华龙国际核电技术有限公司
Hualong Pressurized Water Reactor Technology Corporation, Ltd.

华龙一号核电技术创新与展望

The Innovation and Outlook of the HPR1000 Nuclear Power Technology

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概述

Overview

1. 概述 Overview

1.1 华龙一号 HPR1000 Technology

是中国具有自主知识产权的第三代先进压水堆核电技术

A Chinese Generation-III advanced NPP technology with independent intellectual property rights.

是中国自主创新、集成创新和机制创新的成果

An achievement of China's innovation of research, coordination and mechanism.

华龙一号
HPR1000

是我国在30年核电科研、设计、制造、建设和运行经验的基础上，采用全球最高安全标准研发设计的三代核电技术，满足全面参与国内、国外核电市场竞争要求

A Chinese NPP technology based on over 30 years experience on nuclear power technology.

是“一带一路”倡议的国家名片

A national brand of the Belt and Road initiative.

1. 概述 Overview

1.1 华龙一号 HPR1000 Technology

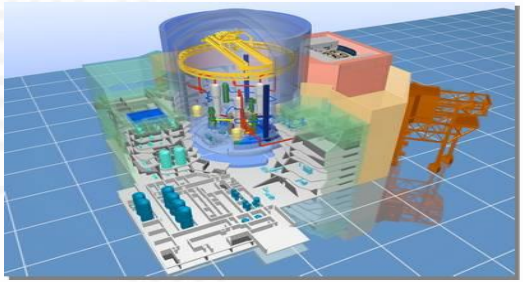
作为渐进改进式先进压水堆技术，华龙一号满足HAF/IAEA SSR/EUR /URD，**以及福岛事故后新的安全要求**

An evolutionary advanced PWR nuclear power technology in correspondence with HAF, IAEA SSR, EUR, URD and the post-Fukushima safety requirements.

1.1 华龙一号 HPR1000 Technology

华龙一号采用成熟技术，充分考虑了全球在建/在运压水堆电厂的经验反馈

HPR1000 builds upon the proven technology and fully considers the feedback from other PWR NPPs in operation and under construction.



华龙一号系统性地提升了安全性、可靠性和经济性

Safety, reliability and cost-efficiency have been systematically improved.

02

主要特点

Key Features

安全性

Safety

经济性

Economy

先进性

Superiority

技术成熟性

Maturity

2. 主要特点 Key Features

安全性 Safety

华龙一号设计采用全球最高标准要求，满足HAF102、URD、EUR等法规标准要求，安全水平达到三代核电技术国际先进水平。

By adopting the highest standards, HPR1000 meets the requirements of HAF102, URD, EUR and other regulation rules and standards, making its level of safety reach the highest among GEN. III nuclear power technology.

经济性 Economy

华龙一号的经济性与当今主流三代机型相比有明显竞争力，其上网电价与目前中国脱硫机组标杆电价相当。

With its on-grid price equivalent to the benchmark price of desulfurization thermal power plant, HPR1000 is of greater economic competitiveness than other GEN.III NPPs .

2. 主要特点 Key Features

先进性 Superiority

能动+非能动结合设计理念，具有20项先进的技术特征。

HPR1000 implements an active and passive safety design philosophy with over 20 significant features.

技术成熟性 Maturity

华龙一号相关工艺设计均选择成熟工艺，立足于我国30多年来核电设计、建造和运行经验，具有良好的可建造性和可运行性。

HPR1000, which took advantages of proven technology distilled form China's over 30 years of designing, constructing and operating NPP experience, is with good constructability and operability.

2. 主要特点 Key Features

安全性
Safety

华龙一号集我国30多年核电建设、运营的成熟经验，充分借鉴世界先进的三代压水堆核电设计理念，汲取福岛核事故经验反馈，采用国际最高安全标准和成熟可靠的先进技术，其安全指标达到全球最高安全水平。

The HPR1000 design is based on China's over 30 years of constructing and operating NPP experience and has implemented and developed advanced design philosophy from other Gen.III NPPs all over the world. By fully considering lessons learned from Fukushima nuclear accident and adopting the highest standard of safety and proven technology, the HPR1000 meets the top level of safety requirements.

