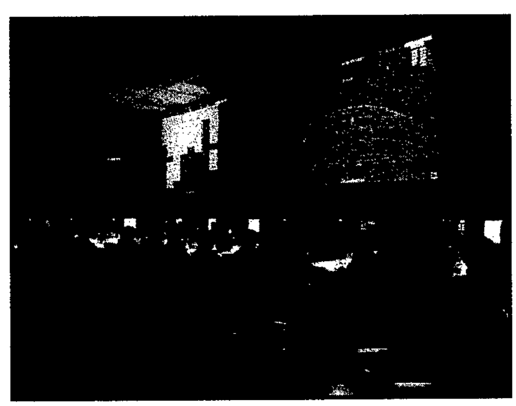


Figure 7. KMR Mission Control Center (KMCC)

The modernized KMCC will incorporate the displays and control for remote sensor operation. Algorithms are being developed to provide target identification, based on both metric and signature properties. Automation is expected to greatly reduce the number of console positions and operators required to conduct a mission.

Extensive simulation capability will be employed. KMCC will coordinate sensor simulations and generate mission scenes that provide context for the simulations. For example, the scene can be varied to contain nominal and/or non-nominal target deployments.

In order to support remote sensor control, the data networks that connect the sensors to KMCC via a fiber-optic submarine cable must be upgraded to achieve very high reliability. A loss of connectivity during a mission would prevent remote operation from KMCC and seriously jeopardize objectives. The upgraded networks will utilize high speed Ethernet (100BaseT) connections and support much higher bandwidths than the present system. A variety of transmission protocols will be supported.

The Concept of Operations, after modernization, is illustrated in Fig. 8. It will be noted that only functions relating to sensor operation and mission execution remain on Kwajalein. All other operations are in CONUS with the exception of the Quick Look post-mission report, which can be generated at either location, using identical workstations and a common set of analysis tools. Mission profiles are generated from customer requirements, translated into sensor real time functional steps and the corresponding execution timelines. Profiles are rigorously tested via simulation prior to being sent to Site.

A Development and Integration Facility based in CONUS will be maintained after modernization is complete. It will be used to develop and validate new system enhancements needed to satisfy customer test requirements. This facility will emulate the sensor suite at KMR as faithfully as possible, and will minimize the integration risk of such enhancements.

