**Background**

Recent industry events have highlighted the importance of understanding, controlling and mitigating the effects of hydrogen (H$_2$) generation under accident conditions. The ability to control and mitigate H$_2$ generation, first and foremost, protects the health and safety of the public and plant personnel; it also preserves the nuclear asset.

In a severe accident or a beyond-design-basis accident (BDBA), the reaction of water with zirconium alloy fuel cladding, radiolysis of water, molten corium-concrete interaction (MCCI) and post-accident corrosion can generate H$_2$. The total mass of H$_2$ produced in-vessel depends on several factors; for most reactors, it is approximately 1,000 kilograms. High peak rates of up to several kg/s for release to containment can result from sporadic releases from the reactor pressure vessel. If this leads to the detonation of H$_2$, personnel and public safety are threatened and various structures can be damaged, including containment and spent fuel buildings. To avoid this risk, passive autocatalytic recombiners (PARs) can be implemented in various reactor designs.

**Description**

H$_2$ control is a complex problem, and without an integrated approach, the solution can be expensive and time-consuming. Westinghouse provides streamlined technical solutions designed to fit plant-specific needs.

**H$_2$ Generation and Distribution Analysis**

Westinghouse performs analyses to define the quantity, transport and distribution of H$_2$ to identify locations requiring new and/or updated H$_2$ mitigation hardware.

- A large number of simulations are performed using global analysis tools to determine the H$_2$ generation source code. Integral codes such as the MELCOR code or the MAAP code form the basis for these analyses and are used to identify the accident scenarios that reflect the greatest threats to the containment or spent fuel buildings.

- The next step consists of using global analysis tools to define H$_2$ distribution and transport by performing detailed calculations with specialized codes used to characterize H$_2$ distribution and transport, such as the MAAP code, GASFLOW code or FATE™ code.

- The last step in the analyses is to determine the optimum PAR configuration, with respect to the number, size and location of the PARs, for mitigation of H$_2$ risks.

**H$_2$ Management System Design**

Westinghouse evaluates and selects hardware options for increased H$_2$ control and monitoring, including the appropriate PARs.

- PARs come with various H$_2$ depletion rates, footprint sizes, and exhaust heights and forms. This supports integration into existing plants and optimization of the overall concept.

- Non-passive equipment, such as igniters, can also be used in an integrated H$_2$ control system.

- H$_2$ monitoring can be incorporated into an integrated H$_2$ control system.

**H$_2$ Mitigation and Monitoring Hardware**

Westinghouse performs the engineering – including creating the design change package (DCP) – licensing, procurement and installation of a new and/or upgraded hardware solution.

Westinghouse manufactures and installs H$_2$ control equipment in cooperation with experienced partners. Westinghouse offers a complete customer-specific package:

- Choice of a specific equipment configuration
- Licensing/DCP support
- Delivery and installation of the equipment
Procedure and Guideline Upgrades
Westinghouse will create and/or update existing procedures and guidelines as appropriate.

Westinghouse will:
- Evaluate current procedures and guidelines for inclusion of \( \text{H}_2 \) control
- Identify and implement upgrades to existing procedures and guidelines (e.g., emergency operating procedures, emergency response guidelines and severe accident mitigation guidelines)

Benefits
The Westinghouse system offers demonstrated startup at the lowest levels of \( \text{H}_2 \) concentration in the industry. By initiating earlier, the Westinghouse system provides the operators and safety systems more time to respond to the accident conditions before the point of flammability is reached. In addition, our housing design is optimized to achieve maximum flow rates to promote atmosphere mixing.

The PAR offered by Westinghouse is certified by the U.S. Nuclear Regulatory Commission for power plants in the United States. Westinghouse offers:
- Global technology resources to meet customer and regulatory needs on a local basis:
  - Little-to-zero maintenance costs throughout the life of the equipment
  - Testing of multiple cartridges to expedite required tests, shortening work time during outages
  - Depletion rates designed to protect against approaching the point of flammability
  - Elimination of all containment penetrations associated with \( \text{H}_2 \) control, thus eliminating penetration testing
- Proven experience in \( \text{H}_2 \) control and mitigation
- Graded approach using integrated solutions covering analysis, procedure and hardware options to provide cost savings
- Completely passive equipment (e.g., PARs) can be used:
  - High reliability (no power source is necessary)
  - Robust with respect to atmospheric conditions or mechanical (seismic) loads (no moving parts)
  - Simple to install and maintain
  - Solution for control of \( \text{H}_2 \) generated by radiolysis effects even in inert boiling water reactor (BWR) containments
- Application for design basis accident (DBA) and BDBA (replace active systems for \( \text{H}_2 \) mitigation for DBA)
- Can be installed in wet-fuel assembly storage pools and in used-fuel areas

Experience
Westinghouse and its partners have proven experience in \( \text{H}_2 \) control and mitigation and offer integrated solutions for utilities that desire to simplify hardware, design, analysis, procedures and installation procurement for \( \text{H}_2 \) control solutions for the following:
- Large dry containments
- Ice condenser containments
- Replacement of thermal recombiner systems to minimize in-service testing in the United States
- BWR containments in the United States and Japan
- BWRs and pressurized water reactors (PWRs) in Germany
- PWRs in South Africa, South America and Europe
- Voda-Voda Energo Reactor containments
- New plant designs (AP1000® PWRs and advanced BWRs)

The operational experience of approximately 20 years for PAR systems in several plants has proven the high reliability and low maintenance of the equipment.

The PARs used by Westinghouse have successfully participated in numerous international test programs for qualification, for example:
- Nuclear Instrumentation System PAR qualification for the U.S. Nuclear Regulatory Commission at Sandia National Laboratory in the United States
- Electric Power Research Institute/EDF test in the KALI-H\(_2\)-test facility of the CEA Cadarache facility in France
- EDF/IRSN test PHEBUS-FPT3 in the Cadarache facility in France
- OECD test in the THAI-test facility in Frankfurt, Germany

Additionally, PAR systems have been installed in wet-fuel assembly storages and used-fuel transportation caskets for the control of \( \text{H}_2 \).
- Westinghouse is the leader in software analysis for \( \text{H}_2 \) generation and transport.
- Westinghouse has in-depth understanding of the MAAP and FATE codes and wrote the original code for each.