

2016

基于多物理场耦合的方法分析熔盐堆工况

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2 模型建立

3 模块选择



4 结果结论



为什么
选多物理耦合

熔盐堆中的参数的关系

- 缓发中子先驱核浓度和中子通量有关
- 中子通量的大小取决于缓发中子先驱核浓度
- 裂变源项取决于中子通量
- 熔盐流速场取决与燃料的裂变源项
- 温度场分布取决于裂变源项

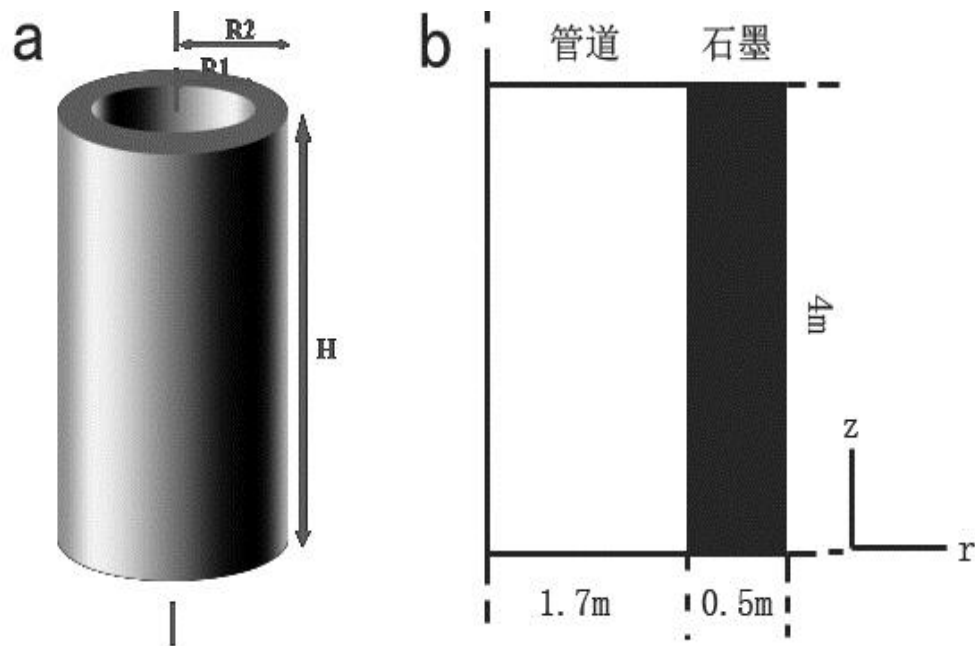
研究
内容

发生工况时参数的变化情况：

- 失流事故
- 石墨膨胀
- 出现空泡
- 控制棒扰动



第四届国际论坛上，熔盐堆是唯一一种以液态为燃料的反应堆，熔盐堆研究不同于其他反应堆。我们将反应堆模型简化为一个石墨围成的空腔结构如图[1a]。为简化计算采用二维轴对称图形如图[1b]。



流体流动接口中单向流中的湍流模式模拟熔盐流体流动
传热模块中流体传热模拟熔盐传热、传热模块中固体传热模拟石墨传热
稀物质传递接口模拟反应堆中先驱核浓度
系数型偏微分方程模拟中子扩散

$$\rho C_p u \cdot \nabla T + \nabla \cdot q = Q$$

$$d_s \frac{\partial u}{\partial t} + \nabla \cdot (-c \nabla u - \alpha u + \gamma) + \beta \cdot \nabla u + au = f$$

$$\nabla \cdot (-D_i \nabla c_i) + u \cdot \nabla c_i = R_i$$

$$\rho(u \cdot \nabla)u = \nabla \cdot [-pI + (\mu + \mu_T) (\nabla u + (\nabla u)^T)] + F$$