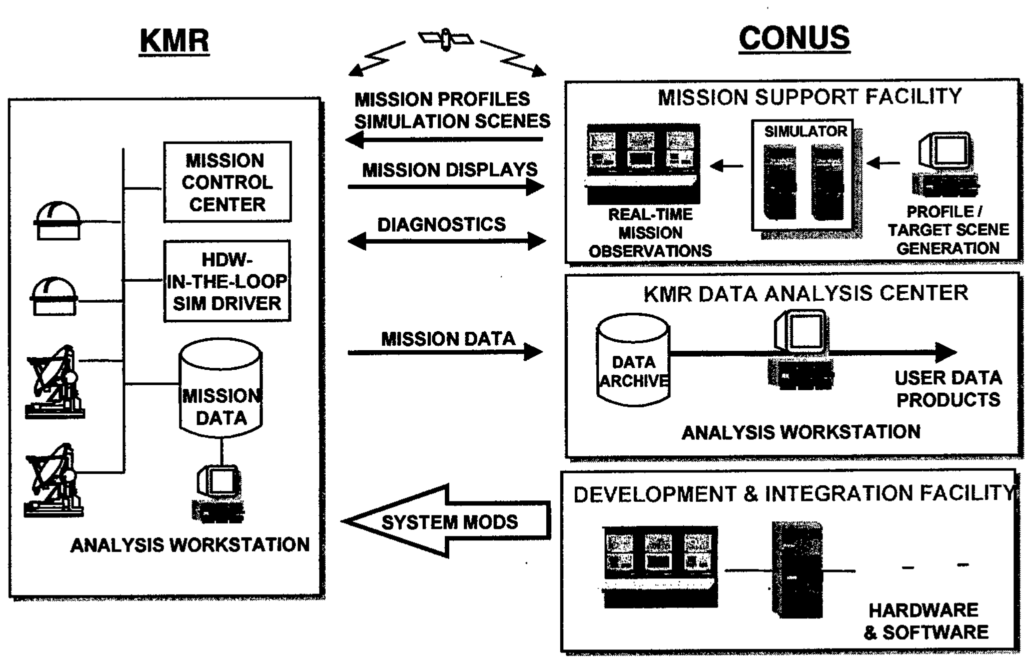


Figure 8. Concept of Operations

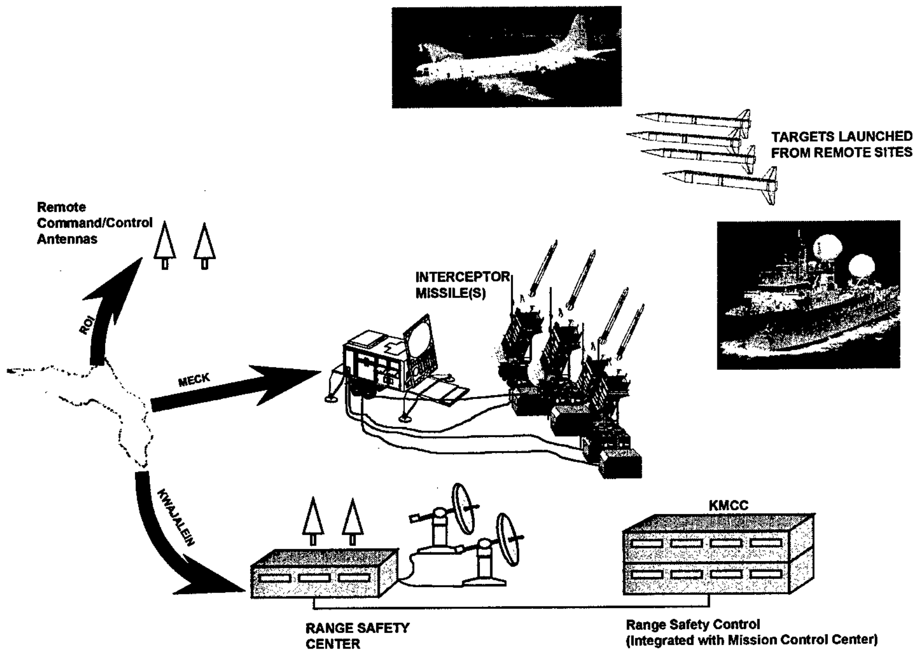


Figure 9. MSE Operational Concept

e. Range Safety Modernization

Another aspect of the KMR modernization is upgrading the Range Safety system to accommodate Multiple Simultaneous Engagement (MSE) missions to be conducted at Kwajalein. The MSE system is being designed to provide safety coverage for up to 4-on-4 test scenarios (Fig. 9). The initial implementation will accommodate up to two interceptors launched against two targets launched from remote sites. Candidate targets are HERA and other threat representative vehicles, while potential interceptors are THAAD, PAC2, PAC3, Hawk, and Navy Upper/Lower Tier defense components. There are a number of potential target or interceptor vehicle launch sites, including Meck and Roi Islands on Kwajalein Atoll, Wake I. and Aur Atoll.

The MSE system is being designed to achieve an overall command control/destruct (CC/CD) reliability of 0.999. The new system achieves its reliability by using a new, fully redundant, architecture. Flight termination is handled via tone modulation of the transmitted destruct signal. Multiple missiles each have a unique tone sequence, and all sequences can modulate the carrier simultaneously. A separate antenna/ transmitter channel for each missile in the air is not needed if omnidirectional, rather than high-gain antennas, are used. This also eliminates the pointing uncertainty of the latter from the reliability budget. In addition, by employing antennas at different locations, for example, Roi-Namur and Kwajalein, the effect of signal attenuation through the rocket plume, which is worst at rear-aspect viewing, is minimized. Finally, the range safety high-gain antennas are still available as additional back-up.

