KAERI/TR-781/96

CANDU-9/480-SEU의 핵연료 취급계통 설계 평가 보고서

CANDU-9/480-SEU Fuel Handling System Assessment Document

한 국 원 자 력 연 구 소

KAERI/TR-781/96

CANDU-9/480-SEU의 핵연료 취급계통 설계 평가 보고서

CANDU-9/480-SEU Fuel Handling System Assessment Document

한 국 원 자 력 연 구 소

제 출 문

한국원자력연구소장 귀하

본 보고서를 "CANDU-9/480-SEU의 핵연료 취급계통 설계 평가 보고서"에 대한 기술보고서로 제출합니다.

1996. 12

연구 기관명 : 원전설계그룹 기계설계팀

참여 연구원

주 저 자 : 황정기

공동저자 : 김현민, 조충희
D.T. Morikawa

책임감수위원 : 김동훈

감 수 위 원 : 석수동

요 약

CANDU 9 핵연료 취급계통 설계의 방법 및 요건들을 살펴보았다.

CANDU 9 480-SEU 핵연료 취급계통의 주요 부품인 핵연료 교환기, 캐리지, 새연료 이송장치, 조사후 핵연료 이송장치 등의 개략적인 설계특성 및 설계요건들을 CANDU 6 및 CANDU 3의 경우와 비교하여 기술하였다. 그리고 CANDU 9 캐리지를 구성하고 있는 부품들에 대하여 지진하중 예비평가를 수행한 결과가 부록에 나타나 있는데 약간의 설계개선이 이루어진다면 캐리지 부품에 작용하는 하중들은 모두 허용기준을 만족하는 것으로 평가되었다.

CANDU 9 480-SEU 핵연료 취급계통의 설계개념은 검증된 CANDU 설계에 근거를 두고 있을 뿐 아니라 개선된 CANDU 기술을 활용하고 있으므로 CANDU 9 원자로 설계에 실행가능한 설계개념이라고 판단된다.

SUMMARY

This report summarizes the rationale for the CANDU 9 fuel handling system, and the design choices recommended for components of the system.

Some of the design requirements applicable to the CANDU 9 480-SEU fuel handling design choices are described. These requirements were based on CANDU 6 or CANDU 3, as well as the overall requirements imposed by the CANDU 9 project. And the design features for the key components of the fuel handling system, such as the fuelling machine, the carriage, the new fuel transfer system and the irradiated fuel transfer system, are described.

The carriage seismic load evaluations relevant to the design are contained in the appendix. The majority of the carriage components are acceptable, or will likely be acceptable with some redesign.

The concept for the CANDU 9 fuel handling system is based on proven CANDU designs, or on improved CANDU technology. Although some development work must be done, the fuel handling concept is judged to be feasible for the CANDU 9 480-SEU reactor.

TABLE OF CONTENTS

1. INTRODUCTION

This document summarizes the rationale for the CANDU 9 fuel handling system, and the design choices recommended for components of the system.

The CANDU 9 480-SEU fuel handling system is similar to the CANDU 3 in layout. The fuelling machine carriage is based on the CANDU 3 design, with some sections strengthened and the overall height increased to accommodate the larger reactor face. The fuelling machine snout is based on the CANDU 3 design. The fuelling machine magazine housing is also based on the CANDU 3 design but sized to a modified CANDU 6 capacity. The fuelling machine ram is based on the CANDU 3 (CANDU 6 / Pickering) design but is increased in length due to longer fuel channel endfitting. The new fuel and irradiated fuel transfer is based on the CANDU 3 designs.

Some of the evaluations relevant to the design are contained in the appendix. Design Concept Decisions (DCD's) were prepared for the fuelling machine ram and the fuelling machine. These documents evaluate the components and options in more detail than contained here.

2. DESIGN REQUIREMENTS

The fuel handling system is required to handle the fuel between arrival at the station and temporary storage in the fuel bay. The purpose of refuelling is to maintain the reactor at the required power output.

The requirements were based on previous experience with other projects, such as CANDU 6, CANDU 3, as well as the overall requirements imposed by the CANDU 9 project. Some of the key requirements applicable to the CANDU 9 480-SEU fuel handling design choices are described below.

