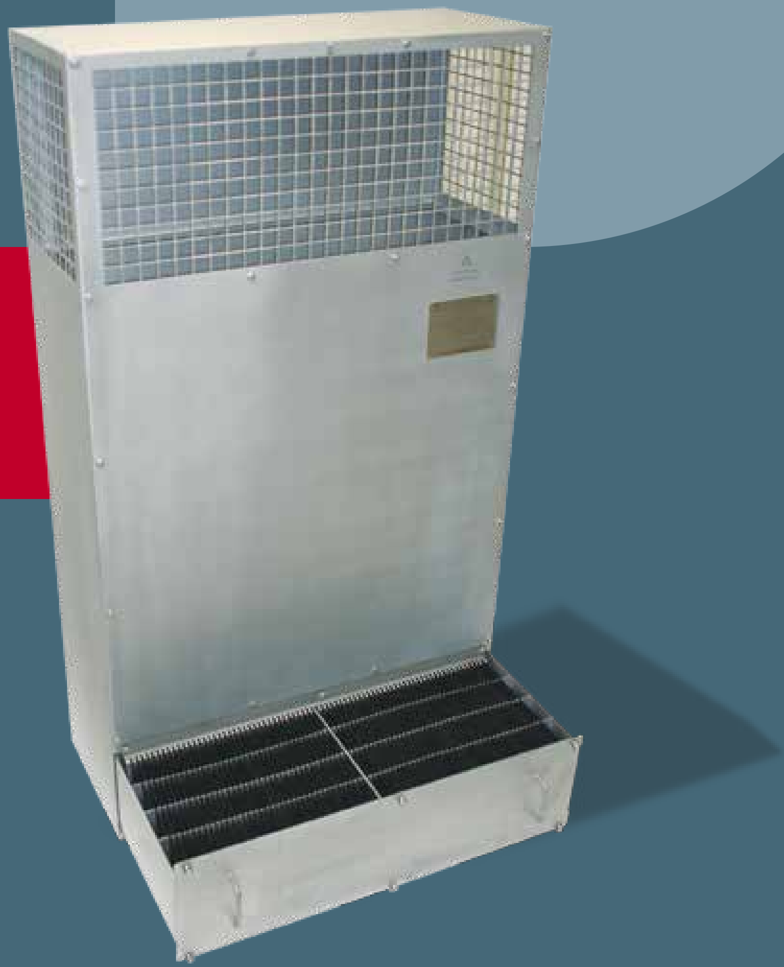
Passive Autocatalytic Recombiner



Hydrogen Control and Mitigation for Combustible Gas Control

AREVA
forward-looking energy

Passive Autocatalytic Recombiner (PAR)

Severe Accident-Qualified PAR for Combustible Gas Control

Passive safety systems play an important part in long-term accident mitigation. Their main benefit is that they require neither operator action nor power supply. In the event of severe accidents due to loss of coolant, large amounts of hydrogen might be released within the reactor containment, leading to a high concentration of explosive gas, which might ultimately affect the integrity of the containment.

Based on the principle of catalytic oxidization, AREVA has developed a hydrogen reduction system which is based on the AREVA Passive Autocatalytic Recombiner (PAR). With a gas treating capacity of up to 880 ft^3/min per PAR unit, the hydrogen concentration can be kept within certain limits even under severe accident conditions.

PAR Catalyst Design and Function

The catalyst design is based on thin stainless steel plates coated with multiple precious metals at a large reaction surface. It allows for low start temperatures and is very efficient in severe accident situations. To promote natural convection, the PAR has a metal housing with a gas inlet at the bottom and a lateral gas outlet at the top. The housing's horizontal cover protects the catalyst from direct spraying of water and aerosol deposition. The numerous parallel plates at the bottom are arranged vertically. An inspection drawer ensures quick access to the catalytic plates.

Upon contact with the catalyst in the lower part of the housing, the gas mixtures containing hydrogen are recombined. The heat from this reaction causes a reduction in gas density that leads to buoyancy-driven flow, thus supplying the catalyst with a large amount of hydrogen that ensures a highly-efficient recombination.

The dimensions of the recombiner and catalyst are well-balanced, allowing for a maximum rate of hydrogen recombination while keeping the size of the components and the number of necessary units as low as possible.

Highly Efficient and Reliable

The AREVA PAR combines high functional reliability with excellent hydrogen mitigation performance, while the investment remains low. Thanks to the thin plate technology and its high capacity, the AREVA PAR allows for an efficient mitigation of hydrogen-related risk within the containment.

