

Earthquake Fatigue Analysis for CANDU® Nuclear Power Plants

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1 ABSTRACT

This paper presents the results of an investigation into the number of cycles for seismic fatigue analysis for equipment located in CANDU®² nuclear power plants. Seismic fatigue analysis has been identified as a governing factor for different equipment analysis and fitness for service. The primary objective of the paper is to review the earthquake fatigue analysis requirements with a focus on the number of the equivalent full stress seismic cycles. Following this the paper derives the number of seismic full stress cycles to be used for seismic fatigue analysis for nuclear power plants equipment, piping and their supports.

By subjecting the overall nuclear power plant system to different earthquake records and using the material fatigue life curve, a method is developed to calculate the number of fatigue cycles equivalent to the total seismic response. This method is applied to the response results of key points of the dynamic model of the system in order to determine the maximum number of equivalent seismic fatigue cycles for various conditions. Based on the results of the time-history analyses performed for CANDU reactor systems, recommendations related to the number of seismic stress cycles are given for seismic qualification of CANDU equipment, piping and their supports. The paper concludes that 25 cycles for seismic fatigue analysis is adequate for all applications. The results of the current work should help the justification for additional life for existing plants and cost effective design for new plants.

2 INTRODUCTION

The objective of this work is to investigate the number of equivalent cycles at the peak response to be used in seismic fatigue analysis. To achieve this objective, the supporting structure (Reactor Building) and the equipment (Reactor) are modelled as a three-dimensional dynamic system. The building and reactor responses are calculated for realistic structural and equipment frequencies, subjecting the overall system to different artificial design ground motions as well as real earthquakes records. Analyses using time-history integration of the equations of motion of the system are performed for a suite of earthquakes. These earthquakes represent the ground motions used in different CANDU plants. For comparison with real earthquakes another suite of historical earthquakes is added and this included the El Centro and Alaska earthquakes. The earthquake ground motions were applied to a typical CANDU 6 three-dimensional Reactor Building. The equivalent numbers of cycles at the peak response for the input ground motions are calculated. The response time histories for the reactor building are calculated as well as the equivalent numbers of cycles at peak response. By subjecting the three-dimensional model of the reactor to the building motions of the vault floor, the equivalent numbers of cycles at the maximum response amplitude for the end fitting, which represents the seismic input to the feeders, are obtained.

The paper reviews codes and standards related to seismic fatigue analysis being practiced in the nuclear industry, with a focus on the number of the equivalent seismic fatigue cycles at the maximum response amplitude. Particular attention is given to seismic analysis of feeder pipes and the application of the ASME design fatigue curves. Based on the results of the new time-history analyses performed for CANDU reactor systems, recommendations related to the number of seismic fatigue cycles are given for seismic qualification of CANDU equipment, piping and their supports. The report concludes that 25 cycles for seismic fatigue

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analysis is adequate for all applications. The current practice of using 200 cycles for piping fatigue analysis is excessive. For existing plants, unrealistically high number of seismic fatigue cycles will make it difficult to demonstrate the feasibility of life extension and can endanger the margin left to accommodate additional thermal and pressure cycles. For new plants, the design may become expensive, just to cater for an arbitrary high number of seismic fatigue cycles.

The safety philosophy for CANDU nuclear power plants (NPP) requires the primary heat transport system and certain other high- pressure systems to be designed to withstand the Design Basis Earthquake (DBE) without failure, to ensure that a gross loss-of-coolant accident (LOCA) will not occur as a direct consequence of such an earthquake. This is assured first by limiting the primary stresses (due to pressure, weight and earthquake inertia loads) to stress Level 'C' of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components. While Level 'C' permits direct primary stresses to reach or exceed the yield point, it is a far more conservative criterion than Level 'D' allowed in the U.S.A. for the Safe Shutdown Earthquake (SSE), which is similar in severity to the DBE.

Avoidance of a LOCA is further assured by performing a fatigue analysis to account for the cyclic stresses developed in such critical systems during the DBE, so that the total cyclic damage caused by the earthquake can be evaluated, along with the fatigue effects produced by normal NPP operation.

To avoid complex and costly time-history fatigue analyses of each critical pressure vessel and piping system, an investigation is made to establish, in general terms, the fatigue effects when such a system responds to the seismic excitation of a reactor building (primary system) which supports it. From this investigation, convenient rules can be established for determining the fatigue behaviour of actual NPP systems. The main objective is to determine the number of seismic full stress cycles at the maximum response amplitude for seismic fatigue analysis of CANDU equipment, piping, and their supports. Having established the equivalent number of cycles to be used in seismic fatigue analysis, which are the number of cycles at the maximum response, the current requirements for the number of cycles as given in CSA N289.3 (or a lower number of seismic cycles) can be validated and the practice to use 200 cycles for piping fatigue analysis can be replaced with a more realistic number of cycles.

For an existing plant, unrealistically high number of seismic fatigue cycles will make it difficult to demonstrate the feasibility of life extension and can encroach on the margin left to accommodate additional thermal and pressure cycles. For new plants, the design may become overly constrained and thus less suitable for normal operating cycles, just to cater for an arbitrarily high number of seismic fatigue cycles.

3 BACKGROUND

Fatigue is a failure mechanism that may be experienced by equipment and components if they are under a cyclic loading condition. To guard against potential fatigue failure, a fatigue analysis is performed which involves determination of stress amplitudes and the associated number of allowable stress cycles in comparison to the applied number of cycles. A dynamic analysis can be performed to establish the response time histories of the equipment or components subjected to dynamic loading. Various techniques are then used to count the number of cycles corresponding to the peak seismic stress amplitudes from the time histories.

