189

Global patterns and drivers of unplanned nuclear reactor outages

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Extended Abstract

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Abstract Summary

Nuclear power is expected to play a growing role in low-carbon electricity systems due to its ability to provide stable and dispatchable generation. However, its reliability is often assessed using average capacity factors, which overlook an important source of operational uncertainty: unplanned reactor outages. This study provides a global empirical analysis of unplanned nuclear outages, examining their magnitude, drivers, and implications for future nuclear deployment.

Using data from 541 reactors across 33 countries over the period 2003–2023, we analyze annual unplanned outage hours through descriptive statistics and panel regression methods. We examine how outage performance varies across reactor characteristics, management practices, and broader sociotechnical contexts, including cumulative industry experience and ongoing construction activity.

Our results show that unplanned outages are a persistent but highly uneven feature of nuclear power operation. The average reactor experiences approximately 344 hours of unplanned outages annually, with a strongly skewed distribution in which a significant share of reactors experience substantially higher downtime. Equipment failures account for the majority of outages. Larger reactors tend to experience longer outages, while performance improves during early years of operation due to learning effects. Preventive maintenance, proxied by planned outage duration, is associated with reduced unplanned outages, and state-owned reactors exhibit lower outage levels than privately operated ones.

Importantly, national context plays a critical role. Countries with greater cumulative operational experience and continuous construction activity tend to achieve better reliability outcomes, while first-of-a-kind reactor deployments are associated with higher outage risks.

Overall, the findings suggest that nuclear reliability is not solely a function of reactor technology, but a product of sociotechnical systems. Effective nuclear deployment

therefore requires not only investment in physical infrastructure, but also in institutional capacity, maintenance practices, and industry-wide learning.