Backed by decades of international experience and a constant exchange of information with our customers, we have gathered broad expertise in the design and installation of PAR systems including on-site activities such as inspection and regeneration services. This is why the AREVA PAR was selected for improving the safety of many existing NPPs. It is also the solution of choice for the latest generation of nuclear power plants: the EPR™ plant.

Operating Experience

To date, **AREVA has delivered and installed PAR-based H_2 control systems in more than 100 nuclear power plants in Europe, Asia and Africa,** including test equipment and, if required, with a regeneration mode. Excellent operating results were achieved even under adverse conditions such as oil fire or oil aerosols from the main coolant pump, boric acid or a significant high concentration of organic carbon-hydrogen compounds.

The AREVA PAR FR1-380T

Severe Accident-Qualified PAR

Improved plant safety with AREVA's high-capacity PAR with a gas treating capacity of up to 880 ft^3/min

Qualification and Functional Tests

The AREVA PAR has been subjected to extensive and long-term testing to evaluate its performance in various accident scenarios in both PWRs and BWRs.

Behavior under the Following Conditions

- Different pressures, temperatures, steam and hydrogen concentrations
- Exposure to catalytic poisons (I_2, CO, H_3BO_3, CH_3I), chemicals caused by thermal cable degradation, and aerosols from a molten core substitute
- Following hydrogen combustion, submergence in water, oil fire, cable fire (French / US-cable)
- Within in-spray water systems (French and Swedish / Korean PWR conditions)
- Low temperature, high humidity atmospheres (CANDU conditions)
- Low oxygen content
- With wetness during start-up; with direct water spray on the catalyst
- Under nitrogen pre-inerted atmosphere (e.g., U.S. BWR power plant conditions)
- After long-term recombination and deflagration
- In a severe accident atmosphere with a degraded core

Large Multi-Compartment Containment Geometries (Battelle Model Containment)

These tests verify hydrogen reduction by catalytic recombination in various ambient conditions:

- Recombination in a multi-compartment geometry with full scale FR1-1500T PAR
- Multi-recombiner tests with simultaneous operation of three PARs
- Experiments on the efficiency of hydrogen mitigation methods

Examinations for the AREVA PAR Qualification

The most important qualification test was performed during the PHEBUS FPT3 (Fission Product Test 3) in Cadarache (France) with participation of various authorities, research institutes and different PAR suppliers. Catalysts of various manufacturers were tested for the first time under real severe accident conditions with a degraded core.

Further testing included:

- Resistance to thermal aging
- Resistance to radiation (operational radiation, radiation following a core melt accident)
- Resistance against operational and seismic vibrations
- Resistance against flow caused by pressure differences following LOCA
- Ignition behavior, up to steam-inerted condition (> 55 vol- % steam)

AREVA PAR Qualification Program

Germany		
Karlstein	since 1989	Ongoing development and qualification
	1998	Absence of feedback of the PARs: Prevention of sump strainer clogging
	2002	CO_2 tests
	2006	TSP Spray Tests (Tri Sodium Phosphate)
Frankfurt	1991	Performance test in a multi-containment geometry (Battelle Model Containment)
	2008	OECD-THAI Hydrogen Recombiner Deflagration / Ignition test
France		
Cadarache	1995	EDF KALI H_2 tests qualification for 900 MW PWR French accident scenario
	1996 to 1998	– Integrated core melt tests - international PAR qualification testing – Full scale tests simulating inactive core melt conditions - IBSN / EDF H_2 PAR tests
	1998	– Pre-tests simulating inactive core melt conditions with catalysts of different suppliers – EDF/CEA KALI H_2 tests deflagration / degradation
	2004 to 2009	– Final active in-pile core melt test with catalysts of different suppliers (FBT3) – Test performance – Evaluation of results
	2009	– OECD CsI-iodine interaction and high aerosol concentration test (up to $3g/m^3$) – OECD-challenging poisoning severe accident atmospheric test – High concentration poisons SnO_2, $LiNO_3$, Iodide
U.S. / France		
Cadarache	1995 to 1996	EPRI/EDF KALI H_2 tests qualification for US-ALWR

The AREVA PAR FR1-380T from below

Hydrogen control and mitigation applications with AREVA PARs

- Replacement of existing hydrogen recombiners for design-basis accidents
- Hydrogen mitigation during severe accidents
- General limitation of combustible gas concentration
- Combination with post-accident venting and ignition functions possible

The AREVA PAR showed the best performance

International Testing, Severe Accident PAR Qualifications

Joint In-pile Severe Accident Research Program PHEBUS (FPT3) Results

The temperature graph indicates an intensive surface kinetic reaction regime of the AREVA PAR which triggers the catalytic reaction very quickly, even after exposure to a severe accident atmosphere with a degraded core.