Range safety for the remote target launch will be covered by a combination of the shipborne Kwajalein Mobile Range Safety System (KMRSS), transportable ground equipment, and modified P-3 aircraft.

KMR SUPPORT FOR BMDO TESTING

When the modernization of KMR's instrumentation is complete, the Range will be better positioned to satisfy likely test requirements well into the 21st Century. There will be continuing need to adapt to evolving user needs. The major technical benefits of modernization to the customers of KMR are improved sensor capability, flexibility in specifying and satisfying test needs, and more timely data reduction. With the highly modularized radar architecture it will be far easier to implement system changes. For example, in the radars, it will be possible to change waveforms, PRFs, integration times etc., by simple parameter changes in the RTP or in an intelligent subsystem.

Analysis Assumptions:

- **Differential triangulation solution**
- **Both targets within beam/FOV and recording window**
- **Intercept Altitude = 10 km**

Sensor Configuration		
	Differential Measurement Error	
Sensor	**Range (m)**	**Angle (µrad)**
MMW WB	**0.2**	**15**
ALCOR WB	**0.4**	**105**
RADOTs	**–**	**7**
Super RADOTs	**–**	**7**

WB = Wideband Waveform

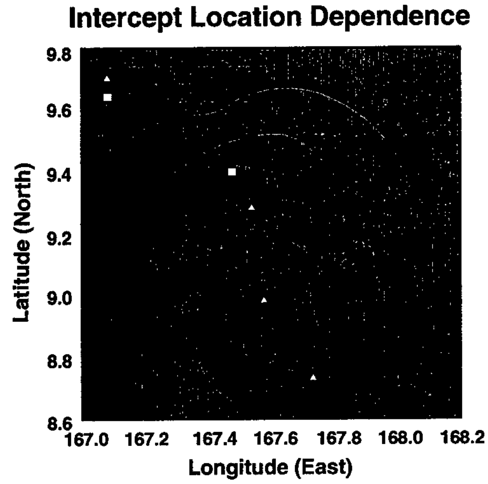


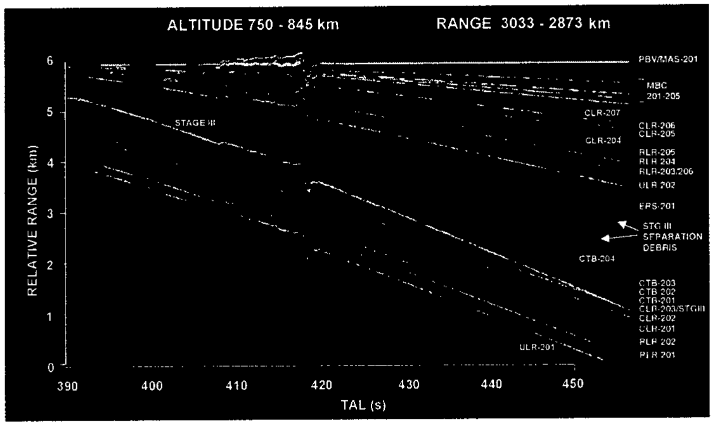
Figure 10. Estimation of Interceptor Miss Distance

The instrumentation is being upgraded in areas where the perceived benefit is high when weighed against the investment. One example, mentioned earlier, is the addition of high-speed visible and MWIR CCD cameras for improved hit-point/miss distance measurements. These new cameras yield improved sensitivity and provide multiple frames with both the interceptor and target vehicle simultaneously in the field of view. Thus, relative closing distance versus time can be obtained quite precisely, within the pixel resolution of the camera.

Figure 10 shows a plot of interceptor miss distance based on a differential triangulation covariance analysis that incorporates both optical and radar measurements. The assumed target vehicle launch point was on Aur Atoll, and the intercept was a head-on engagement at 10km altitude centered on Kwajalein Lagoon. The conclusion is that miss distance can be determined to an accuracy of about 10cm with the assumed geometry and array of instruments. For intercepts away from the atoll, transportable sensors would have to be located at additional, remote sites.