系数型偏微分方程接口



中子扩散方程

$$e_a \frac{\partial^2 \mathbf{u}}{\partial t^2} + d_a \frac{\partial \mathbf{u}}{\partial t} + \nabla \cdot (-c \nabla \mathbf{u} - \alpha \mathbf{u} + \gamma) + \beta \cdot \nabla \mathbf{u} + a \mathbf{u} = f$$

$$\mathbf{u} = [\text{Phi1}, \text{Phi2}]^T$$

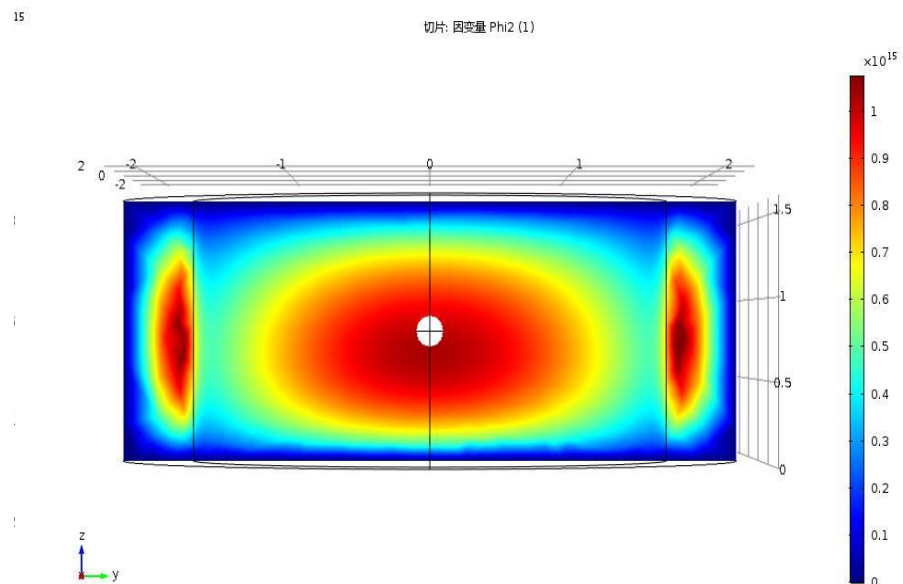
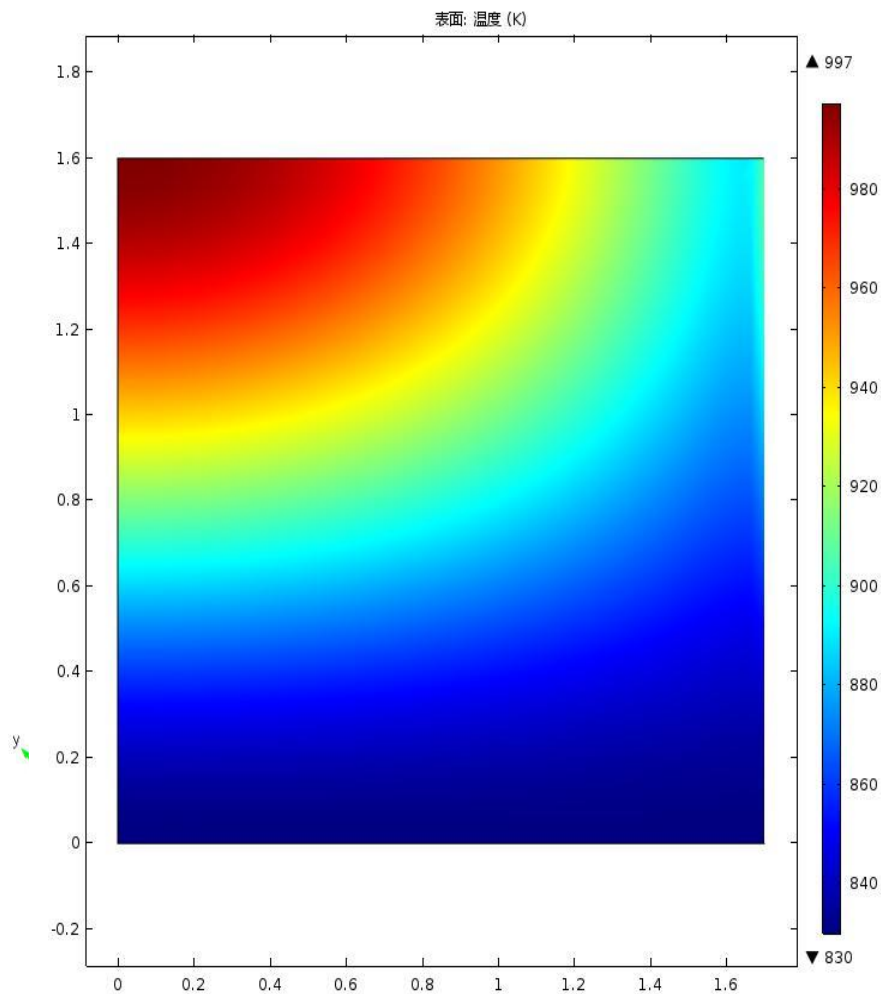
$$\nabla = \left[\frac{\partial}{\partial r}, \frac{\partial}{\partial z} \right]$$