The CANDU 9 reactor is a 480 channel reactor, with longer endfittings and a larger reactor face than the CANDU 6. The fuelling machine ram length required to reach the shield plug is approximately 780mm longer on CANDU 9 than on CANDU 6. The increase in ram stroke also increases the fuelling machine length, compared to CANDU 6.

The larger reactor face requires a taller carriage structure, so that the fuelling machine can access all the channels. The design of the carriage structure and the reactor design will determine the seismic loads and stresses in the carriage. These loads must be evaluated for the cases where the fuelling machine is attached to a fuel channel endfitting or where the fuelling machine is unattached, in order to make a judgement on the feasibility of the carriage type transporter for the CANDU 9 480-SEU. The carriage structure will be classified as a pressure vessel support, and designed in accordance with CAN/CSA-N285.2 which largely refers to the rules of the ASME Boiler and Pressure Vessel Code, section III, subsection NF.

The fuelling machine design may also be the cause of significant loads on the rolled joint and positioning assembly. These components are not fuel handling items, and are assessed elsewhere [1], although the design of the fuelling machine may have a substantial impact on the loads seen by these components.

The refuelling will be done with a fuelling machine clamped at each end of the fuel channel, and refuelling in the direction of the flow, as is done on CANDU 6. However, the fuel will be SEU rather than NU, and the reactor physics require an average refuelling rate of 113.4 bundles per week, based mainly on 2-bundle shifts with some 4-bundle shifts. This will require the fuelling machine to visit 49 channels per week, compared to an average of about 15 channels per week for CANDU 6. This imposes more difficult requirements on the fuelling machine operation, fuel handling availability and cycle times than previous designs. The refuelling time should allow at least half the hours in a week to be available for fuelling machine maintenance. It is also desirable for a single refuelling cycle to be less than 12 hours. Ease of maintenance and quick fuelling machine removal become key considerations. The capacity of the fuelling machine magazine is largely determined by the refuelling requirements, but the size and mass of the magazine will, in turn, affect the seismic loads at the rolled joint and positioning assembly.

The use of 2-bundle shifts requires an evaluation to ensure that the drag force will allow refuelling with flow, without the use of a Flow Assist Ram Extension (FARE) tool. If a FARE tool were required, it would impact on the magazine bundle capacity and the cycle times.

For advanced designs, such as the CANDU 9, it is desirable to minimize personnel exposure and minimize the work necessary in the reactor building. The new fuel and spent fuel transfer systems for CANDU 9 will be selected to meet these requirements.

3. KEY DESIGN FEATURES

The key components of the fuel handling system are the fuelling machine, the carriage, the new fuel transfer system and the irradiated fuel transfer system.

3.1 FUELLING MACHINE

The fuelling machine design chosen for CANDU 9 is mainly based on the CANDU 3 and CANDU 6 type fuelling machines.

The snout will be based on the CANDU 3 design. The design is similar to the CANDU 6 snout and will be manufactured from code acceptable materials. This will avoid problems obtaining a concession from the jurisdiction, and will increase the toughness of the snout, which is needed in a seismic event. Some of the components must be made more robust compared to CANDU 6, in order to use code acceptable materials.

The separators will be similar to the CANDU 6 separators. Separator type refuelling is consistent with current knowledge regarding inlet bundle fretting, power pulse problems and endplate support, and among the advantages, allows more flexibility in modifying the separators to accommodate new fuel bundle designs.

The magazine housing will also be based on the CANDU 3 design. The CANDU 3 magazine housing material selection will simplify manufacture. The CANDU 3 housing design will also eliminate the Grayloc joint which will simplify maintenance.

The magazine rotor design will be based on the CANDU 6 design to save weight, and reduce seismic loads on the carriage structure and the rolled joint and positioning assembly. The magazine capacity will be based on the CANDU 6 which has 12 magazine stations of which 5 are for fuel bundles. A minor modification will be made, as was done on the CANDU 3, to increase the bundle capacity to 6 stations (12 bundles), without increasing the totol number of magazine stations. The preliminary evaluation of the fuel string forces suggests that the FARE tool will not be required for CANDU 9. This evaluation makes some simplifying assumptions which are conservative. This will allow all 6 fuel stations to be used for fuel.

