中国核电工程有限公司
CHINA NUCLEAR POWER ENGINEERING CO., LTD.

2019 ISOE INTERNATIONAL SYMPOSIUM

Research of Occupational Exposure Dose Assessment for HPR1000

China Nuclear Power Engineering Co., Ltd
Reactor Engineering Department

Beijing, October, 2019

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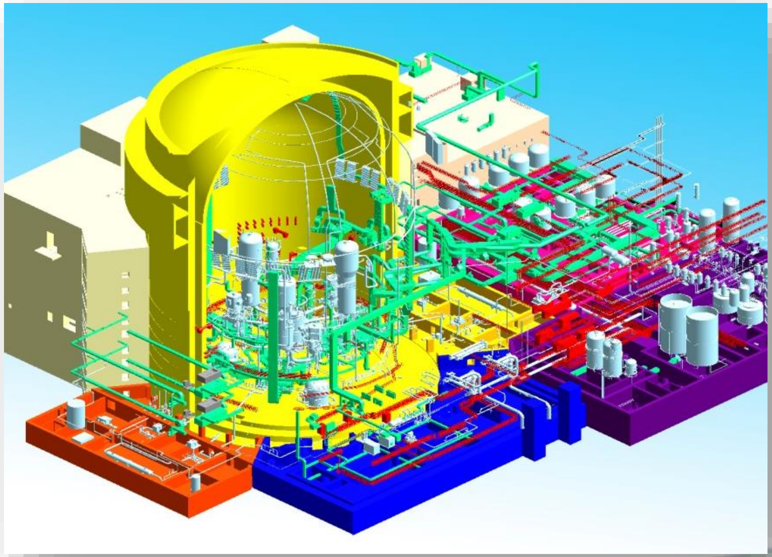
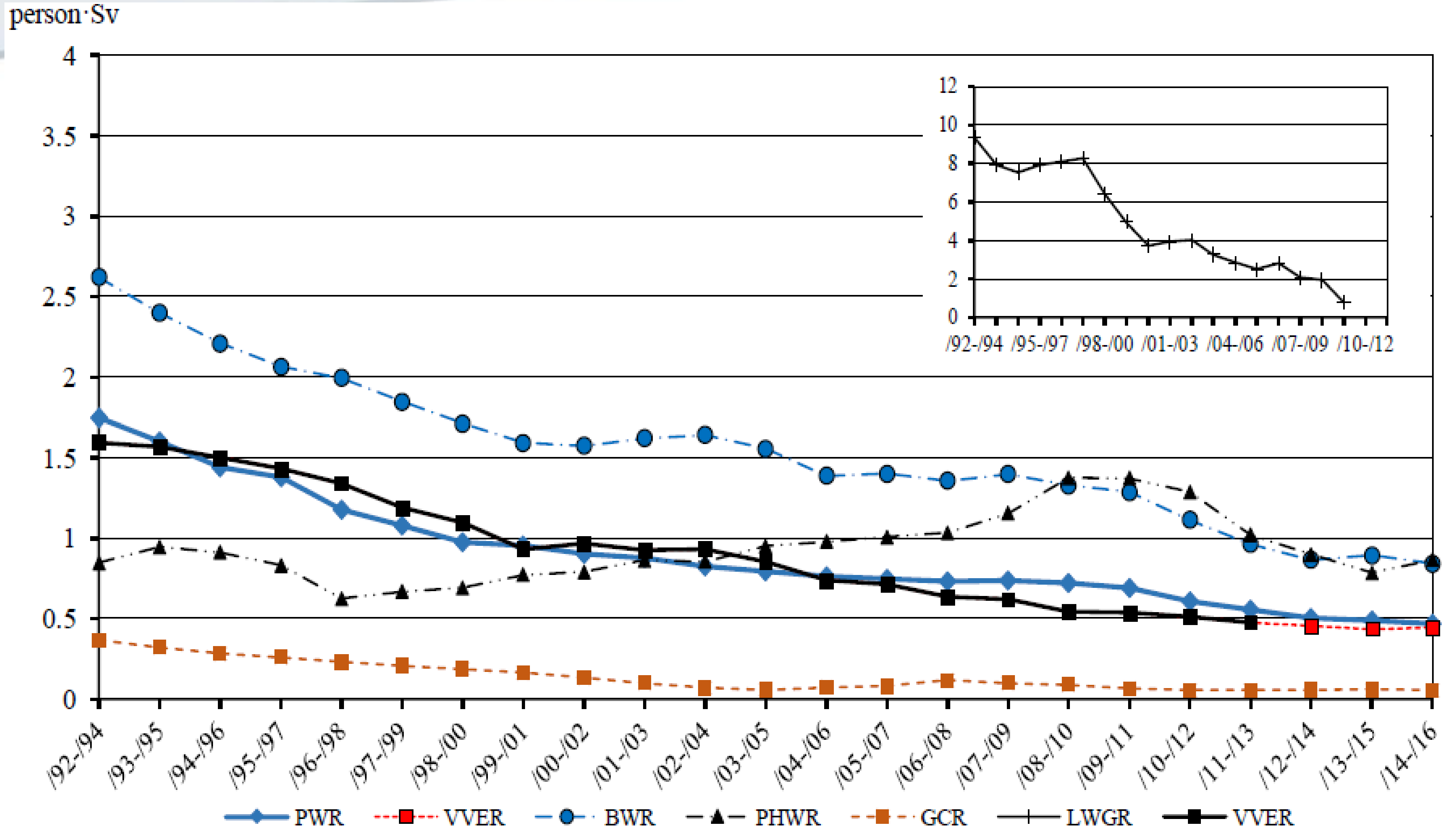
Brief introduction

HPR1000“华龙一号”