$$\text{Fuel region} \begin{cases} \frac{1}{v_{1,F}} \frac{\partial \phi_1}{\partial t} = -\nabla \cdot (-D_{1,F} \nabla \phi_1) - (\Sigma_{a1,F} + \Sigma_{1 \rightarrow 2,F}) \phi_1 + \Sigma_{2 \rightarrow 1,F} \phi_2 + (1 - \beta)(v_1 \Sigma_{f1} \phi_1 + v_2 \Sigma_{f2} \phi_2) + \sum_{i=1}^6 \lambda_i c_i \\ \frac{1}{v_{2,F}} \frac{\partial \phi_2}{\partial t} = -\nabla \cdot (-D_{2,F} \nabla \phi_2) - (\Sigma_{a2,F} + \Sigma_{2 \rightarrow 1,F}) \phi_2 + \Sigma_{1 \rightarrow 2,F} \phi_1 \\ \frac{\partial c_i}{\partial t} = -\nabla \cdot (u c_i) + \beta_i (v_1 \Sigma_{f1} \phi_1 + v_2 \Sigma_{f2} \phi_2) - \lambda_i c_i \quad i = 1 \div 6 \end{cases}$$

$$\text{Graphite region} \begin{cases} \frac{1}{v_{1,G}} \frac{\partial \phi_1}{\partial t} = -\nabla \cdot (-D_{1,G} \nabla \phi_1) - (\Sigma_{a1,G} + \Sigma_{1 \rightarrow 2,G}) \phi_1 + \Sigma_{2 \rightarrow 1,G} \phi_2 \\ \frac{1}{v_{2,G}} \frac{\partial \phi_2}{\partial t} = -\nabla \cdot (-D_{2,G} \nabla \phi_2) - (\Sigma_{a2,G} + \Sigma_{2 \rightarrow 1,G}) \phi_2 + \Sigma_{1 \rightarrow 2,G} \phi_1 \end{cases}$$