The modified CANDU 6 capacity magazine was the most suitable choice, based on cycle times and seismic loads. The refuelling time will be about 65 hours per week. More importantly, the larger magazine increases the fuelling machine mass and directly impacts on the rolled joint and positioning assembly seismic loads. The cycle time and fuelling machine availability for maintenance are best balanced by the choice of the modified CANDU 6 capacity. The CANDU 9 480-SEU fuel handling cycle time and maintenance availability is acceptable.

The ram assembly will be based on the CANDU 6/Pickering type ram, with four small diameter ballscrews. There are two criticl issues that must be addressed with respect to the ram ballscrews. First, the ram ballscrews will be longer on the CANDU 9 than on CANDU 6 or CANDU 3. Considerable effort was needed to develop the existing design and same development effort will be needed to prove the longer ballscrews. The second key issue is the ram life. Because the number channel visits has increased significantly for the CANDU 9, the ballscrew life will be unacceptable based on current CANDU 6 ballscrew maintenance experience. Therefore the ballscrew life between maintenance must be improved to meet the requirements for the design. It is believed that these issues can be resolved but it will require a significant development program.

3.2 CARRIAGE

The CANDU 9 carriage will be a trolley type transporter, similar to CANDU 3, rather than the bridge and fixed column type as in CANDU 6.

The entire carriage is driven into the maintenance lock in order to accept new fuel and unload spent fuel. The carriage can also be driven into the maintenance lock in order to be maintained. This is a significant advantage over the bridge type system, where the reactor must be shut down to perform bridge maintenance, and higher personnel exposure must be accepted. The carriage type design will also improve construction schedules, because the major assemblies can be assembled and tested off-site, rather than assembled and tested on site.

Some of the key carriage components were evaluated in order to assess the feasibility of the carriage design for CANDU 9. The evaluation was done using the conservatively calculated seismic loads, which are significantly higher than the normal operating loads. The results indicate that although many of the components are over-stressed, the design should be acceptable with design modifications. Note that these calculations were done to examine feasibility, and the calculations are therefore simplified design calculations. Detailed stress analysis will be done at a later stage of design.

There are some key items to note in the preliminary seismic evaluation. The shielding box was deleted to remove as much cantilevered mass as possible, and the size and design of the fuelling machine magazine were selected in order to minimize the mass attached to the endfitting. The lower turntable section was increased in thickness over that for the CANDU 3. As well, most of the improvement in loads for the attached case are a result of the reactor improvements, rather than carriage improvements.

In order to reduce maintenance time, the fuelling machine will be mounted in a suspension frame that can be rolled off the carriage, to speed up fuelling machine replacement. A large capacity overhead crane will not be needed to remove the fuelling machine head, as in CANDU 3.

3.3 NEW FUEL TRANSFER

The new fuel transfer system for CANDU 9 will be based on the CANDU 3 design.

The CANDU 9 new fuel transfer system will be located outside the reactor building(In CANDU 6, the new fuel transfer mechanisms are located inside reactor building). This will facilitate maintenance, prevent use of valuable containment space, and reduce personnel exposure compared to CANDU 6. The transfer mechanism will form part of the containment boundary, so that the fuelling machine and associated supplies do not have to be qualified as containment.

3.4 SPENT FUEL TRANSFER

The spent fuel transfer system for CANDU 9 will be based on the CANDU 3 design.

The CANDU 9 spent fuel tranfer sustem is located outside the reactor building(In CANDU 6, the spent fuel discharge bays are located inside the reactor building). The CANDU 9 transfer mechanism forms the containment boundary. This avoids complications in having the fuelling machine form the containment boundary. Any improvements or subsequent developments to the CANDU 3 transfer system will be considered for CANDU 9.

4. CONCLUSIONS

The concept for the CANDU 9 fuel handling system is based on proven CANDU designs, or on improved CANDU technology. Although some development work must be done, the fuel handling concept is judged to be feasible for the CANDU 9 480-SEU reactor. The critical areas identified are fuelling machine ram ballscrew life and fuel handling seismic design.