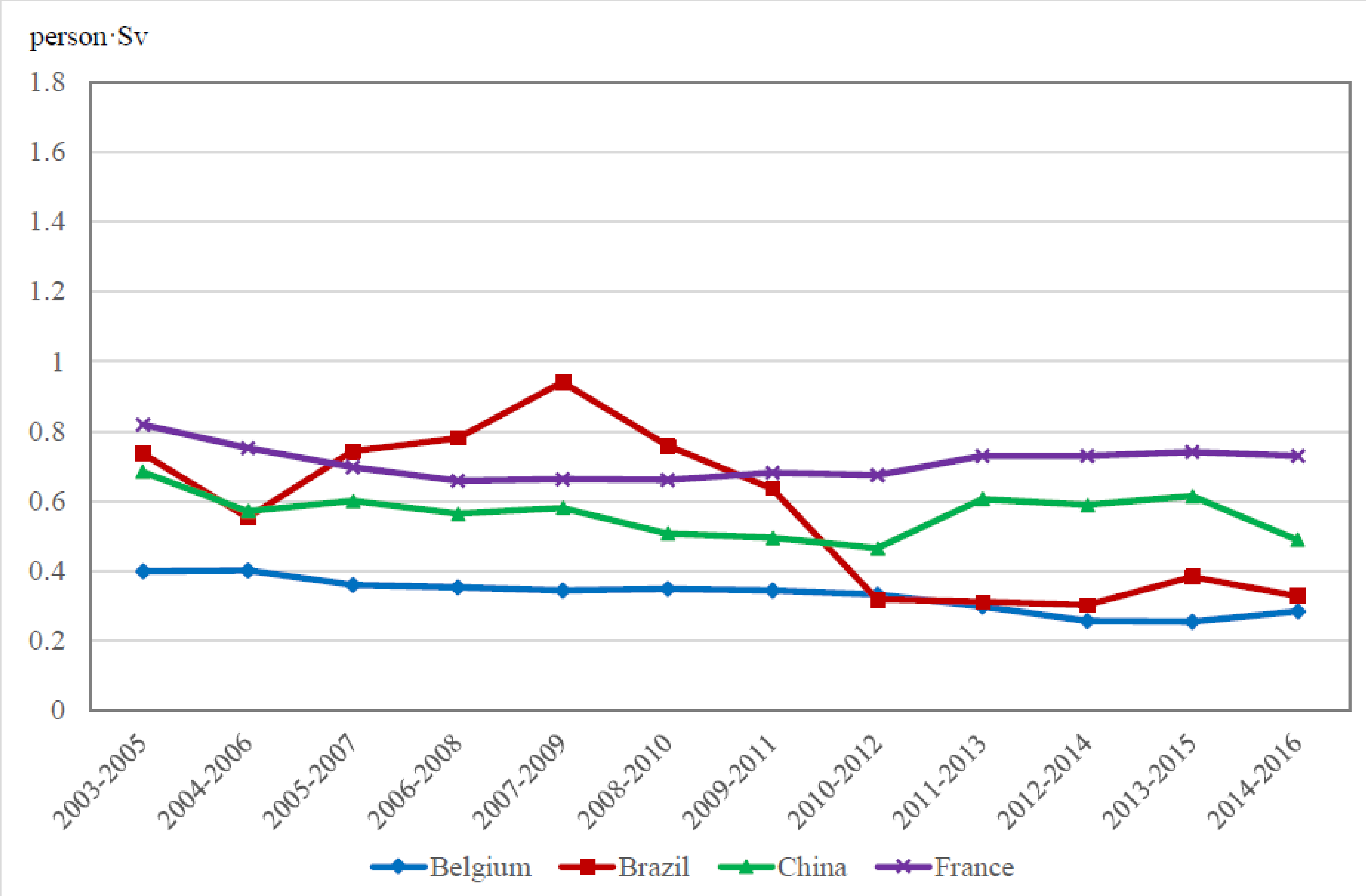
3rd generation 1000MWe PWR NPP
Chinese proprietary intellectual property rights

- 177 assemblies
- Double containments
- Active and passive safety systems



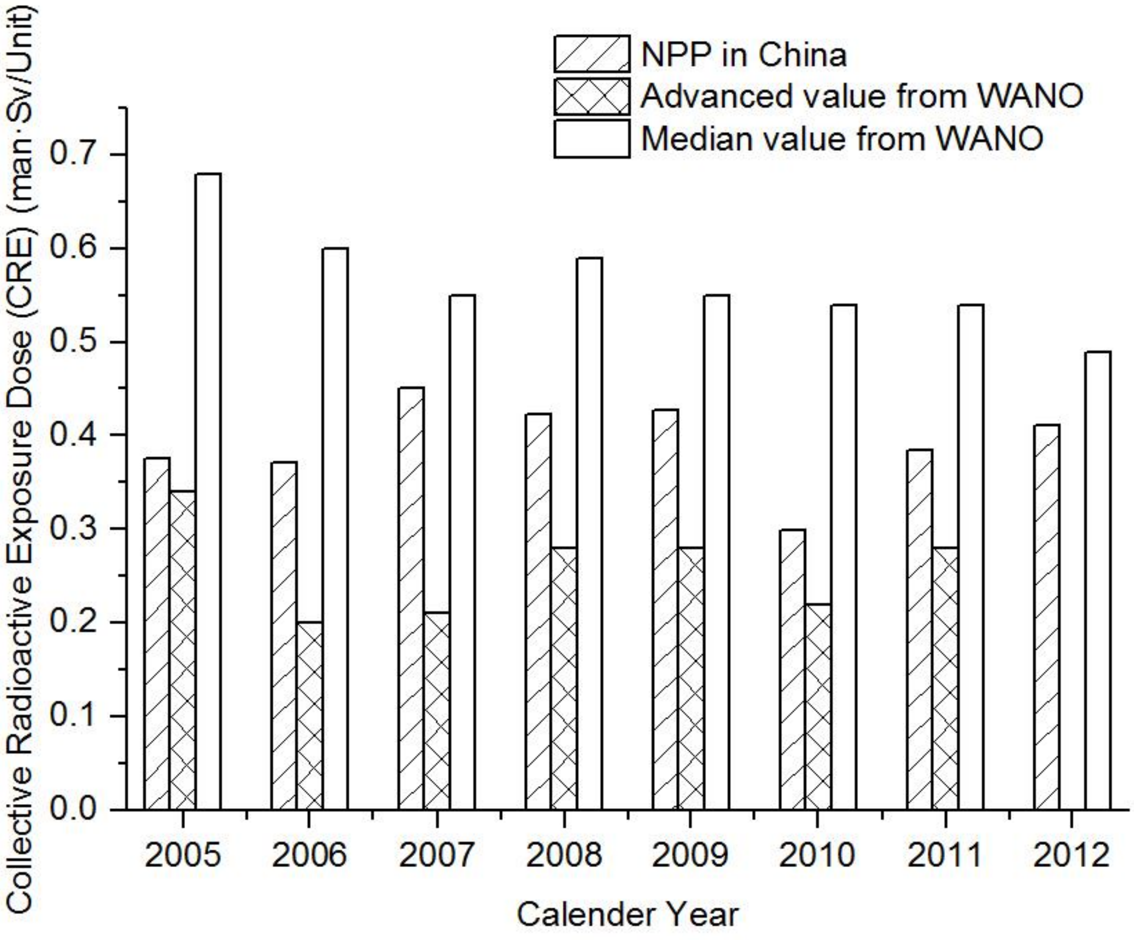


Annual average effective dose trend of global nuclear power plants



Annual average effective dose trend of PWR NPPs （China）

Brief introduction



Collective Radioactive Exposure Dose (man·Sv/Unit ·a)
(from NNSA annals)

Brief introduction

Radiation Protection Design rules:

- Reduce occupational exposure
- Guarantee radiation dose and radioactive matter discharge are lower than regulative limits
- Mitigate the consequences of accidents
- ALARA

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Design Objective

Dose limit：An authorized dose limit or dose constraint is one that has been established or formally accepted by a regulatory body.

Dose constraint：Used for optimization of protection and safety, the intended outcome of which is that all exposures are controlled to levels that are as low as reasonably achievable.

Laws and regulations	Occupational effective dose limits（mSv/a）
GB 18871	20/50*
GSR Part 3	20/50*
10 CFR 20	50

*Note：An effective dose 20mSv per year averaged over 5 years, 50mSv in any single year.

Design Objective

Laws and regulations	Occupational effective dose constraint（mSv/a）
EUR	5 mSv/a
URD	Supervision
Supervision department requirements（China）	15 mSv/a
NCRP (USA)	Accumulative（working years*10mSv）
NRPB (UK)	15mSv/a（average in 5years）
Slovenia	A category: 15mSv/a； B category: 6mSv/a
ANSTO (Australia)	15mSv/a
EDF	Early warning: 16mSv/a（continuous 12 months）； Warning level: 18mSv/a

Design Objective

Laws and regulations	Collective effective dose limit
EUR	0.5man·Sv/Unit·a（average）
URD	1 man·Sv/Unit·a（average）
Supervision department requirements（China）	1man·Sv/GWe·a（single year）

China 3rd generation PWR:

Type	Collective effective dose（man·Sv/Unit·a）
AP1000	0.7（Zinc injection 0.4）
EPR	0.4（Without zinc injection）

Design Objective

"HPR 1000" radiation protection design objective:

Collective effective dose

Average over plant lifetime (target*) : < 0.5man·Sv/Unit·a

Personal effective dose (target): < 5mSv/a

*Note: This target doesn't include collective doses due to exceptional repairs or replacement of major components.