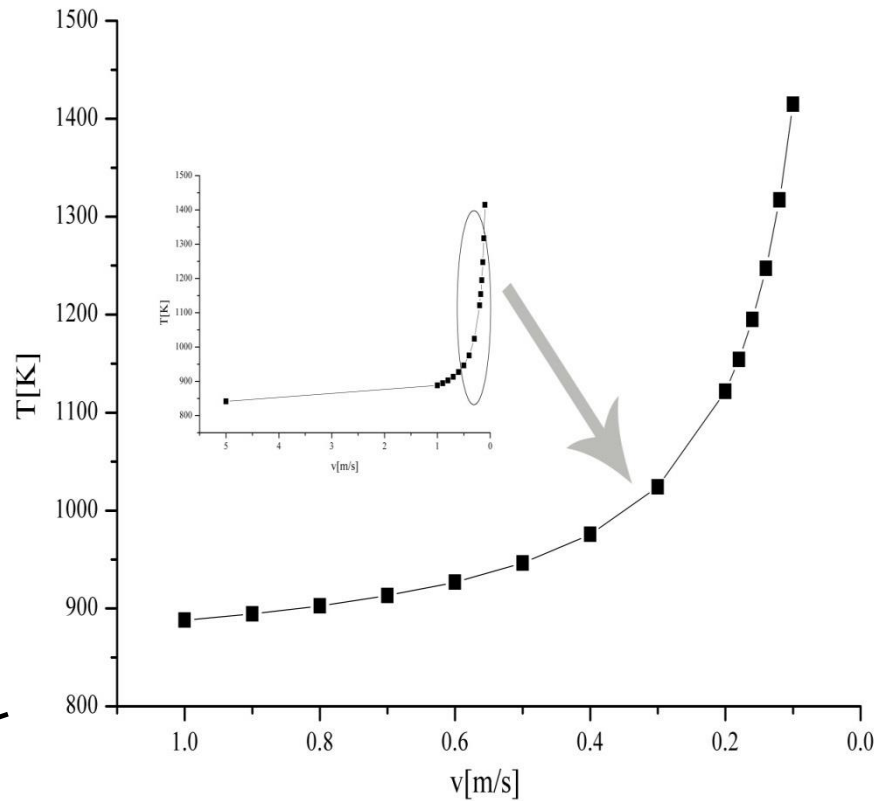
反应堆中热中子通量分布、温度场分布



失流事故

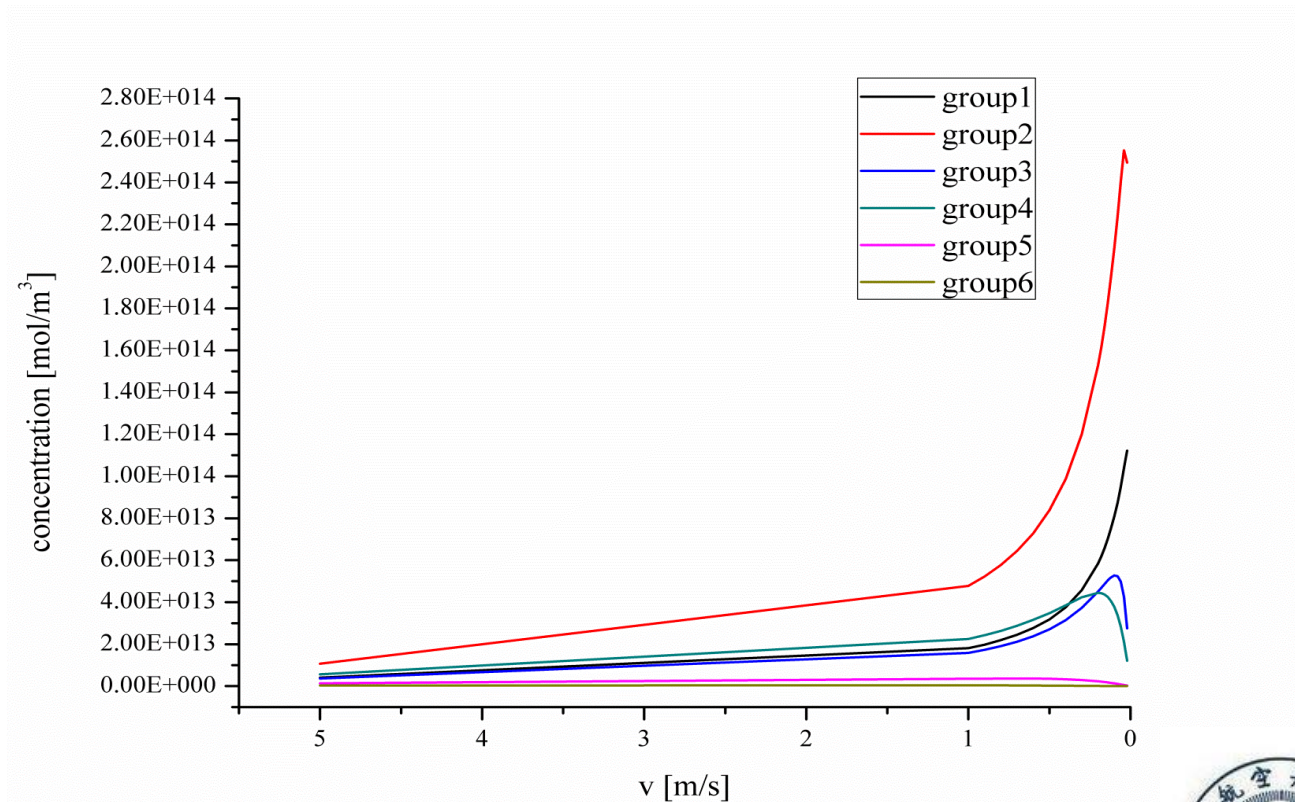
失流事故是指反应堆冷却剂系统因主泵失去电源、断轴或卡轴等电气或机械故障而使反应堆冷却剂流量减少或中断的事故。