5. REFERENCES

1. CANDU 9 Technical Description, 69-01371-TED-003, September 1994.

2. CANDU 9 Reactor Higher Seismic Design, 69-31200-ASD-001, October 1994.

APPENDIX A

CARRIAGE SEISMIC LOAD EVALUATION - SUMMARY

CANDU 9 480-SEU CARRIAGE SEISMIC LOAD PRELIMINARY EVALUATION - SUMMARY

1. INTRODUCTION

A large CANDU is being assessed by a joint study by KAERI and AECL. The purpose of the current phase of the study is to assess the feasibility of a 480 channel, SEU fuel reactor.

As part of this study, a fuel handling system has been selected for preliminary examination. Many issues have been examined to determine if the fuel handling concept is feasible. One issue is the ability of the fuelling machine carriage to withstand the seismic loads. The following is a summary of the results of the seismic load evaluation of the carriage.

The preliminary seismic loads were supplied from the reactor seismic model. The reactor design for higher seismic loading is discussed in "CANDU 9 Reactor Higher Seismic Design", 69-31200-ASD-001, October 1994 [2].

2. SEISMIC LOADS

The loads on the carriage were supplied from the seismic model developed to assess the reactor structure. The loads on the carriage structure are different depending on whether the fuelling machine is clamped onto a channel endfitting (attached) or not clamped to the endfitting (unattached). The loads will also vary depending on the location of the carriage in the horizontal direction and the elevation of the fuelling machine.

Five unattached cases were examined: channel lattice positions A13, M13, Y13, D04 and D21. For the unattached condition, three positions were examined: A13, M13 and Y13. For each of these channels, two cases were run: (i) the fuelling machine clamped onto the fixed end of the channel, and (ii) the fuelling machine clamped onto the free end of the channel. In the model, the fuelling machine was always clamped to the outlet end of the channel, and therefore the two cases were achieved by switching the fixed and free ends of the channel (inlet or outlet).

Due to the damping in the model, there was a 10% non-conservatism in all the loads.

The loads were supplied in global co-ordinates, where the "x" axis is the horizontal axis parallel to the carriage rail, the "y" axis is the vertical axis, and the "z" axis is the horizontal axis parallel to the fuel channel centre line.

3. METHOD OF EVALUATION

This evaluation is not a stress analysis. The main objective of the evaluation was to assess feasibility, and therefore the calculations are of a design nature. The calculations use design simplifications, and classical analysis techniques. If components were overstressed, a judgement was made on whether the stress could be solved by simple design changes, based on the magnitude of the stress, and design considerations, such as feasibility of using thicker plate, using larger diameter bolts, etc. The general method of this evaluation was:

a. identify the loads to be applied,
b. identify the key points that should be evaluated,
c. evaluate the stress at these key points, and
d. compare the stresses to the allowables.

There are many carriage components that are on the load path. Because the purpose of the evaluation was to assess feasibility, only some key components were examined. The components were selected based on discussion with experienced AECL-CANDU staff in fuel handling design and analysis.

The loads to be applied were selected from the five unattached cases and the 6 attached cases. In some cases, a worst case could be identified by inspection. In other cases the peak loads were scattered among several cases, and a single worst case could not be easily identified. In these cases the worst enveloping loads were often used. The loads were applied to give the worst stress at the point being considered, and some cases this will be conservative.

Only the stresses at key points on the component were examined. These critical points were chosen based on inspection. For example, in the evaluation of the carriage wheel loads, only two items were examined: the peak stress at the extreme fibre of the middle of the shaft, and the static load capacity of the cylindrical roller bearings. Note that contact stresses, wheel stresses, etc, were not evaluated.

The allowable stresses were selected to be consistent with ASME section NF. In some cases, the specific rules of evaluation in section NF were used, such as when evaluating buckling. However, in most cases the stresses were evaluated based on the maximum shear stress criterion, because it was desired to obtain a quick design evaluation. Hence the maximum shear stress was determined from Mohr's circle, and compared to the half the allowable stress intensity. These allowables were only used for the design type calculations as discussed. Final design of the supports will require rigorous analysis in accordance with the applicable codes.