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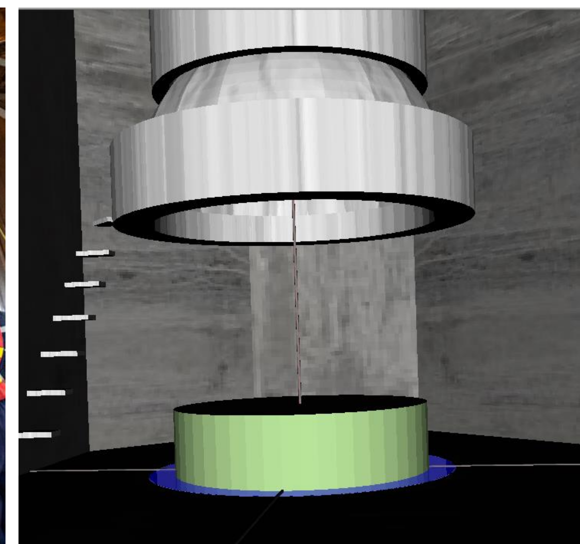
Modeling and Calculation Analysis Method

For occupational exposure of PWR NPPs, personal and collective effective dose can be assessed by modeling and calculation methods. For the calculation of the conventional external exposure dose, the operational quantities (can be directly calculated and measured) can be used to assess exposure dose instead of the protection quantities.

The external exposure dose of the person can be obtained by the dose rate and the time of exposure of the person , and the formula is as follows:

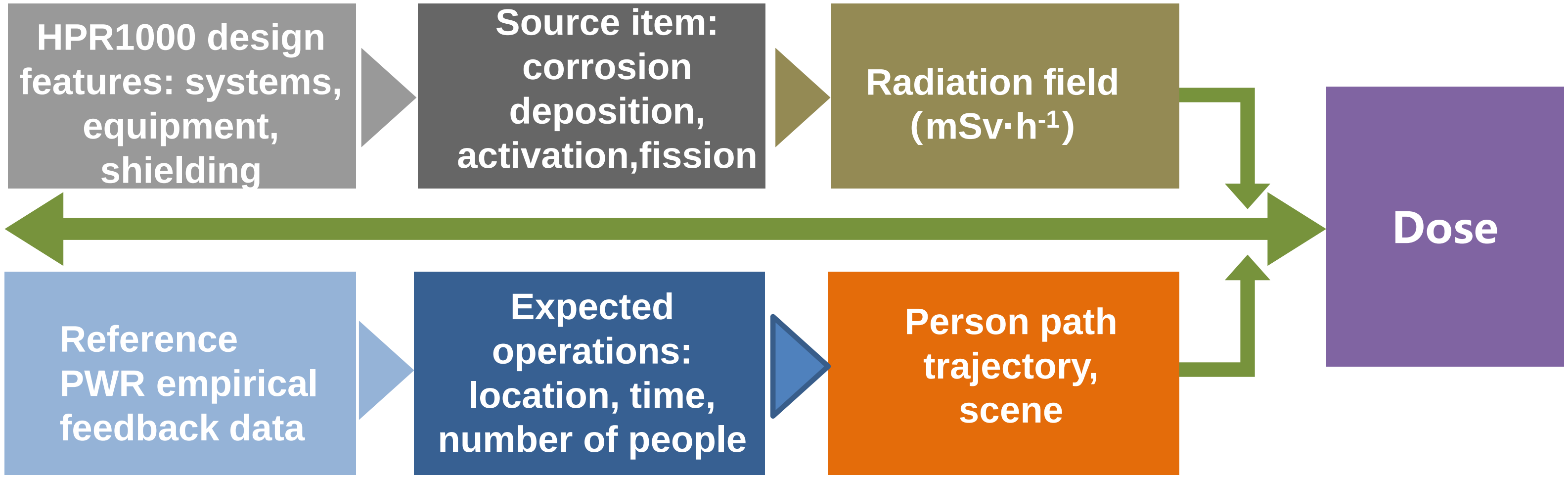
$$E_\tau = \dot{D}_R \bullet \tau$$



Modeling and Calculation Analysis Method

Data from the operational experience of China in-service NPPs show that reactor vessel operations (during overhaul) are typical high-level doses. Reactor vessel operations contribute up to 12% of the total collective dose.

The method of modeling and calculation is used to evaluate the occupational dose of nuclear power plants. The reactor vessel opening operation can be selected as a sample for evaluation and verification.



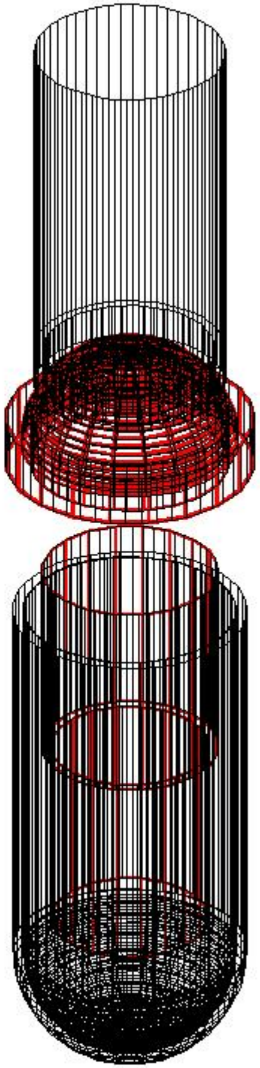
A typical example: Reactor Vessel Head Opening Operation

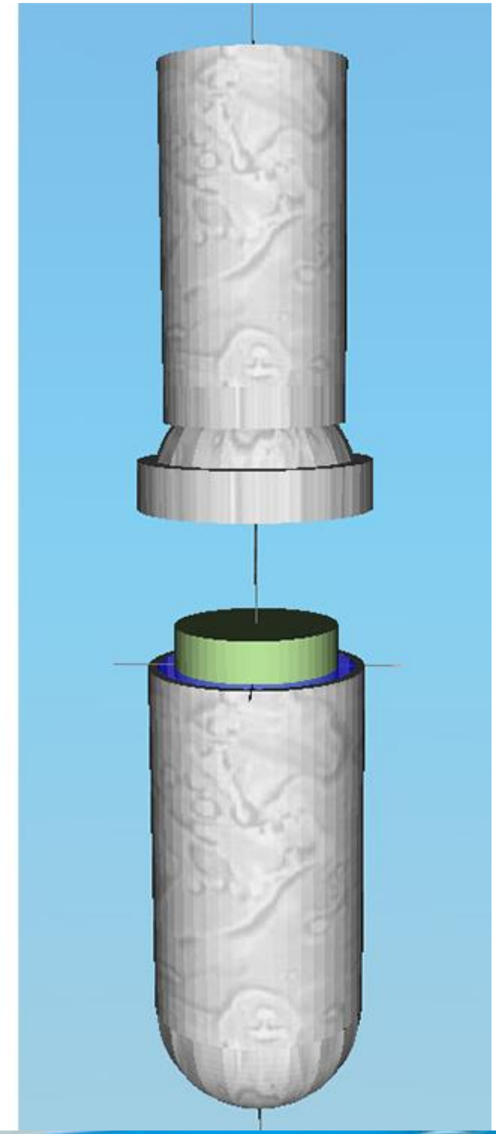
Work	NO.	Trajectory	Number of Task	Number of People
Reactor Vessel Head Opening Operation	1	Before Opening the Reactor Vessel Head - Dose Rate Measurement	8	1
	2	Before Opening the Reactor Vessel Head - Disassembly and Assembly Work	8	4
	3	Reactor Vessel Head Lifting 0.5m - Measurement and Inspection	4	3
	4	Reactor Vessel Head Lifting 14m-inspection	3	6