The new architecture of the signature radars encompasses a significant degree of built-in automation. As a consequence of automation, tasks that are presently performed manually will dramatically change the way missions are conducted and result in being able to handle more complex tasking. For example, object identification currently relies on a radar operator to make a decision. In the future, this will be semi-automated in a two-step process; classification (object type e.g., re-entry vehicle or decoy) performed at the radar, followed by identification (RV1, RV2, decoy1, decoy2 etc.). The latter is performed in KMCC, where data fusion and creation of target track files is handled.

Figure 11 is illustrative of the complexity of mission payloads likely to be seen in the future, particularly in NMD missions. Such a large number of objects might be deployed, for example, in tests involving seeker Target Object Map and discrimination experiments. The Figure shows a TRADEX Radar range-time intensity (RTI) plot, taken from the MDT mission, which employed a similar target complex. Almost thirty objects are visible in the radar beam. Rapid identification would be required if individual tracks were required on many of these objects. Further, if the object deployment were non-nominal it may be almost impossible for an operator to manually identify the objects of interest. The modernized radars will be able to lift much of this burden from the operator.



PBV = Post-Boost Vehicle
MAS = MSX Aeroshell
MBC = Multi-Balloon Cannister
CLR = Cannisterized Light Replica
RLR = Rigid Light Replica
ULR = Ultra Light Replica
ERS = Emissive Reference Sphere
CTB = Cannisterized Traffic Balloon

Figure 11. TRADEX Range-Time-Intensity Plot From the MDT (MSX Dedicated Test) Mission

KMR's remote location and the absence of broad population areas make it ideally suited for "Family of System" testing in which multi-layer defense elements participate. With the completion of modernization, KMR's simulation capability will provide realistic target scenes using high fidelity target models that are compliant with the DoD Higher Level Architecture (HLA) standards. The simulation system will allow the fusing of simulated data with measured data, which can be used by other systems that are brought to KMR for User Object Experiment System (UOES) tests. As portrayed in Figure 12, with the completion of the upgrades at KMR, the capability will exist to relay data in real time via satellite to battlefield simulation facilities in CONUS, or alternatively, recorded data can be used to drive simulation nodes.

SUMMARY

This paper has described the main features of the KMR Modernization and Remoting program. The commonality and maintainability of the radar, telemetry, and optical instrumentation systems achieved from KMAR will permit containment of KMR costs in the current and anticipated future austere budget environment. Although motivated from the point of view of achieving a dramatic reduction in the cost of operating and maintaining the Range sensors, the modernization is bringing major benefits to the user community. The modern systems will have much greater flexibility to respond to new requirements, and the new architecture and new instrumentation have been specifically tailored to satisfy TMD and NMD testing needs.

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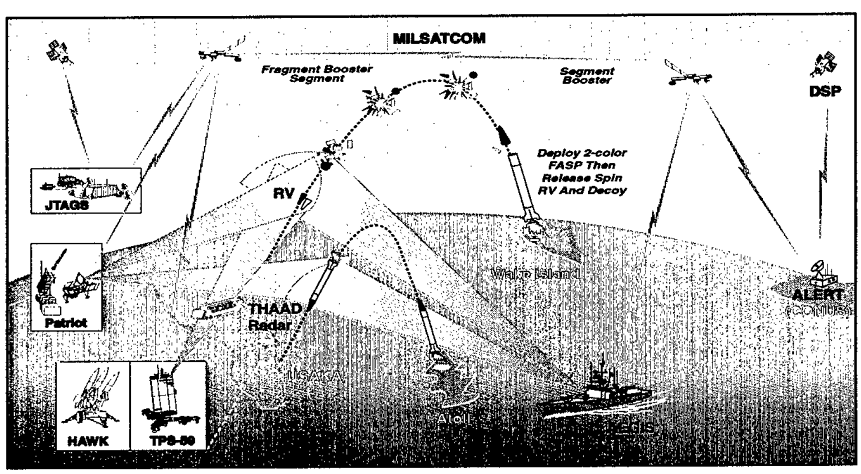

Figure 12. Planned KMR Testing; from BMDO System Integration Test (SIT) 2000 Program Introduction, April 1998