**《高温气冷堆技术》课程大纲Outline for HTGR Technology**

**（2024年12月）**

# 高温气冷堆技术（81010202）

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| **一、课程简介**（概述课程教学内容和预期达成的教学目标，500字以内）  课程将以模块式球床高温气冷堆系统为主要针对对象，系统地介绍高温气冷堆的发展历史、未来发展趋势、系统构成、基本设计方法和特性(元件、物理、热工、安全分析、源项分析)、设备特点、安全特性、运行特性、应用领域。将重点介绍具有固有安全的模块式高温气冷堆的设计理念和设计原理。  课程特点1：全面： 课程将较全面地介绍模块式高温气冷堆的各个方面，包括发展历史、未来发展趋势、系统构成、基本设计方法和特性(元件、物理、热工、安全分析、源项分析)、设备特点、安全特性、运行特性、应用领域，  特点2：重点突出：将重点介绍具有固有安全的模块式高温气冷堆的设计理念和设计原理，并与压水堆电站进行针对性的比较，  特点3：结合实际：课程将结合HTR-PM的实际设计方案，讲解高温气冷堆核电站设计的全过程；  特点4：实用性强：课程计划以点带面，让学生体会设计一个反应堆系统应关注的方面和基本方法，要以系统的观念在各方面进行平衡与优化，并掌握高温气冷堆的特点，为今后从事高温气冷堆的设计、工程、应用建立一个较完整、全面的框架知识。  Features for this course:   1. Full scope of HTGR technology 2. Emphasis on inherent safety and high temperature output, comparison with LWR 3. Dealing with design of real HTR plant 4. Try to establish a whole knowledge framework of HTGR power plant | | | | | |
| **二、学分** | 2 | **三、学时** | **32** | **四、授课语言** | 英语 |
| **五、适用对象**（列举课程适用的学科、学位项目、研究生类型等）  课程主要针对要从事核能工程与技术专业的研究生。  This course is target for graduate students majored on nuclear engineering. | | | | | |
| **六、师资要求**（概述对课程负责人和任课教师的基本要求，包括学科专业背景、研究领域和专长、教学经验、行业实践经验、组织协调能力、英文教学能力等）  要求教师具有比较全面的核工程知识，特别是高温气冷堆核电站的系统、特点、发展趋势等方面的知识和经验。采用全英文教学，具有英文教学能力。  Teacher is equiped with knowledge and experience of nuclear reactor engineering, and especially the design and construction of whole HTGR plant. The course will be taken by full English. | | | | | |
| **七、教学方式**（列举课程采用的教学方式，包括课堂讲授、分组研讨、案例教学、实验实践、慕课自学等）  课程采用课堂讲授、分组讨论的方式。学生广泛阅读文献，建立对核能的系统的框架知识体系。  The main style is lecture in classroom, plus wide scope of discussion. Wide scope of literature survey and summary is required. | | | | | |
| **八、教学内容大纲与主要教学设计**（教学内容大纲列至二级目录，并对应大纲简介研究性教学、课程思政等教学设计）   |  |  | | --- | --- | | 课程内容  **Course content** | **教学要点** | | Ch 01 General aspects of High Temperature Reactors  第一章 高温气冷堆通用特性 | 1.1 Overview  1.2 Future sustainable energy technologies  1.3 Principle characteristics of HTR  1.4 Application of modular HTR in the energy economy  1.5 Safety aspects of modular HTR  1.6 Fuel cycles of modular HTR  1.7 Intermediate and final storage  1.8 Overview on the HTR-PM project  1.9 Overview on the HTR development up to now | | Ch 02 Physical aspects of core layout  第二章 物理特性 | 2.1 Overview on physical aspects of core layout and design of modular HTR plants  2.2 Criticality of a modular HTR, estimation of the neutron balance  2.3 Influence of reflectors  2.4 Coefficients of reactivity  2.5 Demand of reactivity compensation and worth of control systems  2.6 Fast neutron doses on reflectors.  2.7 Influence of flow of balls, action on the burnup of fuel  2.8 Distributions of fuel, neutron flux and power density in the reactor core  2.9 Principles of kinetics of nuclear reactors  2.10 Program systems for physical layout of the core  2.11 Aspects of core layout and design  2.12 Physical aspect of the first loading and running of the pebble core  2.13 Deloading of pebble bed cores | | Ch 03 Thermo-hydraulic aspects of core layout  第三章 热工水力特性 | 3.1 Heat production inside the core  3.2 Thermal power of the core  3.3 Data of the coolant gas helium  3.4 Basic equations of the thermo-hydraulics of the core  3.5 Heating up of helium coolant in the core  3.6 Temperature profiles in fuel elements  3.7 Heat transfer in the pebble-bed core  3.8 Pressure drops in the core and reflector structures  3.9 Special aspects of thermo-hydraulic layout of the core of modular HTR  