Modeling by VISIPLAN

Reactor Model:

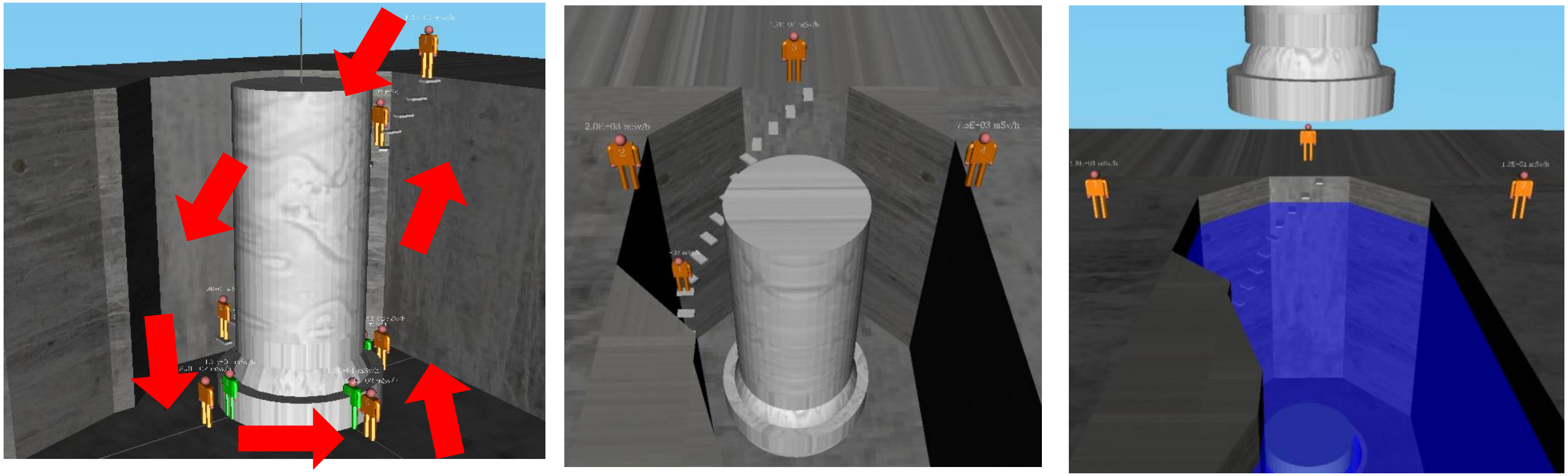
- Rod Drive Mechanism
- Reactor Vessel
- Core Internal
- Core Fuel Assembly
- Reactor Coolant





Trajectory of Reactor Vessel Head Opening Operation

Trajectory of Reactor Vessel Head Opening Operation

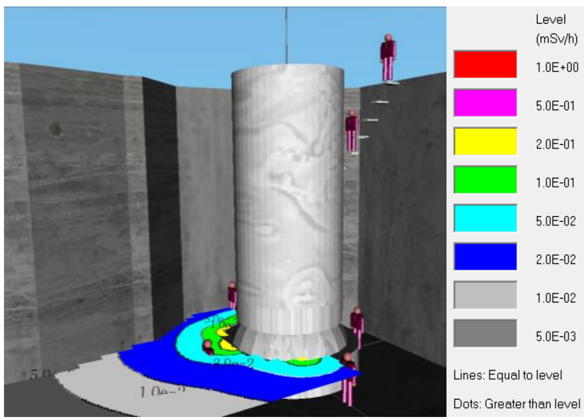


Trajectory 1： before opening the reactor vessel head - dose rate measurement
Trajectory 2： before opening the reactor vessel head - disassembly and assembly work

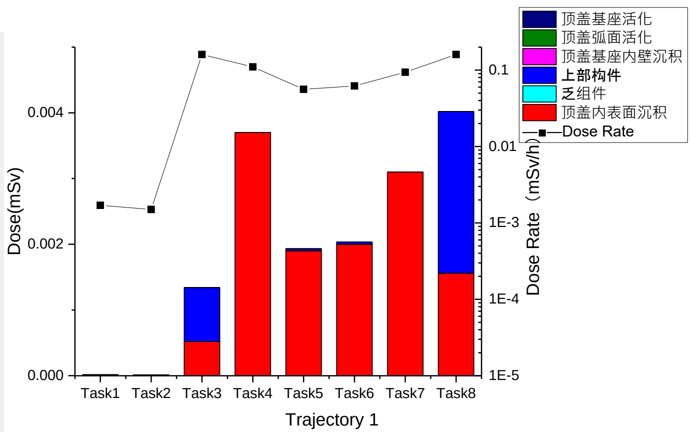
Trajectory 3： reactor vessel head lifting 0.5m - measurement and inspection
Trajectory 4： reactor vessel head lifting 14m-inspection

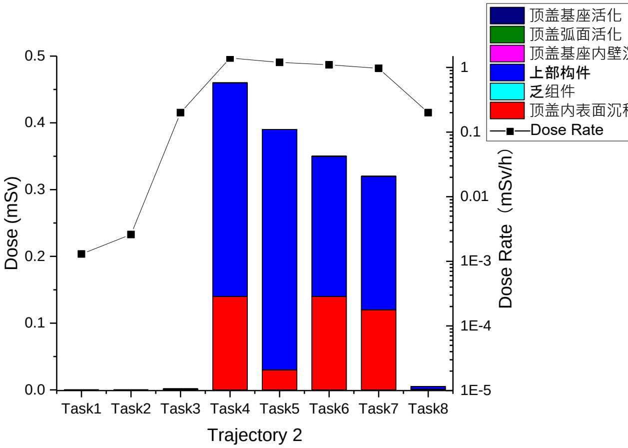
Before Opening the Reactor Vessel Head

Radiation Field



Occupational exposure dose





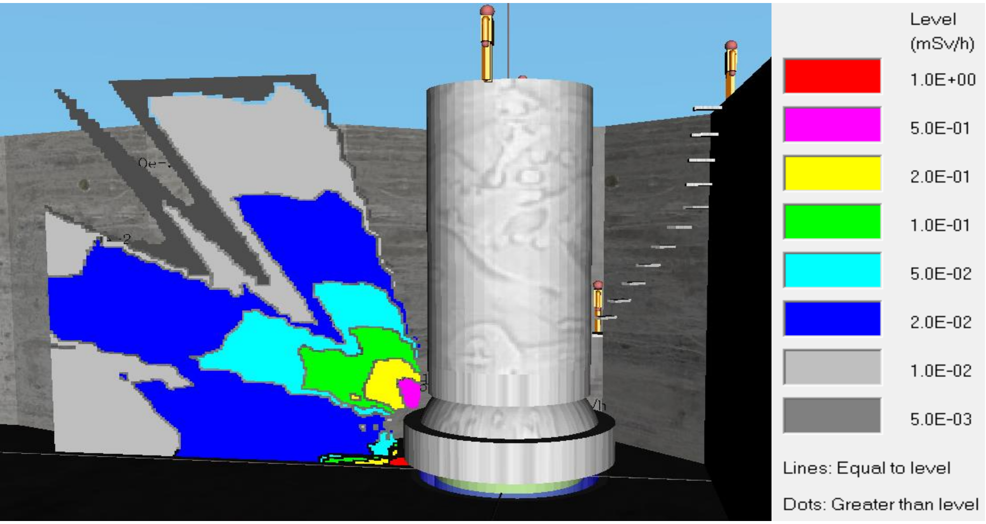
- The maximal personal effective dose about 13.4μSv；
- The maximal dose rate about 100μSv/h;

