Quantitative Evaluation of Aircraft Impact Probability on TRR-1/M1 Research Reactor

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EXTENDED ABSTRACT

Abstract

This paper presents a comprehensive assessment of external accident risks to the Thailand Research Reactor-1/Modification 1 (TRR-1/M1) research reactor, with specific focus on aircraft crash scenarios. The study evaluates the probability of critical reactor core damage due to direct and indirect aircraft impacts, utilizing Thailand's national air traffic statistics, aircraft categorization, flight maneuver patterns, and structural penetration modeling. The total annual probability of reactor core damage resulting from an aircraft crash was determined to be 6.12×10^{-8}, which is well below the IAEA-defined threshold of 1.0×10^{-7} per reactor-year. This classifies the event as "incredible" and confirms that TRR-1/M1 meets international safety criteria for external hazards. The analysis underscores the reactor's structural robustness and contributes to the risk-informed safety case in support of continued reactor operations.

1. Introduction

Nuclear facilities must undergo rigorous safety assessments for both internal and external initiating events. For the TRR-1/M1 research reactor located in Thailand, potential external hazards were systematically reviewed. No industrial, transportation, or military facilities exist in the vicinity that would credibly lead to an accident resulting in radiological release exceeding IAEA safety limits. The only credible external initiating event identified is an aircraft crash because the TRR-1/M1 is located close to the international airport. While extremely rare, the consequences of a direct or indirect aircraft impact on a nuclear facility necessitate quantitative risk evaluation.

2. Methodology

2.1 Scope and Assumptions

The total probability of aircraft crash related to core damage, P, per year will lead to critical reactor damage is essentially the summation of three probabilities:

$$P = P_c + P_{p/c} + P_{d/p} \qquad (1)$$

where:

P_c :	Probability of aircraft crash on the reactor building
$P_{p/c}$:	Probability of core damage due to a missile generated from a collision within gas tight room
$P_{d/p}$:	Probability of damage to the core when aircraft crash directly into the pool opening

Equation (1) is derived from standard probabilistic risk decomposition principles applied in PSA, where the total event probability is represented as the sum of mutually exclusive damage pathways [1, 2]. These probabilities are assumed to be independent due to mutually exclusive damage mechanisms: P_c represents direct building impact, Pp/c involves internal missile effects, and Pd/p involves precise pool strikes.

2.2 Aircraft Movement Data and Classification

Aircraft movement data were obtained from the Airports of Thailand (AOT) for the period 2000–2020 [3]. Aircraft were categorized as Civil Aviation (International and Domestic) and State and Military Aircraft. Flight maneuvers considered include takeoff, landing, and closed traffic patterns. The Don Mueang International Airport (DMK), near the TRR-1/M1 research reactor, showed significant growth, contributing most of the low-cost airline traffic.

2.3 Probability Calculations

The probability of aircraft crash on the reactor building (P_c) is the product of three factors including the number of aircraft movements, the accident probability per aircraft movement per unit area and the effective area of the target of interest.

$$P_c = \Sigma_i \Sigma_j \Sigma_k (N_{ijk} C_{ijk} A_{ijk}) \quad (2)$$

where N_{ijk} is the number of annual movements of type j for aircraft type i in flight pattern k
C_{ijk} is the crash probability per movement of type j for aircraft type i in flight pattern k
A_{ijk} is effective target area associated with the structure of interest for aircraft type i in movements of type j and in-flight pattern k.

The base dimension of the reactor building for the effective target area is 1307.94 m^2. The effective area does not include the control rod drive and the crane above the reactor core. The conditional probability of penetration through 1.5 ft reinforced concrete by aircraft weight more than 12,500 lb was estimated at 0.045 per crash. The conditional probability of 0.045 was based on impact analysis using empirical aircraft crash data from reinforced concrete structures [4]. The value 2.18×10^{-9} was derived using shielding configuration and structural layout probability modeling [2]. Surrounding structures prevent lateral missile intrusion; thus, only direct hits are considered credible for penetration.

3. Results and Analysis

The probability of damage to the reactor core due to a missile generated from a collision with the crane is 2.18×10^{-9} per year. The probability of damage to the reactor core when a plane crash directly onto the pool opening is 1.37×10^{-8} per year. Thus, the total probability of airplane crashes related core damage of TRR-1/M1 is 6.12×10^{-8} per year. This value is considerably less than 10^{-7}, the threshold value for the significant risk contributor. This probability is significantly below the safety threshold of 1.0×10^{-7} per year, as identified by IAEA and referenced reactor studies below which external events are considered non-significant risk contributors.

4. Discussion

The aircraft movement trends in Thailand show a strong increase, particularly in low-cost civil aviation since the reopening of Don Mueang Airport. Despite increased flight volume, the reactor's design and surrounding infrastructure significantly mitigate risk. The probabilistic safety assessment (PSA) shows a high degree of conservatism, accounting for structural resistance and shielding of critical components. Moreover, missile generation from surrounding impacts is effectively ruled out by the reactor's spatial arrangement, and the probability of a direct strike on the small pool opening is extremely low. The total core damage probability due to aircraft crash is not only below regulatory thresholds but also aligns with international best practices in external event hazard screening.

5. Conclusion

The aircraft crash risk assessment for TRR-1/M1 confirms the event as an "incredible accident scenario," with a total probability of core damage of 6.12×10-8 per year. This value is well below IAEA's limit for significant risk contributors and supports continued reactor operations without additional design changes. The results highlight the effectiveness of reactor siting, structural integrity, and hazard mitigation strategies in ensuring public and environmental safety. The term 'incredible' follows IAEA SSR-3 criteria for probabilities below 10^{-7} per reactor-year. Further investigation could involve a more detailed structural vulnerability analysis using finite element impact simulations for both conventional and emerging aircraft types, including unmanned aerial vehicles (UAVs). Additionally, the probabilistic model could be expanded to incorporate dynamic air traffic projections and seasonal variations in flight density to refine risk estimates. Consideration of secondary effects such as post-

impact fire, fuel dispersion, or cascading failures in auxiliary systems could also be included to broaden the risk assessment scope. Finally, comparative analyses with international benchmark cases or validation through Monte Carlo simulation could strengthen confidence in the results and support safety case documentation for long-term research reactor licensing.

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