Some typical stress intensities, such as those below, were used where the material has not been identified :

a. structural steel, A572-84, Grade 42, S_m = 20.0 ksi, code case N-71-15.
b. bolting, 4340-H, SA-540, B23, S_m = 50 ksi.
c. bolting, 17-4PH SA-564, 630, S_m = 38.3 ksi.
d. alloy steel, 4340 A668-83 (forging) S_m=1/3 UTS = 53 ksi, code case N-249-9.

4. RESULTS

The results of the carriage seismic load preliminary evaluation are briefly described below. Note that "acceptable" indicates that the stresses at the key point(s) examined were acceptable.

1. Snout Tip Displacement

   The snout displacements are large, for the unattached cases, but will not result in interference with the carriage.

2. Ram End Displacement

   The ram displacements, like the snout displacements, are large for the unattached cases. Pitch and yaw dampers should be considered.

3. X-Lock Loads - Lower

   The lower x-lock loads do not exceed the design loading. Acceptable.

4. Lower Turntable Bearing Loads

   The bearing loads do not exceed the catalogue rating. Acceptable.

5. Lower Turntable Local Bending

   The stresses in the lower turntable are acceptable, based on several simplifications to the geometry to allow classical analysis. This complex part will need more analysis later.

6. Bottom of Column Loads

   The stresses at the bottom of the column are acceptable. Larger diameter bolting will be required, and dowels will be needed to carry the shear loads.

7. Column Cross Beam Loads

   The column cross beam section stresses and bolt stresses are acceptable.

8. Ballscrew Loads

   The ballscrews will not buckle under the unattached case loads. The ballscrew will buckle under the attached case loading. The preload will have to be increased to prevent compressive loading, or other options considered.

9. Elevator Bearing Loads

   The elevator bearings are loaded beyond their catalogue rating, but should be acceptable. They may need replacing after a seismic event.

10. Ballnut Support Beam Loads

The ballnut support beam is over stressed. This part will require redesign.

11. Elevator/Outer Suspension Frame Joint (OSF) Loads
The elevator/OSF joints are overloaded, and will require larger diameter bolting and shear pins. This should be feasible.

12. Z-drive Support Loads - Horizontal and Vertical
The bolts on the horizontal member of the z-drive support are overstressed. The bolting arrangement will require some redesign, such as increasing the bolt diameter, increasing the bolt spacing or increasing the number of bolts. The bolting on the vertical member is acceptable.

13. Trunnion Fine X-drive Loads
The fine x-drive internal components should be acceptable.

14. Z-screw Loads
The z-screw loads will not buckle and have acceptable stresses.

15. Z-spring Loads

The z-spring mechanism is acceptable.

16. Yaw Spring Loads

The yaw spring mechanism is acceptable, but will require redesign. Dampers should be considered.

17. Upper Turntable Loads

The yoke arms and the turntable slewing ring are acceptable. The trunnion block bolts are overstressed and will require larger diameter bolts and redesign.

18. Ram Support Loads

The ram support loads appear acceptable.

19. Magazine/Cradle Joint Loads

The lugs are overstressed, and will contribute to a large load on the magazine flange. This area will require redesign.

20. Pitch Spring Loads

The pitch spring mechanism is acceptable, but will require redesign. Dampers should be considered.

21. Trunnion Body Loads

The trunnion body is slightly over stressed, and will require redesign.

22. Upper X-lock Loads

The upper X-lock loads on the face do not exceed the design loading. However, these locks take additional z-direction loads, and will require redesign for these loads.

23. Snout/Endfitting Forces and Moments

This is a fuelling machine component, but is a key assembly. The clamping barrel stresses appear acceptable, but the centre support may be overstressed. This is a complex assembly, which will obviously require detailed modelling and analysis at a later stage.

24. Anchor (Wheel) Loads

The wheel assembly loads are acceptable.

25. Top Beam Anchor Loads

The embedment loads should be acceptable, based on discussions with Civil Engineering. The bridge section is overstressed, which can likely be resolved by using slightly thicker plate.

26. Anti-Liftoff Hooks

The anti-liftoff hooks are acceptable.

27. Guide Rollers

The guide rollers are acceptable.

28. Elevator Inner Connecting Beam

The elevator inner connecting beam is acceptable.