- The maximal personal effective dose about 1.25mSv；
- The maximal dose rate about 1~10mSv/h;

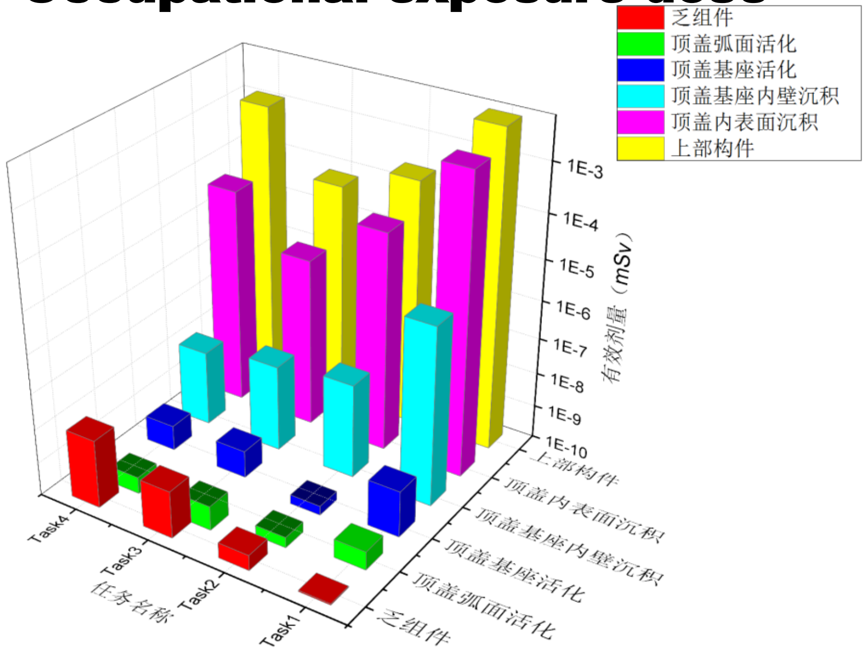
Trajectory 1& Trajectory 2

Reactor Vessel Head Lifting 0.5m

Radiation Field



Occupational exposure dose

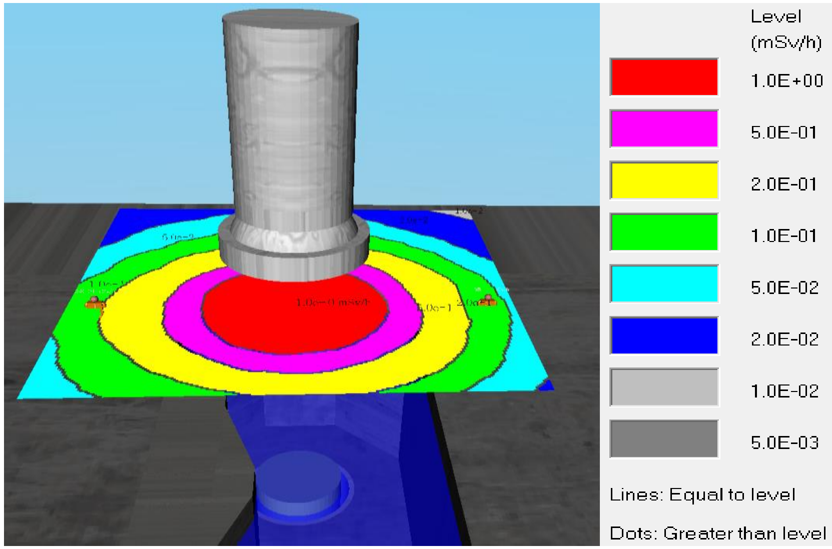


- The maximal personal effective dose about 9.7μSv;
- Task 1 contributed 83% of the total dose;
- 72% of the total dose due to upper internal， 28% of the total dose due to deposition item of cover.

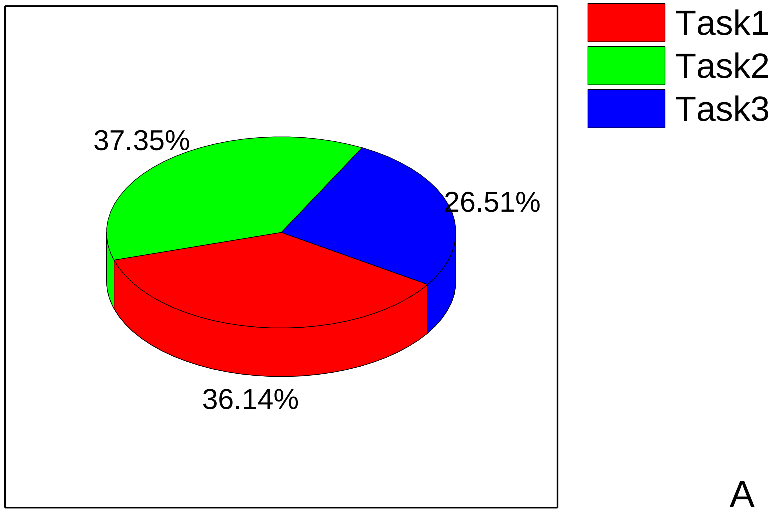
Trajectory 3

Reactor Vessel Head Lifting 14m

Radiation Field



Occupational exposure dose



- The collective effective dose about 83μSv;
- The dose due to deposition item of cover.