温度判断是否紧急停堆



The result of the loss of flow

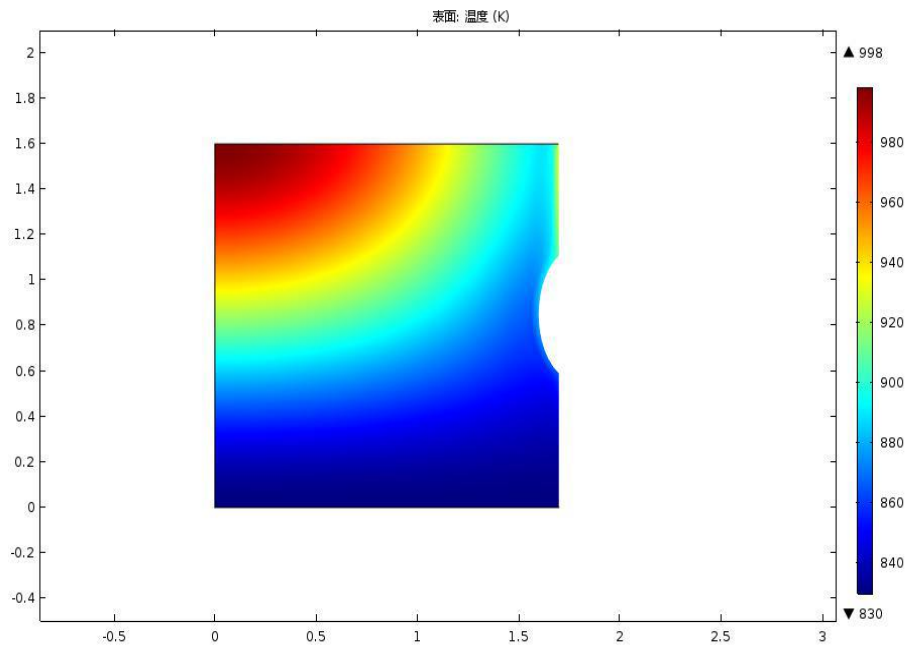
失流事故



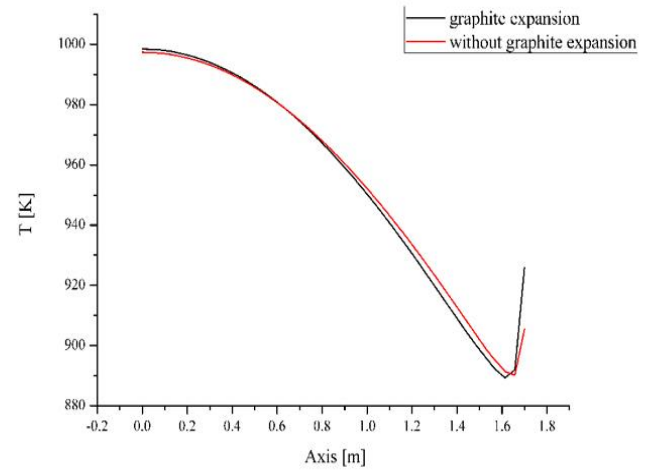
缓发中子先驱核浓度的变化



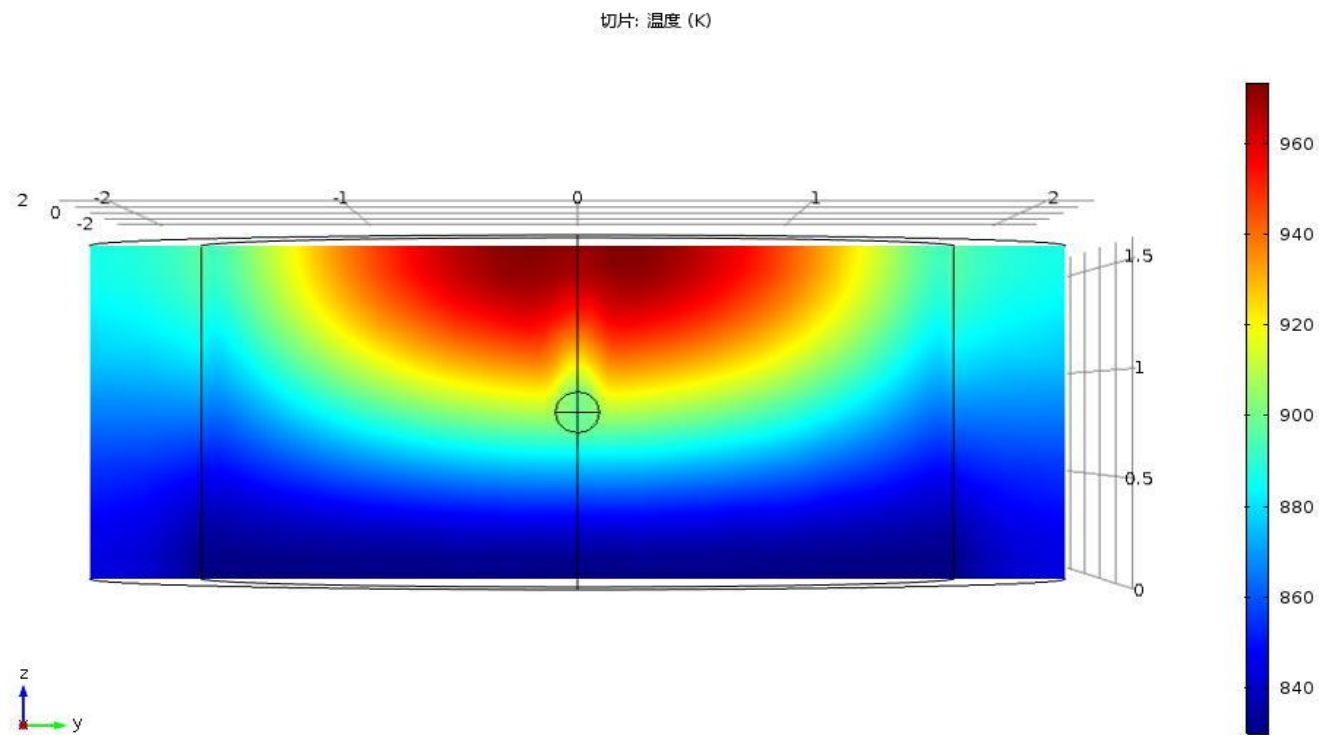