5. CONCLUSION

The majority of the carriage components are acceptable, or will likely be acceptable with some redesign. Some components will require more careful consideration or more extensive redesign such as the Y-drive ballscrews, the ballnut support beam, snout, and the magazine and cradle joints.

서 지 정 보 양 식

수행기관보고서번호	위탁기관보고서번호	표준보고서번호	INIS 주제코드
KAERI/TR-781/96			

제목/부제	CANDU-9/480-SEU의 핵연료 취급계통 설계 평가보고서
연구책임자 및 부서명 (TR, AR인 경우 주저자)	황 정 기 (운전기계분야)
연 구 자 및 부 서 명	김현민, 조충희 (운전기계분야) D.T. Morikawa

출 판 지	대전	발행기관	한국원자력연구소	발행년	1996. 11
페 이 지	p. 25	도 표	있음(O), 없음( )	크 기	18× 26 cm
참고사항					
비밀여부	공개 (O), 대외비( ), __ 급비밀			보고서종류	기술 보고서
연구위탁기관				계약 번호	

초록 (15-20줄내외)

CANDU 9 핵연료 취급계통 설계의 방법 및 요건들을 살펴보았다.

CANDU 9 480-SEU 핵연료 취급계통의 주요 부품인 핵연료 교환기, 캐리지, 새연료 이송장치, 조사후 핵연료 이송장치 등의 개략적인 설계특성 및 설계요건들을 CANDU 6 및 CANDU 3의 경우와 비교하여 기술하였다. 그리고 CANDU 9 캐리지를 구성하고 있는 부품들에 대하여 지진하중 예비 평가를 수행한 결과가 부록에 나타나 있는데 약간의 설계개선이 이루어진다면 캐리지 부품에 작용하는 하중들은 모두 허용기준을 만족하는 것으로 평가되었다.

CANDU 9 480-SEU 핵연료 취급계통의 설계개념은 검증된 CANDU 설계에 근거를 두고 있을 뿐 아니라 개선된 CANDU 기술을 활용하고 있으므로 CANDU 9 원자로 설계에 실행가능한 설계개념이라고 판단된다.

주제명키워드 (10단어내외)	CANDU 9, 핵연료 취급계통, 캐리지, 핵연료 교환기, 새연료 이송장치, 조사후 핵연료 이송장치, 지진하중 평가

BIBLIOGRAPHIC INFORMATION SHEET			
Performing Org. Report No.	Sponsoring Org. Report No.	Stamdard Report No.	INIS Subject Code
KAERI/TR-781/96			

Title/Subtitle	CANDU-9/480-SEU Fuel Handling System Assessment Document
Project Manager and Department	Hwang, Jeong-ki (Mechanical Equipment Design Dept.)
Researcher and Department	C.H. Jo, H.M. Kim (Mechanical Equipment Design Dept.) D.T. Morikawa

Publication Place	Taejon	Publisher	KAERI	Publication Date	1996. 11
Page	p. 25	Fig. & Tab.	Yes(O), No ( )	Size	16 × 26 cm
Note					
Classified	Open(O), Restricted( ), ___ Class Document	Report Type	Technical Report		
Sponsoring Org.		Contract No.			

Abstract (15-20 Lines)

This report summarizes the rationale for the CANDU 9 fuel handling system, and the design choices recommended for components of the system.

Some of the design requirements applicable to the CANDU 9 480-SEU fuel handling design choices are described. These requirements were based on CANDU 6 or CANDU 3, as well as the overall requirements imposed by the CANDU 9 project. And the design features for the key components of the fuel handling system, such as the fuelling machine, the carriage, the new fuel transfer system and the irradiated fuel transfer system, are described. The carriage seismic load evaluations relevant to the design are contained in the appendices. The majority of the carriage components are acceptable, or will likely be acceptable with some redesign.

The concept for the CANDU 9 fuel handling system is based on proven CANDU designs, or on improved CANDU technology. Although some development work must be done, the fuel handling concept is judged to be feasible for the CANDU 9 480-SEU reactor.

Subject Key words (About 10 words)	CANDU 9, fueling hadling system, carriage, fuelling machine, new fuel transfer system, irradiated fuel transfer system, seismic load evaluation