Trajectory 4

Occupational exposure dose

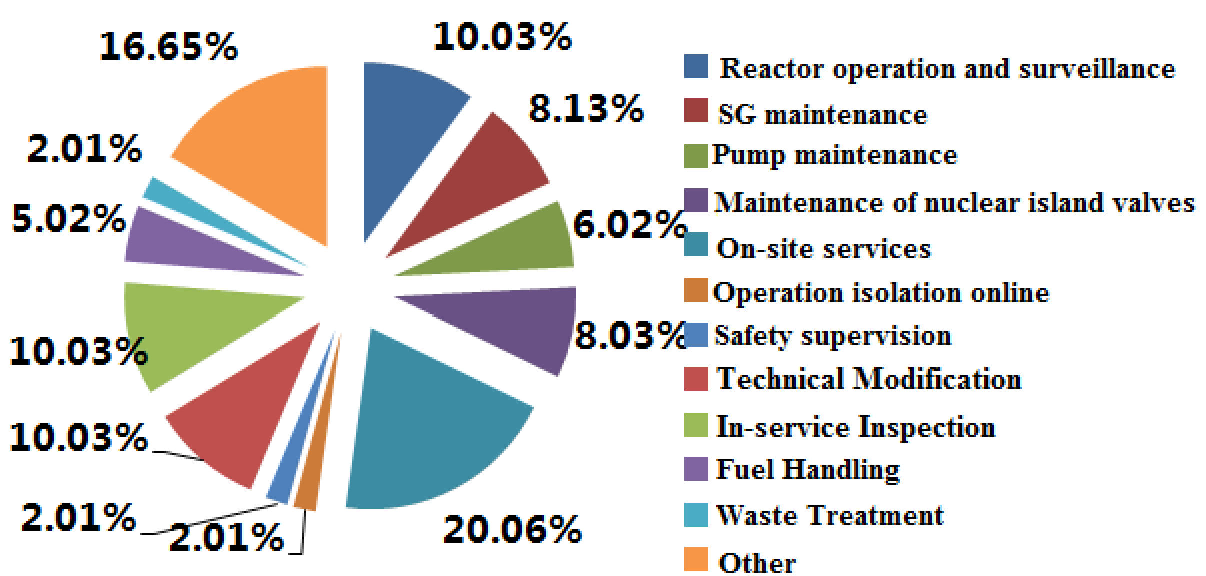
The collective effective dose of Reactor Vessel Head opening operation

Works	Operating Time（min）	Numbers of Personnel	Collective Dose (mSv)	Persents (%)
1 Before Opening the Reactor Vessel Head - Dose Rate Measurement	10±2.4	1	0.014±0.00336	0.21
2 Before Opening the Reactor Vessel Head - Disassembly and Assembly Work	83±20.6	4	6.10±1.51	91.83
3 Reactor Vessel Head Lifting 0.5m - Measurement and Inspection	40±4.0	3	0.029±0.0029	0. 44
4 Reactor Vessel Head Lifting 14m-inspection	30±3.0	6	0.50±0.05	7.53
Total	163±30	14	6.64±1.57	100

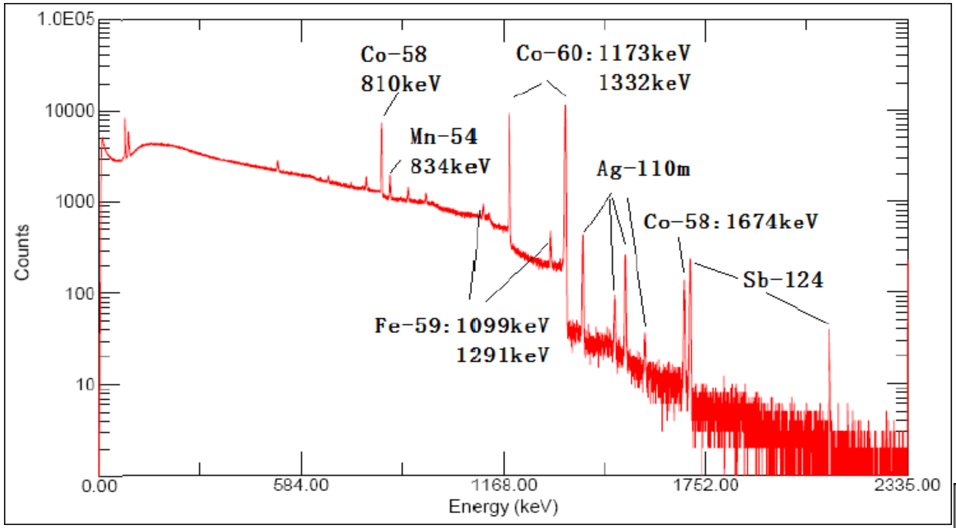
Empirical Data Analysis Method

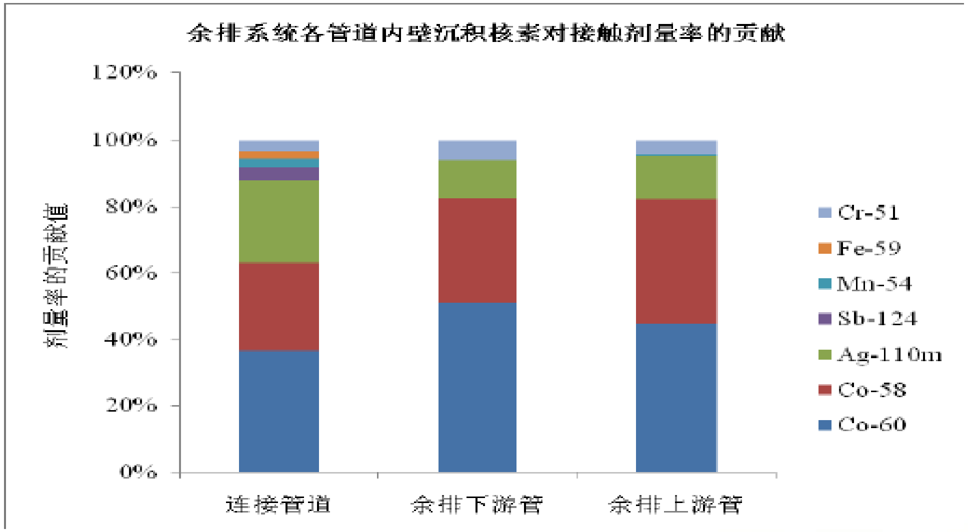
For HPR1000, occupational radiation exposure is mainly from the contribution of radioactive system components and equipment, whereas the dose due to airborne radioactivity makes a very small contribution to the total collective dose.

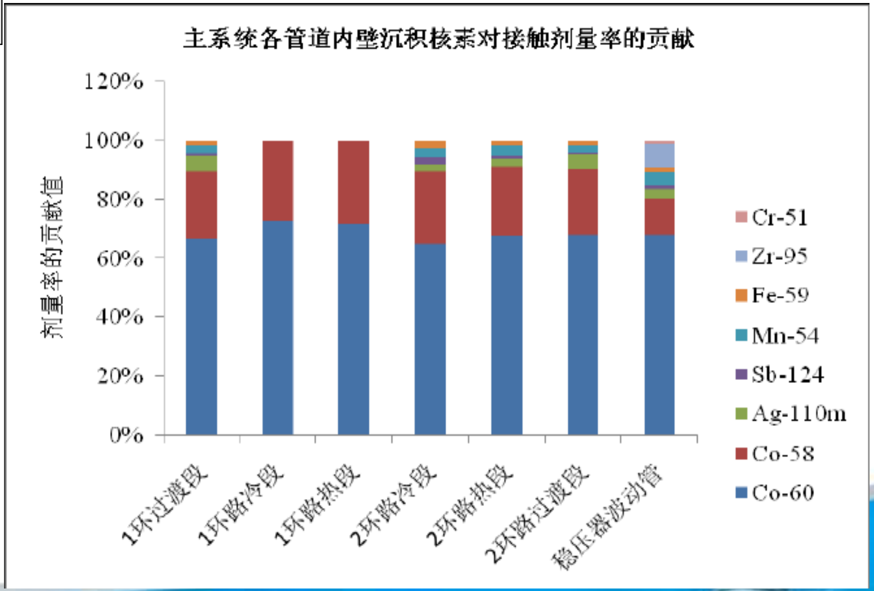
Take into account the design and operation of HPR1000, it has a lot in common with operational PWR NPPs in China, such as Daya Bay NPPs, Qinshan Phase II and Ling Ao NPPs(Units 1&2). They operating for about 90 reactor-years, by analysis the measurement records of above plants, the expected dose level of HPR1000 is obtained.