These comprehensive real severe accident tests could be the model for a new international PAR qualification standard. From the results of this extensive qualification program, it can be deduced that the AREVA PAR is qualified for design-basis and severe accident environmental conditions.

Recent Results of International PAR-Severe Accident Qualification

During tests in the frame of the EC/IRSN Core Melt Program PHEBUS (with real molten core), **AREVA's PARs showed the best performance** in these categories:

- Very fast start-up
- Highest efficiency
- Absolutely constant hydrogen depletion rates

Testing and Maintenance

As soon as the PAR housings with the catalysts are assembled, the hydrogen reduction system is ready for operation. A functional check of a process section of the PAR will confirm this during the site acceptance tests and the in-service inspections to be performed later.

The design allows for a quick and easy removal of the catalytic plates. The functionality of this process section is usually tested under representative conditions with test gas containing hydrogen. The testing device is comprised of a movable trolley, a heated cabinet, measurements, an operational panel, an analysis unit and gas supply. The start of the catalytic reaction is indicated by a decreasing hydrogen concentration in the test gas. The result shows that the PAR reaches its nominal hydrogen depletion performance.

"More than 100 nuclear power plants are equipped with AREVA's PARs."

Benefits at a Glance

Low investment and high cost benefit

- Simple design that requires neither power supply nor operator action / automation
- Easy maintenance and in-service inspection
- Flexible: available as safety-classified / non-safety-classified PAR type

Reliable and flexible system

- Patented design, applied in more than 100 NPPs worldwide
- Design-basis and severe-accident qualified hardware
- H_2-depletion even under inert conditions
- Long-term H_2 / O_2 control
- High catalytic performance due to multiple precious metal catalyst with high inner porosity
- High proportion of precious metal content providing important design margins

High hydrogen depletion and flow rate of up to 880 ft^3/min per unit

- Generation of strong and large convection loops increasing atmosphere mixing that results in enhanced system efficiency
- Low number of PAR units within the containment
- Little space required for PAR system installation
- Reduced maintenance effort during plant operation

Thin-plate technology

- Fast heat-up of catalytic plates
- Self-acceleration (autocatalytic) of recombination
- High inlet cross section (98% free area) due to thin catalytic plates' low pressure drop
- High inlet flow velocity up to 1 m/s

Technical Data

The AREVA PAR is available in different sizes, allowing for the best possible arrangement in the various compartment areas.

	FR1-150	FR1-320	FR1-960	FR1-380T	FR1-750T	FR1-1500T
Length (in.)	7.8	14.5	39.7	16.9	31.5	61
Depth (in.)	6.5	6.5	6.5	12.8	12.8	12.8
Height (in.)	39.3	39.3	39.3	55	55	55
Approx. weight (lbs.)	39.6	57.3	132.3	110.2	176.3	286.6
No. of catalytic plates	15	32	96	38	75	150
Inlet flow rate at 14.5 psi and 140° F (ft^3/min) up to	30	65	195	195	390	880
Depletion rate (lbs/h) at 21.8 psi and 4 vol- %	0.4	0.9	2.65	2.65	5.3	11.8

AREVA in North America (AREVA Inc.) combines U.S. and Canadian leadership to supply high added-value products and services to support the operation of the nuclear fleet. Globally, AREVA is present throughout the entire nuclear cycle, from uranium mining to used fuel recycling, including nuclear reactor design and operating services. AREVA is recognized by utilities around the world for its expertise, its skills in cutting-edge technologies, and its dedication to the highest level of safety. Through partnerships, the company is active in the renewable energy sector. AREVA Inc.'s 4,300 employees are helping build tomorrow's energy model: supplying ever safer, cleaner and more economical energy to the greatest number of people.

us.areva.com

AREVA Inc.
For more information, contact:

James Bakke
Manager, Mechanical Products
Tel: 704.805.2528
Email: James.Bakke@areva.com

Lew McKeague
Product Development Manager
Tel: 434.832.3506
Email: Lew.McKeague@areva.com

Nuclear Parts Center
Tel: 434.832.2967
Cell: 434.610.3880
npc@areva.com

us.areva.com

ANP:U-343-V3-16-ENG