3.10 Principle of core layout  3.11 Comparison of data of core cooling in some HTR concepts  3.12 Comparison of thermo-hydraulic aspects of reactors | | Ch 04 Fuel elements  第四章 燃料元件 | 4.1 Description of the component  4.2 Aspects of layout and design of HTR fuel elements  4.3 Temperature distributions in HTR- fuel elements  4.4 Irradiation behavior of fuel elements  4.5 Stresses in fuel elements  4.6 Corrosion of fuel elements  4.7 Fission product release from fuel elements in normal operation  4.8 Different types of spherical fuel elements  4.9 Some further experiences with HTR fuel elements  4.10 Comparison of LWR and HTR fuel elements | | Ch 05 Reactor components  第5章 反应堆主设备 | 5.1 Overview on all components  5.2 Internal reactor structures  5.2.1 Overview on the internal components  5.2.2 Technical aspects of core internals  5.2.3 Loads on core internals  5.2.4 Graphite and its irradiation behavior  5.2.5 Results of analysis of reflector structures during operation  5.3 Primary enclosure  5.3.1 Overview  5.3.2 Aspects of dimensioning and materials for pressure vessels of primary circuit  5.3.3 Neutron irradiation of reactor pressure vessel and design aspects  5.3.4 Activation of the reactor pressure vessel  5.4 Comparison of vessel of modular HTR with components from other reactors.  5.5 Shutdown and control systems  5.6 Fuel handling system  5.7 Measurement installations for core parameters | | Ch 06 Components of the helium cycle  第6章 一回路相关设备 | 6.1 Overview  6.2 Hot gas duct  6.3 Steam generator  6.4 Helium circulator  6.5 Gas purification plant  6.6 Helium circuits for decay heat removal  6.7 Helium auxiliary Systems  6.8 Reactor protection system | | Ch 07 Reactor containment building  第7章 安全壳建筑 | 7.1 General remarks and requirements  7.2 Aspects of LWR and HTR containments or containment buildings  7.3 Several overview on concepts of reactor containment buildings for HTR  7.4 Overview on HTR containments and buildings applied until now  7.5 Planning work for the containments in the past | | Ch 08 Power conversion cycle  第8章 能量转换系统 | 8.1 Overview on flow sheet  8.2 Some thermo-dynamic aspects of the steam cycle  8.3 Aspects of steam turbine  8.4 Condensation and cooling systems  8.5 Feed water preheating system and feed water pumps  8.6 Optimization of the steam cycle  8.7 Potential of steam cycles  8.8 Cogeneration processes using steam cycle | | Ch 09 Operational aspects  第9章 运行特性 | 9.1 Overview on requirements and conditions of plant operation  9.2 Burnup of fuel and production of higher isotopes  9.3 Fission product inventory  9.4 Dynamical equations for the total plant  9.5 Applications of the dynamical equations  9.6 Concept of control and operation of a modular HTR  9.7 Xenon dynamics and influence of Samarium on reactivity  9.8 Decay heat removal during normal operation  9.9 Release of radioactive substances during normal operation  9.10 Aspects of waste management in modular HTR | | Ch 10 Safety aspects and analysis of accidents  第10章 安全特性与事故分析 | 10.1 General remarks  10.2 Overview on relevant accidents  10.3 Loss of coolant accidents  10.4 Total failure of the active decay heat removal  10.5 Reactivity accidents  10.6 Water ingress into the primary system  10.7 Ingress of air into the primary circuit  10.8 Accidents on the secondary side of the steam cycle  10.9 Impacts from the outside on the reactor plant  10.10 Release of fission products during accidents  10.11 Radiological