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**Independent Review of
TRW Discrimination Techniques
Final Report**

(Title UNCLASSIFIED)

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EXECUTIVE SUMMARY

[U] The exoatmospheric kill vehicle (EKV) is the most technically challenging aspect of National Missile Defense (NMD) development. The EKV must acquire and track the target complex, discriminate and select the reentry vehicle (RV), maneuver to the RV, and kill it by kinetic impact. Target discrimination and selection must be done with or without handover information about the target from the rest of the NMD system.

[U] TRW has developed an onboard autonomous discrimination architecture and a set of algorithms for the Boeing EKV. These algorithms have been evaluated against threats described in the *Technical Requirements Document* (TRD) using simulated data, as well as against the target suite flown on integrated flight test IFT-1A using data collected by the Boeing EKV. During the past two years, various technical concerns have been raised regarding the concept, implementation, and performance of TRW's discrimination baseline algorithms (BLA).

[U] Recently a POET team was tasked by BMDO JN/I to conduct an independent review of TRW's baseline discrimination techniques. With cooperation from the Ground-Based Interceptor Program Office (GBI PO), TRW, NRC, and DCIS, the POET team has completed three major tasks: (1) a review of the scientific, mathematical, and engineering principles of TRW's BLA; (2) a review of the BLA's performance against the IFT-1A data as reported by TRW to the Government; and (3) a determination of the projected performance of the BLA against possible IFT-3 scenarios.

[U] In fulfillment of the first task, the POET team reviewed the concept, design, implementation, and operational performance analyses of the BLA, primarily by studying technical documents provided by TRW, JN/I, the GBI PO, and DCIS. The POET team's major findings may be summarized as follows:

[U] 1. Overall, the BLA are well designed and work properly, with only some refinement or redesign required to increase the robustness of the overall discrimination function. (Specific comments on redesign are listed in items 2 and 3 below; items 4 and 5 pertain to robustness).

[U] 2. The gap-filling algorithm (GFA), which was designed to fill data gaps induced by low signal-to-noise ratio (SNR) signals early in the engagement timeline, has not yet been demonstrated to be effective. Its use may actually hurt rather than help with baseline discrimination, as demonstrated in the IFT-1A postmission data analyses.

[U] 3. Among the eight features included in the BLA, only a few can be used in combination for the discrimination function. Because they are derived from only two independent radiant-intensity sequences as measured by the EKV sensor, the eight

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features are highly correlated. One of the consequences of this particular design is that the covariance matrices of certain feature subsets may become noninvertible.

- [U] 4. The performance of the discrimination architecture may be fragile. Training data sets that closely match actual threats are crucial to the performance of the multimodal Bayesian quadratic classifier (MBQC) for the fine (i.e., precision) discrimination function. Performance may degrade significantly if incorrect prior knowledge regarding target signatures is used in the classifier database. The target signatures are heavily influenced by threat type, target characteristics, sensor-to-target geometry, and engagement timeline. Therefore, unexpected targets in the threat may challenge the performance of the MBQC. It would be desirable to expand the current discrimination architecture to make it more robust by including, for example, real-time adaptation capability and certain threat-type-based system-level discrimination.

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- [U] 6. The target to be intercepted is selected on the basis of an "importance" measure, which is an ad hoc combination of two different methods of inference. One of the inputs, the probability of being a lethal target (P_{AT}), is defined within the probability theory, yet its combination with another input (an ad hoc "confidence" factor) for the "importance" calculation is done using fuzzy logic. As a result, it is impossible to calculate the probability of selection (P_{select}) analytically, and Monte Carlo simulation becomes the only way for statistical evaluation of the discrimination performance.

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[U] In fulfillment of the second task, the POET team investigated the purported discrepancies among TRW's IFT-1A data analysis reports and analyzed flight-test data in order to validate important algorithms and to check on the accuracy of key discrimination results reported by TRW. The POET's results may be summarized as follows:

- [U] 1. The discrepancies in feature ellipses among the 45-day, 60-day, and revised 60-day reports result from the fact that in the 60-day report the size of the ellipses was mislabeled and for the 45-day report an improperly constituted GFA was used. Further, the POET team determined that TRW's decision to turn off the GFA for the IFT-3 mission was technically justified.

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[U] 3. Outputs of the important discrimination algorithms reported by TRW have been verified. The fading memory filter was properly designed and tuned, the features were correctly extracted, and the classifier database included in the mission data load (MDL) was consistent with the reported feature ellipses.

[U] 5. The Kalman filter that was originally developed by TRW to provide enhanced discrimination features (but was later removed) could be tuned to perform properly for the IFT-1A MRV data and a set of noisy simulated data. But a robust procedure for filter initialization must be developed to make this a generally useful algorithm.

[U] In fulfillment of the third task (which was to be performed if time permitted), the POET team predicted the performance of the BLA against IFT-3 scenarios based on experience gained from IFT-1A. According to the GBI PO, five target suite options are currently under consideration for IFT-3. The most stressing target suite for EKV discrimination contains the same ten targets as those deployed in IFT-1A: an MRV, a multiple service launch system (MSLS), and eight penails. Regardless of which target suite is selected, signature data collected on the IFT-1A targets will be extremely useful for constructing a representative MDL classifier database for IFT-3. If targets are deployed nominally in IFT-3, it is the POET team's assessment that the TRW BLA will successfully select the MRV as the intercept target, even for the most stressing target suite.

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[U] The issue has been raised that TRW's discrimination concept and its implementation will not and cannot function to meet the TRD requirements. At the request of Mr. Keith Englander (JN/I), the POET team has made point-by-point responses to the issues raised in a 16-page document authored by DCIS. Those responses are included in Appendix B of this report. Overall, the issues raised serve to emphasize that discrimination is a highly complex and difficult function. Though it is not the intention of the POET team to interpret the TRD requirements, it sees no evidence that suggests any obvious noncompliance with the TRD.

[U] One of the most important criticisms raised by DCIS is that during the IFT-1A postmission analyses TRW unjustifiably shifted the preflight feature distribution ellipses between the 45-day report and the 60-day report in order to increase the BLA's discrimination performance. As previously noted, TRW's explanation that an improperly constituted GFA caused the discrepancies appears to be correct. The decision not to use the GFA for IFT-3 also seems reasonable. Another important issue concerns the "improper" concept of ranking probability used by TRW for selecting an intercept target. It is clear to the POET team that all points raised concerning this issue were based on misunderstanding of Bayes rule and misinterpretation of TRW's approach.

[U] It is a legitimate concern that the robustness of the BLA's discrimination function could be compromised by the assumption that threat-typing information would be available for use in the MDL database and that target characteristics, motion parameters, and engagement geometry would be known for a given threat system. **Reliable prior knowledge on many of the threat types included in the TRD cannot be obtained.** The POET study did not evaluate to what extent the BLA may be used to meet the general requirements described in the TRD beyond the ability to determine which object among a threat cloud is lethal (given that the threat type is known). However, the POET team's concerns regarding the potential lack of robustness of the current BLA have been indicated earlier. The POET team also recognizes that the concept of threat typing can have significant impact on EKV discrimination performance and that such impact should be examined carefully in the context of overall NMD architecture design and threat assessment. Within the EKV scenario it may be important to structure the discrimination architecture to take advantage of threat-typing information while at the same time reducing potential risk.

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