2. 主要特点 Key Features

安全性
Safety

CDF < 1× 10^{-6} /堆•年，LRF < 1× 10^{-7}/堆•年，做到了实际消除大规模放射性物质释放。

The HPR1000 has achieved the goal of practical elimination on the massive radioactive releases, with CDF < 1× 10^{-6} /reactor year，LRF < 1× 10^{-7}/reactor year.

2. 主要特点 Key Features

安全性
Safety

在吸取了福岛事故的经验教训后，“华龙一号”还增强了安全系统，延长反应堆操纵员不干预的时间。在应对台风、地震、海啸、飞机撞击等外部灾害，华龙一号”可以抵御目前经历过的所有台风级别，可以抵御9级烈度的地震以及商用大型飞机的外部撞击。

After learning the lessons of the Fukushima accident, the HPR1000 also enhanced its safety system, prolong the time for operators not acting. As for external disasters, the HPR1000 can withstand typhoon of all levels, and can withstand earthquakes of magnitude 9 and external impacts of large commercial aircraft.

经济性
Economy

华龙一号在采取了切实有效的提高安全性的措施的同时，注重提升经济性，使其与国际三代核电技术相比具有经济竞争性。

While taking practical measures to improve safety, the HPR1000 also focuses on improving cost-efficiency and making it economically competitive with GEN.III nuclear power plant in other countries.

2. 主要特点 Key Features

经济性
Economy

- ✓ **单堆热功率提升至** 3180 MW，**发电功率超过** 1200 MW

  Thermal power 3180MWt, Nominal power ⩾ 1200 MWe

- ✓ **优化了能动和非能动安全系统的配置** Enhanced active + passive safety measures
- ✓ **电厂平均可利用率** ⩾ 90% Average plant availability ⩾ 90%
- ✓ **主要设备已开展标准化** Standardized manufacturing of key equipment

2. 主要特点 Key Features

经济性
Economy

- ✓ **机组批量化建设后单位投资降低至 14500（元/kW）**

  In case of mass-construction, the unit investment of the HPR100 will be reduced to 14500 yuan/kW .

- ✓ **经济性领先同类三代技术机组，华龙一号项目对比脱硫脱硝火电机组、光伏、风电等新能源项目仍具有一定的竞争性。**

  The HPR1000 is economically competitive with GEN.III nuclear power plant and comparable to the cost-efficiency of desulfurization thermal power plant, solar photovoltaic and wind power, etc.

2. 主要特点 Key Features

先进性
Superiority

具有20项先进的三代核电机组技术特征

- ✓ 177个12英尺燃料组件的反应堆 177 12-feet advanced fuel assemblies
- ✓ 能动与非能动相结合的安全措施 Active + passive safety measures
- ✓ 堆芯热功率3180 MWt，机组额定功率不小于1200MWe

  Thermal power 3180MW, Nominal power≥1200MWe
- ✓ CDF <1×10^{-6}/reactor year, LRF <1×10^{-7}/reactor year
- ✓ 堆芯热工裕量≥15% Safety margin ≥15%
- ✓ 单堆布置 Single-unit layout
- ✓ 安全停堆地震 0.3g Safety Shutdown Earthquake(SSE): 0.3g

2. 主要特点 Key Features

先进性
Superiority

具有20项先进的三代核电机组技术特征

- ✓ **大自由容积双层安全壳** Double shell containment with large free volume
- ✓ **抗大型商用飞机撞击** Resistance against impact of large commercial aircraft
- ✓ **60年设计寿命** 60 years overall plant design life
- ✓ **18~24个月换料周期** Refueling cycle of 18~24 months
- ✓ **电厂平均可利用率≥90%** Average plant availability ≥90%
- ✓ **操纵员不干预时间不低于30分钟** Minimum 30min non-intervention
- ✓ **完善的设计扩展工况应对措施** Comprehensive counter-measures for DEC

2. 主要特点 Key Features

先进性
Superiority

具有20项先进的三代核电机组技术特征

- ✓ **全数字化仪控系统** Digital Control System (DCS) and advanced MCR
- ✓ **堆芯测量从堆顶引入** Improved in-core instrumentation inserted from upper head
- ✓ **安全壳内置换料水箱** In-Containment Refueling Water Storage Tank (IRWST)
- ✓ **破前漏技术（LBB）** Leak-Before-Break (LBB)
- ✓ **放射性废物离堆处理，待处置固体废物年产生量小于50m³/堆•年**