consequences of accidents and risk | | Ch 11 Fuel cycles and waste management  第11章 燃料循环与废物管理 | 11.1 Overview on fuel cycles  11.2 Fabrication of fuel elements  11.3 Intermediate storage of spent fuel elements  11.4 Accidents in intermediate storage systems for spent fuel elements  11.5 Final storage of spent fuel elements  11.6 Non-proliferation and safeguard aspects | | Ch 12 Economic aspects of power plants and questions of optimization  第12章 经济特性与优化 | 12.1 Overview on economical considerations  12.2 Equation for calculation of the cost of electricity generation  12.3 Investment costs and capital factors  12.4 Efficiency and full power hours of operation  12.5 Cost of fuel supply and waste management  12.6 Total costs of electricity generation  12.7 Comparison of production costs of different power plants and sensitivity of costs  12.8 Escalation of costs and methods of evaluation  12.9 External costs of electricity production  12.10 Investment costs of newly developed concepts of nuclear power plants | | Ch 13 Development of HTR technology  第13章 高温气冷堆技术的发展 | 13.1 General overview  13.2 Plants, which have been operated in the past  13.3 HTR plants, which have been planned in the past  13.4 The modular reactor concept  13.5 Modular HTR, which are in operation  13.6 Planned new HTR plants  13.7 Aspects of analysis and valuation of reactor concepts | | Ch 14 Some experimental results on safety aspects of modular HTR  第14章 安全相关实验 | 14.1 Overview on some safety relevant questions  14.2 Experiments for valuation of the principle of self-acting decay heat removal  14.3 Proof of the reactivity behavior of the core of modular HTR  14.4 Experiments regarding water ingress into the primary system  14.5 Experiments regarding air ingress into the primary system  14.6 Behavior of fission products  14.7 Special further safety experiments for HTR plants  14.8 Test of intermediate storage vessels | | Ch 15 Future aspects of HTR-development  第15章 高温气冷堆的发展前景 | 15.1 Some general requirements in nuclear technology and overview on future possibilities of development  15.2 Realization of higher thermal power in modular HTR  15.3 Realization of very high helium temperatures using the OTTO cycle  15.4 Improvements of fuel elements  15.5 Burst-protected primary enclosures  15.6 Thorium fuel cycle and breeding effects  15.7 Conversion of isotopes with very long half-life time  15.8 Improved concepts for the intermediate storage of spent fuel elements  15.9 Improved concepts for the final storage of spent fuel elements or high level radioactive waste  15.10 Pebble-bed VHTR - concept for future process heat application | | | | | | |
| **九、考核要求**（简介课程考核方式和要求、成绩构成等）  本课程采用闭卷考核方式，占比50%，另外30来自每周调研报告，20%来自期末总结报告。  Final examination in form of close book is arranged. Investigation report for each week is arranged. | | | | | |
| **十、课程教材**（应经院系教学委员会审查通过方可列入）  主要教材：  1）Kurt Kugeler , Zhang Zuoyi. Modular High-temperature Gas-cooled Reactor Power Plant, Springer-Verlag Berlin Heidelberg, 2019, (Jointly published with Tsinghua University Press, Beijing, China, 2019). ebook ISBN 978-3-662-57712-7, Hardcover ISBN 978-3-662-57710-3  参考资料：  1）吴宗鑫，张作义，先进核能系统和高温气冷堆,清华大学出版社，2004  2）高文，高温气冷堆，原子能出版社，1982 | | | | | |
| **十一、先修课程要求**（说明先修课程要求以及与相关本科生课程的衔接关系等）  无特殊要求。  由于采用全英语教学，需要比较好的英语听说读写能力。  希望对核能有基本的了解，从而通过本课程的学习，可对比地对高温气冷堆的特殊性有更深入的理解。  No special requirement.  But good English and background of nuclear reactor enginering is appreciated. | | | | | |