

Consideration of the Single Failure Criterion to the Closing Function of Check Valves in Research Reactors

Suki Park^{a*}, Dongwook Jang^a, Donghyun Kim^a, Wooseok Jo^a, Cheol Park^a, Jong-Pil Park^a

^aKorea Atomic Energy Research Institute, 111, Daedeok-Daero 989 Beon-Gil, Yuseong-Gu, Daejeon, 34057, Korea

*Corresponding author: skpark@kaeri.re.kr

***Keywords:** single failure criterion, check valve, research reactor, loss of coolant event, loss of coolant flow event

1. Introduction

Unlike commercial nuclear power plants (NPPs), research reactors frequently employ simple check valves within their Primary Coolant Systems (PCS). Typically, the PCS consists of two or more redundant trains. Check valves situated downstream of the primary pumps serve a critical safety function: maintaining core cooling flow by preventing reverse flow in the event of a pump failure or a piping breach. If a pipe break exceeds a critical size and the check valve fails to close, severe core damage may ensue, depending on the timing and magnitude of the breach.

A significant regulatory challenge exists regarding the classification of check valve failures. The failure of a check valve to move to its intended position is not consistently defined as either an active or passive failure across different standards. For instance, ANSI/ANS-58.9 classifies the failure of a check valve to change position as an active failure [1]. Conversely, SECY-77-439 asserts that the failure of a simple check valve to move to its required position upon demand should be considered a passive failure [2].

Furthermore, IAEA Safety Series No. 50-P-1 indicates that some Member States treat self-operating components, such as check valves, as active components if their state changes during an event sequence following an initiating event. The series suggests that a conservative approach is to assume check valve failure within the Single Failure Analysis (SFA) [3].

Consequently, the application of the Single Failure Criterion (SFC) to the safety-related closing function of check valves poses substantial challenges to both reactor designers and regulatory reviewers. This study evaluates the appropriateness of applying the SFC to the closing function of check valves located downstream of primary coolant pumps in research reactors.

2. Required Functions of the Check Valves

Research reactors typically comprise a reactor pool, a Primary Cooling System (PCS), a Secondary Cooling System (SCS), and various auxiliary fluid systems. The PCS is generally designed with two or more trains. As shown in Figure 1, each train incorporates a Primary Cooling Pump (PCP), a Heat Exchanger (HX), Flap Valves (FVs), Siphon Break Valves (SBVs), and Check

Valves (CVs). The CVs are positioned downstream of the PCPs.

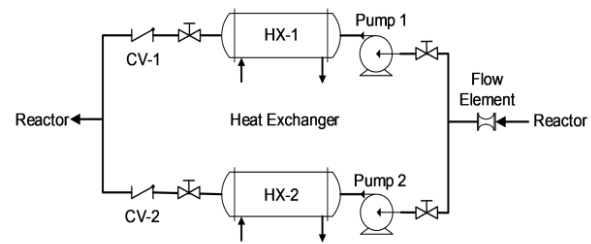


Fig. 1. Simplified Configuration of the PCS

During normal power operation, the reactor core is cooled by forced convection. Upon a loss of forced flow, cooling is maintained through inertial flow followed by natural convection facilitated by the flap valves.

The primary safety function of the check valves is to prevent flow reversal when a backward differential pressure is applied. If a check valve fails to close following a pump failure or an upstream piping breach, a significant portion of the coolant flow from the intact pump would bypass the reactor core. This flow bypass redirects coolant to the damaged train or the site of the pipe break. Such a reduction in core flow, if it falls below the safety limit, could lead to fuel damage even after a reactor trip.

Consequently, the reliable closure of these check valves is a critical safety-related function. However, it should be noted that a minor amount of leakage through the valve seat is often permissible, provided that a sufficient flow rate is maintained through the core to effectively remove decay heat.

3. Consideration of the Application of the Single Failure Criterion to the Check Valves

3.1 Review on the Regulations and SECY Reports

The Nuclear Regulatory Commission (NRC) governs the SFC primarily through 10 CFR Part 50, Appendix A. The single failure means an occurrence which results in the loss of capability of a component to perform its intended safety functions. Multiple failures resulting from a single occurrence are considered to be a single failure. Fluid and electric systems are considered to be designed against an assumed single failure if neither (1) a single failure of any active component (assuming passive components function properly) nor (2) a single

failure of a passive component (assuming active components function properly) results in a loss of the capability of the system to perform its safety functions.

10 CFR Part 50, Appendix K requires the SFC: An analysis of possible failure modes of ECCS equipment and their effects on ECCS performance must be made. In carrying out the accident evaluation, the combination of ECCS subsystems assumed to be operative shall be those available after the most damaging single failure of ECCS equipment has taken place.