石墨膨胀



在轴向1.2m处得到温度沿径向变化

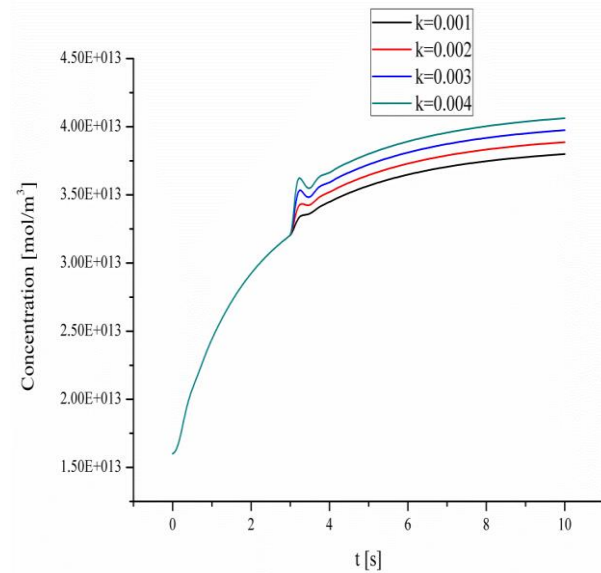
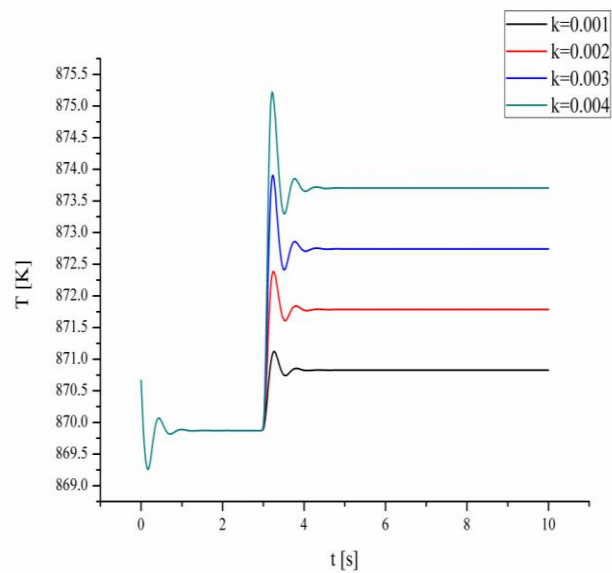
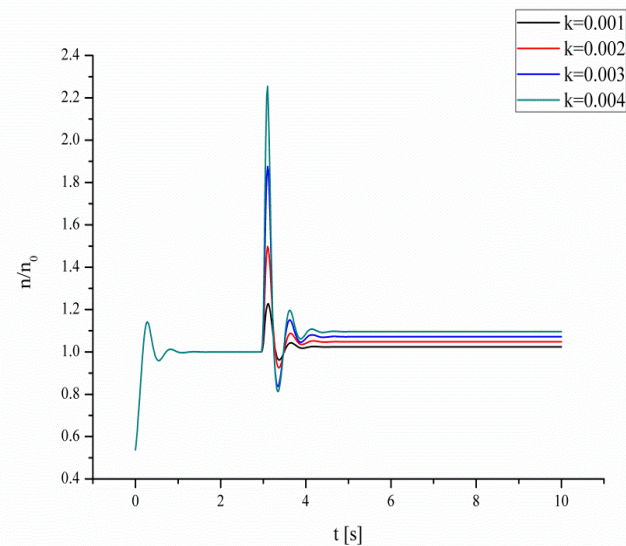


出现空泡时，温度场的分布



控制棒扰动

瞬态反应性阶跃变化堆芯中点处参数变化



参考文献



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提问环节



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谢 谢 点 评 ！

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