Empirical Data Analysis Method







Empirical Data Analysis Method

The operational nuclear power units of China includes Daya Bay （Unit 1&2）, Ling Ao (Unit 1&2), and Qinshan Phase II, which have an operation history about 90 reactor·year. Table 1 gives the personal dose distribution of Daya Bay(Unit 1&2) and Ling Ao(Unit 1&2) in 2004 and 2007 respectively. Table 2 provides the distribution of personal dose of Qinshan Phase II (two units) in previous years due to external exposure.

Table 1 Personal Dose Distribution of Daya Bay Unit 1&2 and Ling Ao Unit 1&2 In 2004 and 2007

Dose range (mSv)	Numbers of personnel			
	2004		2007	
	DaYa Bay	Ling Ao	DaYa Bay	Ling Ao
＜0.2	1439	1512	1822	1704
0.2～0.5	330	306	343	335
0.5～1	332	289	296	251
1～2	341	189	203	248
2～5	220	98	110	148
5～10	34	15	11	12
10～20	1	0	0	0
＞20	0	0	0	0
Tatol	2697	2409	2785	2698

Table 2 Personal Dose Distribution of Qinshan Phase II (Two Units) In Previous Years Due to External Exposure

Dose range (mSv)	Numbers of personnel							
	2003	2004	2005	2006	2007	2008	2009	2010
< 0.1	1154	1022	1155	1224	1208	1040	1158	1285
0.1~1.0	416	448	549	696	847	758	694	625
1.0-3.0	83	167	198	174	195	157	175	100
3.0~5.0	4	25	40	23	16	9	26	7
5.0~15.0	1	3	8	10	12	0	7	0
Total	1658	1665	1950	2127	2278	1964	2060	2017

Table 1 and Table 2 show that the number of people with dose more than 5 mSv/a is less than 0.15 %.
The personal effective dose is kept below the dose limit and the dose constraint, and it can be optimized to 5mSv/a(Target) for HPR1000.

Development of Occ Database System

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证书号：软著登字第0924968号

软件名称：中核工程职业照射剂量评价数据库系统
[简称：ODADS]
V1.0

著作权人：中国核电工程有限公司

开发完成日期：2013年12月20日

首次发表日期：2013年12月20日

权利取得方式：原始取得

权利范围：全部权利

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目前操作功能：计量指标列表

新增计量指标

计量指标列表 | 查询

	序号	指标名称	指标简称	指标类型	指标单位	状态	创建时间	创建人	修改时间	修改人
☐	11	机组能力因子	UCF(%)	基础指标	%	启用	2013-05-13	admin		
☐	12	集体剂量预测值	集体剂量预测值(men·mSv)	衍生指标	men·mSv	启用			2013-06-17	153879
☐	13	集体剂量	集体剂量(men·mSv)	基础指标	men·mSv	启用	2013-01-28	admin	2013-06-04	admin
☐	14	最大个人剂量	最大个人剂量(mSv)	基础指标	mSv	启用	2013-01-28	admin	2013-06-04	admin
☐	15	场所剂量率水平	场所剂量率水平(mSv/h)	基础指标	mSv/h	启用	2013-01-28	admin	2013-06-17	153879

电站信息

目前操作功能：电站信息列表

电站信息列表 | 查询

	序号	电站名称
☐	1	福清2号电站
☐	2	模型虚拟电站
☐	3	秦山核电站1
☐	4	秦山核电站
☐	5	福清核电站

总记录：5 页码：1/1 每页：10

删除

目前操作功能：查看模板

列表数据导入模板 修改模板 预览模板

查看模板 | 添加业务指标项（行表头） | 业务项排序 | 添加统计指标项（列表头） | 统计项排序 | 模板预览

模板复制管理

导入模板主题名称 ______ 导入模板主题简称 ______ 保存

模板规则配置

统计指标 每一项 业务指标 每一项 下限值 ______ 上限值 ______ 保存

模板预览信息

	作业时间	作业人数	场所剂量率水平	最大个人剂量	集体剂量
蒸汽发生器-小计	1~9	1~9	1~9	1~9	1~9
一次侧人孔开启和关闭	1~9	1~9	1~9	1~9	1~9
堵板的安装和拆卸	1~9	1~9	1~9	1~9	1~9
水室疏水孔焊瘤处理	1~9	1~9	1~9	1~9	1~9
一次侧水室内部TV检	1~9	1~9	1~9	1~9	1~9
U型管涡流检查	1~9	1~9	1~9	1~9	1~9
二次侧开关手孔、眼孔	1~9	1~9	1~9	1~9	1~9
二次侧泥浆冲洗	1~9	1~9	1~9	1~9	1~9
在役检查	1~9	1~9	1~9	1~9	1~9
安全监督及其他配合	1~9	1~9	1~9	1~9	1~9
堵管作业	1~9	1~9	1~9	1~9	1~9

导出模板

Empirical Data Analysis Method

Table 3 summarizes the anticipated annual collective doses (average over plant lifetime) of HPR1000 for main items, which adds up to a total of 490 man·mSv/unit·a. Hence, the collective effective dose value of HPR1000 is lower than 0.5 man·Sv/Unit·a *.

Contents of the operation		Expected collective dose target (man·mSv/unit·a)
Reactor operation and surveillance		100
Maintenance	SG maintenance	60
	Pump maintenance	25
	Maintenance of nuclear island valves	35
	On-site services	100
	Operation isolation online	20
	Safety supervision	20
In-service inspection		60
Fuel handling		50
Waste treatment		20
Total		490

*Note: This target doesn't include collective doses due to exceptional repairs or replacement of major components.

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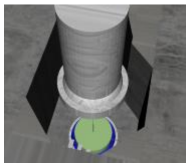
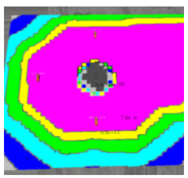
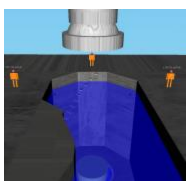