SECY-77-439 report [2] provides guidelines for applying the SFC to fluid systems important to safety. They depend heavily on whether the failure is “active” or “passive.” By SECY-77-439 report, an active failure in a fluid system means the failure of a component which relies on mechanical movement for its operation to complete its intended function on demand, or unintended movement the component. A passive failure in a fluid system means a breach in the fluid pressure boundary or a mechanical failure which adversely affects a flow path. Examples of the active failure include the failure of a motor-operated or air-operated valve to move or assume its correct position on demand, spurious opening or closing of a motor- or air-operated valve, or the failure of a pump to start or to stop on demand. On the other hand, examples of the passive failure include *the failure of a simple check valve to move to its correct position when required*, the leakage of fluid from failed components such as pipes and valves, particularly through a failed seal at a valve or pump or line blockage. SECY-77-439 report states that in the study of passive failures it is current practice to assume fluid leakage owing to gross failure of a pump or valve seal during the long-term cooling mode following a LOCA (24 hours or greater after the event) but not pipe breaks. No other passive failures are required to be assumed because it is judged that compounding of probabilities associated with other types of passive failures, following the pipe break associated with a LOCA, results in probabilities sufficiently small that they can be reasonably discounted without substantially affecting overall systems reliability. Even though a certain passive valve failure such as dropping of a valve disc had occurred, SECY-77-439 concluded that changes in safety criteria are not warranted at that time.

Meanwhile, SECY-94-084 report[4] describes that in passive systems, the failure of a check valve is considered as an active component subject to the SFC. However, this does not apply of the valve exhibits reliability comparable to that of passive components. Nevertheless, SECY-94-084 mentions that for current plants the NRC staff normally treats check valves, except for those in containment isolation systems, as passive devices during transients or design-basis accidents. Therefore, the staff would not consider the failure of a check valve to be a single active failure.

3.2 Failure Rates of Pipes and Check Valves

According to references widely cited in Probabilistic Safety Assessments (PSAs) for NPPs, piping failure rates depend on factors such as pipe classification (e.g., high-energy or medium-energy), pipe diameter, and total system length. For research reactors, the piping failure rate is significantly lower than that of commercial NPPs, primarily due to the less demanding operating conditions characterized by low pressure and temperature.

For a standard swing check valve in a standby safety system - such as the Emergency Core Cooling System (ECCS) or Auxiliary Feedwater (AFW) - the probability of a fail-to-close (FTC) event is estimated at 1.04×10^{-4} per demand, according to Generic LWR data (NUREG/CR-6928) [5]. Alternatively, IAEA-TECDOC-1922 indicates a failure-to-close probability of 5.79×10^{-4} per demand for check valves [6].

3.3 Reliability Enhancement through Periodic Testing

According to NRC Regulatory Guide 1.22, periodic testing may serve as an alternative to component redundancy if the test interval is sufficiently frequent to ensure high availability.

In research reactors, the operability of check valves—specifically their ability to transition between open and closed states—is verified during each operational cycle. The proper closure of these valves is validated by sequentially starting and stopping the pumps in an alternating manner while monitoring key parameters such as flow rate, differential pressure across the valve, or upstream pressure. Any failure of a check valve to seat properly during these pump transients would result in anomalous readings, which are immediately detectable by the operators. Given that the typical operational cycle for a research reactor is approximately one month, the high frequency of these tests ensures a high level of functional reliability.

4. Conclusions

In conclusion, the exemption of the Single Failure Criterion (SFC) for check valves installed in the primary coolant system of research reactors is proposed based on the following justifications:

- SECY-77-439 classifies the failure of simple check valves to move to their required position as a passive failure, rather than an active one.
- The failure rate for check valve closure is approximately 10^{-4} per demand, which is sufficiently low to ensure safety. Furthermore, the structural failure of piping in research reactors is considered a highly improbable event.
- The functional integrity and closing capability of these check valves can be rigorously verified during each reactor operational cycle by monitoring flow rates and pressure differentials.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Science and ICT (MSIT) of the Republic of Korea (Grant No. RS-2025-02313658).

REFERENCES

- [1] ANSI/ANS-58.9, Single Failure Criteria for Light Water Reactor Safety-Related Fluid Systems, 1981.
- [2] NRC, Single Failure Criterion, SECY-77-439, 1977.
- [3] IAEA Safety Series No. 50-P-I, Application of the Single Failure Criterion, 1990.
- [4] NRC, Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs, SECY-94-084, 1994
- [5] Eide, S. A., Wierman , T.E., Gentillon , C. D., Rasmuson , D. M., Atwood , C.L., Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants, NUREG/CR-6928, 2007.
- [6] Baron, J. et.al., Reliability Data for Research Reactor Probabilistic Safety Assessment, IAEA-TECDOC-1922, 2020.