  Solid rad-waste volume<50m³/reactor · year
- ✓ **职业照射集体剂量小于0.6人•Sv/堆•年**

  Collective dose of occupational exposure<0.6 person · Sv/reactor · year

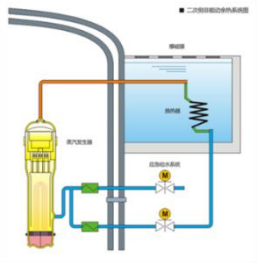
先进性
Superiority

采用能动与非能动相结合的设计理念，具有完善的严重事故预防和缓解措施，具有很高的安全性和技术先进性。

The HPR1000, implementing an active and passive safety design philosophy with comprehensive counter-measures for severe accidents, is an advanced nuclear power plant with high level of safety.

二次侧非能动系统

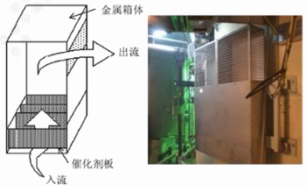
Secondary Side Passive Cooling System



可用于超设计基准工况
下72小时内堆芯排热

非能动消氢系统

Passive Hydrogen Control System



非能动氢气复合器子系统

氢气监测子系统

防止事故下安全壳内局部氢气浓度过高，
避免氢气燃爆对安全壳完整性的威胁

2. 主要特点 Key Features

成熟性
Maturity

HPR1000充分借鉴了包括AP1000、EPR在内的第三代先进核电技术；

充分依托成熟的国内核电装备制造体系和能力，采用经验证的成熟技术，实现了集成创新。

The HPR1000 design, which has fully implemented and developed the GEN.III reactor technology including AP1000 and EPR, adopted proven technology and relied on China's mature equipment manufacturing capabilities, has achieved integrated innovation success.

2. 主要特点 Key Features

成熟性
Maturity

- ✓ **华龙一号主系统和能动安全系统的配置与现有电厂的成熟设计基本一致，得到了充分验证**
  The configuration of the primary system and active safety system of the HPR1000 is consistent with the design of the existing power plant and has been fully verified.
- ✓ **大部分先进设计特征并非首次应用，已在国内外核电项目中得到应用和验证**
  Most of the advanced design features of the HPR1000 have been applied and validated in nuclear power plants at home and abroad.

二次侧非能动实验
Secondary side passive system experiment facility

成熟性
Maturity

- ✓ **首次采用的设计，通过了一系列验证性试验，具备良好性能**
  The first adopted designs have passed a series of verification tests.
- ✓ **设计充分考虑了我国已有的核电装备制造体系，以及成熟的工程建设技术和工程管理经验。**
  The HPR1000 design fully considers China's nuclear power equipment manufacturing system, as well as mature engineering construction technology and management experience.

IVR实验和流致振动实验
Experiment facilities of IVR and flow induced vibration

2. 主要特点 Key Features

成熟性
Maturity

关键设备自主化

Domestic manufacturing

capability of key equipment

压力容器

Reactor vessel

蒸汽发生器

Steam Generator

主管道及波动管

Main-pipeline and Surge line

主泵

Main Pump

汽轮机

Turbine

2. 主要特点 Key Features

成熟性
Maturity

华龙示范工程进展顺利，没有出现首堆工期重大延误

The HPR1000 demonstration plant is making steady progress with no major schedule delay in construction.