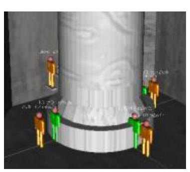
Modeling & Calculation



Radiation Field



Dose



Design Optimization

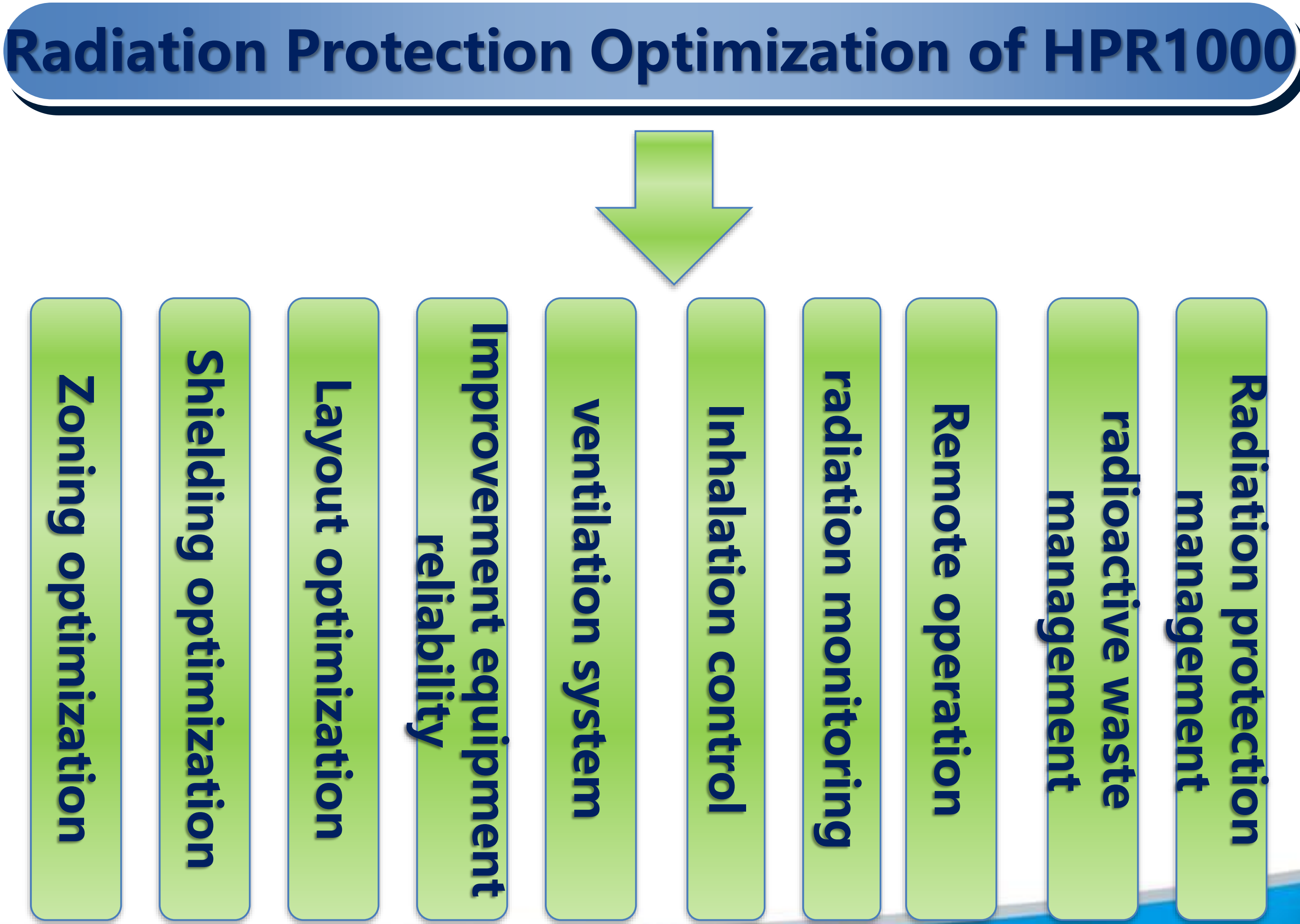
Dose Assessment

Operational States

Dose Assessment Criteria

Optimization

RP Optimization

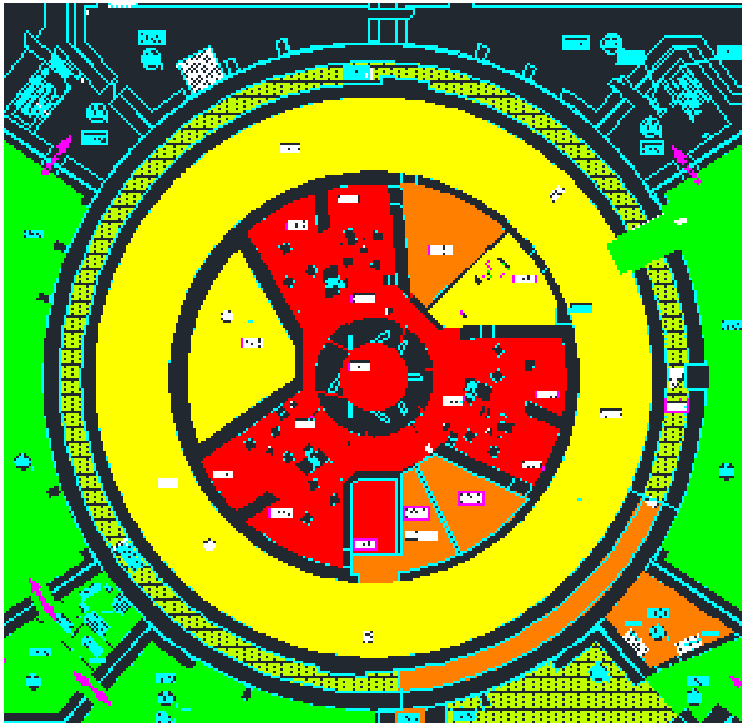


RP Optimization

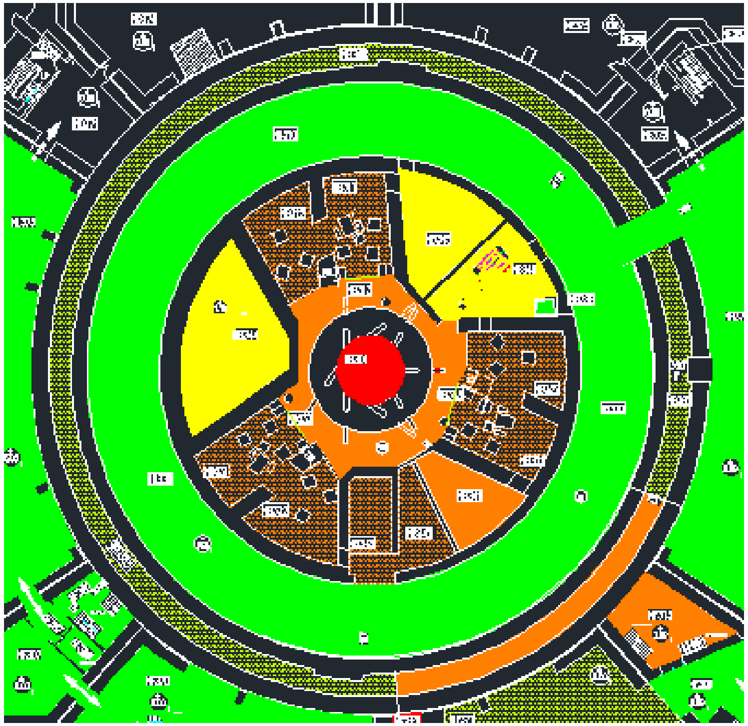
Generation Ⅱ+ in China		HPR1000	
zone	Dose rate（mSv/h）	zone	Dose rate（mSv/h）
White zone	≤0.0025	White zone	≤0.0025
Green zone	≤0.01	Green zone	≤0.01
Yellow zone	≤1	Yellow Ⅰ zone	≤0.1
		Yellow Ⅱ zone	≤1
Orange zone	≤100	Orange Ⅰ zone	≤10
		Orange Ⅱ zone	≤100
Red zone	＞100	Red zone	＞100

RP Optimization

Zoning of different conditions



Operation condition



Shutdown condition

Dose assessment of HPR1000

- Dose assessment can indicate the level of radiation protection optimization.
- In preliminary design, dose assessment was carried out based on the dose constraint value, operation experience feedback.
- Target of annual collective dose
  less than 0.5 man·Sv/unit·a (average over plant lifetime)

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Target of occupational exposure dose for HPR1000

Collective effective dose	
HPR1000	Target of annual collective effective dose less than 0.5 man·Sv/unit·a (averaged over plant lifetime)*

Personal effective dose	
HPR1000	5mSv/a

*Note: This target doesn't include collective doses due to exceptional repairs or replacement of major components.

Thank you!