华龙一号

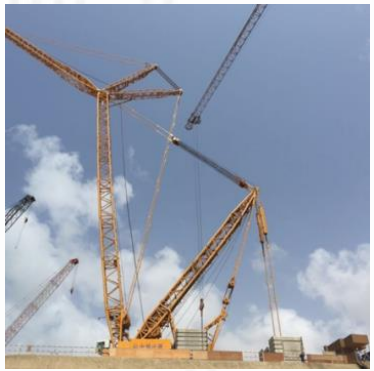
“华龙一号”全球首堆示范工程中核集团福清核电5号机组开工以来，工程建设情况良好，工程重大里程碑节点均按照计划如期实现。截至目前，5号机组压力容器、蒸汽发生器、主泵等长周期设备进展顺利，硼注箱、安注箱、容控箱、衰变箱等86台预装设备已吊装到位，反应堆厂房已施工至45米。6号机组安注箱、硼注箱已吊装就位，6号反应堆厂房钢衬里第10段已施工完成，内部结构0米板施工完成。（福建日报记者 王永珍/文 周明太/图）

防城港核电项目二期3、4号机组采用的是我国具有自主知识产权的三代压水堆核电技术品牌“华龙一号”，满足全面参与国内、国际核电市场竞争要求，是“走出去”的一张亮丽的国家名片，已确定为英国布拉德韦尔B项目的参考电站。3号、4号机组分别于2015年12月24日、2016年12月23日开工建设，2018年1-4月项目完成投资29.21亿元，项目自始建以来累计完成投资283.46亿元。

成熟性
Maturity

海外项目工程建设同样进展顺利，下图为采用华龙一号技术的巴基斯坦K2/K3机组。

The overseas project construction is proceeding steadily as well. The following picture shows the Pakistan K2 and K3 unit using the HPR1000 technology.



- ✓ 我国自主三代核电技术“华龙一号”海外项目--卡拉奇核电站2号（K2）机组于2015年9月18日实现第一罐混凝土浇筑，2017年10月13日完成K2穹顶吊装，
- ✓ 2018年9月29日，3号机组（K3）核岛穹顶顺利吊装就位，标志着3号机组建设由土建施工全面转入设备安装阶段。

03

展望

Outlook

华龙技术发展

HPR Technology Development

华龙技术创新思路

The Evolution of HPR Technology

项目展望

Vision of HPR Technology

3. 展望 Outlook

3.1 华龙技术发展 HPR Technology Development

分析国内电力与核电市场，由于厂址征地、拆迁工程较大，严格的环境保护和海洋生态保护等等，核电项目“硬”投入越来越大，再加上随着国内电力市场改革加速，核电参与市场竞价，上网电价、机组利用小时数等受市场需求影响较大，种种因素对核电发展提出了挑战。

在不降低安全性的前提下，通过技术创新进一步提升经济性，成为华龙技术发展需要迫切开展研究的主要课题之一。

Due to the rising cost of land acquisition, demolition and relocation, as well as the more stringent environmental protection and marine ecological protection requirements, the “rigid” investment in nuclear power projects is increasing both at home and abroad. Factors like market reform, electric power bidding, on-grid tariffs, utilization hours have also greatly affected the development of nuclear power.

With the restriction of not reducing level of safety, further improving of cost-efficiency through technological innovation has become one of the main topics for the development of the HPR1000 technology.

3.2 华龙技术创新思路 The Evolution of HPR Technology

保证三代技术安全性指标要求，着力提升经济性，提升核电市场竞争能力

Meeting the requirements of the GEN.III safety standards, focusing on improving cost-efficiency and improving the competitiveness of the nuclear power in electricity market.

1

优化
运行参数

Optimization of operating parameters

2

优化
专设安全系统配置

Optimization of engineered safety features

3

优化
应对设计扩展工况措施

Optimization of countermeasures for DEC

4

安全壳
双层改为单层

Double-shell to single-shell containment

5

优化
电源配置

Optimization of power supply

3.2 华龙技术创新思路 The Evolution of HPR Technology

1

优化运行参数

Optimization of operating parameters

在保证热工安全裕量以及现有设备技术能力条件下，通过优化反应堆核设计和热工水力设计，提高反应堆功率，以增大机组出力。

Increasing the reactor power and electricity output by optimizing neutronics design and thermal hydraulic design whilst preserving thermal safety margin and equipment manufacturing applicability.

3.2 华龙技术创新思路 The Evolution of HPR Technology

2

优化
专设安全系统配置

Optimization of engineered safety features

在满足单一故障、冗余设计的设计原则基础上，采用DVI技术减少安全系统独立系列，并取消专用母管，同时部分系统共用，可减少部分系统设备以及相应的厂房。

While the design principle of single failure and redundant design is maintained, DVI technology is used to reduce the independent series of safety systems. The dedicated main-pipeline is eliminated. Shared facilities and systems can also reduce the amount of equipment and corresponding compartment.

3.2 华龙技术创新思路 The Evolution of HPR Technology

3

优化应对设计扩展工况措施

Optimization of countermeasures for DEC

通过风险指引技术研究，分析系统的薄弱环节，平衡取舍，避免系统多重配置，裕量过大。

To avoid the extravagant redundancy of system configurations and reduce the unreasonable margin by analyzing the weakness of the system through the risk guidance technology.

3.2 华龙技术创新思路 The Evolution of HPR Technology

4

安全壳双层改为单层

Double-shell to single-shell containment

对安全壳进行结构优化，使单层安全壳既抵御内部事件，又能防外部事件（包括商用飞机恶意撞击），可显著减少工程量，减少施工难度及缩短建造工期。

To optimize he containment into a single-shell containment which can significantly reduce construction difficulty and shorten construction time, while maintaining the resistance of both internal events and external events (including the impact of large commercial aircraft).

3.2 华龙技术创新思路 The Evolution of HPR Technology

5

优化电源配置

Optimization of power supply

在满足电厂安全要求的前提下，进一步优化电源配置，减少过度冗余。

To further optimize the power supply configuration within the safety limitations so as to reduce excessive redundancy.

3.2 华龙技术创新思路 The Evolution of HPR Technology

采用上述技术创新思路后，经初步确定论典型事故分析，满足15%热工安全裕量要求，有效地保证了反应堆的安全；经PSA初步评估，安全指标与华龙一号融合技术方案相当。

同时经初步测算，能有效提升经济性（节省超过5%的工程造价）。

After adopting the above-mentioned technical innovations, the improved HPR1000 design satisfies the 15% thermal safety margin requirement. According to the preliminary PSA assessment, the safety indicators is equivalent to the existing HPR1000 design.

Meanwhile, the postulated project cost is reduced by 5%, which gives a considerable rise of cost-efficiency.

3. 展望 Outlook

3.3 项目展望 Vision of HPR Technology

华龙一号是我国三代核电的主力机型，除了在建的福清5/6及防城港3/4号机组外，漳州、太平岭项目一期工程已经核准开工，后续规划采用华龙一号技术建设的海南二期、宁德二期、浙江苍南、漳州、太平岭后续及防城港5/6号等项目，预计共建设30台以上的华龙机组，通过华龙一号的批量化建设，必将对我国核电设计与研发、设备制造、工程建设、运维，以及国际核电技术合作产生重大影响。

The HPR1000 has become the major model of China's GEN.III NPP. In addition to the ongoing Fuqing unit 5/6 and Fangchenggang unit 3/4, the first phase of the Zhangzhou unit 1/2 and Taipingling uint 1/2 has been permitted for construction. Hainan Phase II, Ningde Phase II, Zhejiang Cangnan, Zhangzhou, Taipingling and Fangchenggang 5/6 are also planned to us the HPR1000 technology. It is estimated that more than 30 HPR1000 units will be built. The mass-production of HPR1000 will improve China's nuclear power capabilities, and will actively promote international cooperation of nuclear energy.

结束语 Conclusion

- ✓ **华龙一号核电技术跻身世界前列，是“国之重器”，将在国家能源结构调整和能源资源优化中起到非常重要的作用。**
  As “a pillar of our nation”, the HPR1000 will play a major role in national energy structure adjustment and energy resource optimization.
- ✓ **华龙国际积极推动华龙一号项目，积极推动自主技术和装备制造产业持续发展，引领企业向中高端升级。**
  We will actively promote the HPR1000 projects, support the “going global” of China’s advanced technology, and finally guide the industrial upgrading.
- ✓ **通过持续优化、持续创新，为国内外核电市场提供优质的华龙技术，为和平利用原子能，造福全人类做出应有贡献。**
  By providing high-quality HPR technology for the market through continuous innovation, HPR hopes to contribute to the peaceful use of nuclear energy and a better life of human being.

华龙一号，提供安全、清洁、经济和可靠的全球能源解决方案

HPR1000, a safe, clean, economic and reliable global energy solution.

THANKS

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