Whenever the floor response spectrum method is used in piping seismic analysis, the number of cycles to apply at the maximum response is not known and must be established by other means in order to carry the fatigue assessment.

While all codes and international guides agree on the need for fatigue analysis for nuclear power plants components, there are differences, both on the number of stress cycles to be used and on whether the fatigue analysis should be done for the Design Basis Earthquake or the Operating Basis Earthquake. As an example, the ASME Code does not call for a fatigue analysis for SSE. The U.S. practice is to consider a fatigue analysis for five (5) OBEs as Level B for which the ASME Code requires a fatigue analysis rather than for a single SSE event that is classified as a level D event. Analysis for the OBE is not required if the OBE level is low enough (less than 1/3 SSE).

The current CSA N289.3 differentiates between two types of equipment; ground supported and floor supported systems. The number of cycles for seismic fatigue analysis is 15 cycles for ground supported systems, 25 cycles for floor supported systems. The 25 cycles for fatigue analysis are therefore considered applicable to all mechanical equipment. For piping, CSA Standard Clause 6.3.3.2 (d) of CAN3-N289.3 states that “it is adequate to consider 200 seismic cycles when determining the equivalent seismic fatigue effects from the design fatigue curves of Figure I-9.0 of ASME Code III”. The 200 seismic cycles was recommended as a conservative number for piping fatigue analysis. There was a belief that seismic fatigue would not become a governing factor in piping design or a life-limiting factor in operation while 25 cycles were specified for other floor supported components. The major CANDU piping systems that are connected to well-supported and seismically qualified equipment can be considered floor supported where the number of seismic cycles can be one order of magnitude lower.

The EPRI experience database indicates that well engineered piping systems do not fail by seismic induced inertia or fatigue loading and piping systems are seismically rugged. This fact needs to be reconciled to ensure that an overly conservative number of seismic cycles should not result in seismic being life limiting factor.

The USNRC requirements for fatigue analysis which is applicable for all components are: “20 full cycles of the maximum SSE stress range (no OBE), or 1 SSE seismic event (10 cycles) + 5 OBE seismic events (50 cycles)”. The SSE is treated as level D and there is no fatigue analysis for Level D in the ASME Code.

The CSA 289.3 requirements for fatigue analysis (15 cycles for ground supported system and 25 cycles for floor supported system) should satisfy those of current USNRC guidelines. This is because of the differences in seismic stresses between the OBE and SSE. The 15 cycles for ground-supported systems is more realistic than USNRC requirements since earthquake ground motions are broadband in nature and that should be reflected in a smaller number of equivalent cycles.

The industry is definitely progressing towards reducing the recommended conservative number of seismic fatigue cycles for analysis of earthquake events to a more realistic number, especially for the fitness for service assessments of the operating plants.

The ASME seismic fatigue curves are applicable irrespective of the allowable stress levels A, B, C and D. This was also substantiated by review of the Japanese tests by Hara and Shibata that demonstrates that the ASME fatigue curves are adequate for strain and stress-controlled loadings for fatigue assessment. The WRC bulletin also shows that ASME S-N curve can be applied to Level C loading.

4 Dynamic Models and Analysis Methodology

For the purpose of the current investigation, both the primary and secondary systems are idealized as three-dimensional systems. The primary system model is a full three-dimensional dynamic system representing the actual CANDU 6 reactor building. The model accounts for the three-dimensional nature of the seismic effects including torsion. The reactor model is also three dimensional in nature and represents a typical CANDU 6 core housed in a concrete vault as shown in Figures 1 and 2. The selected seismic ground motion excites the primary system (Reactor Building). The motion of the primary mass at the elevation where the reactor is located excites the secondary systems that include the calandria and reactor vault. Damping values of CSA N289.3 were implemented in the models. Since this investigation is primarily concerned with fatigue, these levels of damping are adopted although considered conservative. The time-history dynamic response of each system was calculated using well established numerical integration methods and well established STARDYNE computer program. The time step used was selected to correspond to the selected earthquake time histories (in general 0.01 s).

Because of the generic nature of the study, CANDU 6 models were used. The work utilizes the reactor building and the reactor models to produce seismic motions that can be used as input to secondary systems, equipment or feeders. The objective is to arrive at representative time-histories that are typical for fatigue analysis calculations and to define the number of equivalent cycle. This is considered an improvement of the original work done by Duff and Heidebrecht where single one-degree of freedom systems were used.

Different earthquake records were used in the study. The first set of records considered are the artificial spectrum-compatible time histories used in the recent time history seismic analyses for a CANDU 6 reactor

building. These time histories meet the power spectrum requirements as practiced today in the industry. In addition the three orthogonal components of the time histories are statistically independent with relatively small correlation coefficients. The fatigue characteristics of these ground motions are considered conservative and, as a result, it is expected that the resulting design recommendations would have a broad range of validity for other applications. Other sets of spectrum-compatible design time histories are those used for other plant sites. These time histories consist of one horizontal component and one vertical component since some of the early seismic analyses were based on two-dimensional analysis. The two horizontal components were assumed the same in the current work (i.e. same time variation). In addition a fourth set that includes a number of historical earthquake records obtained during real earthquakes from El Centro, California and Alaska are also used in the current work. The different time history records used in the study are listed and described in Table 1.

In each case of analysis, the ground motion is applied for a minimum of 20 seconds of excitation or longer and the computations are based on that duration. Even though there would still be some secondary motion after the end of the earthquake, it can be demonstrated that the additional cumulative fatigue damage after that time would be small compared to usage accumulated during the strong motion excitation.

The time histories used cover a wide range of time histories. These are considered adequate for fatigue analysis for all site conditions in Canada. The absolute amplitudes for these earthquakes are not significant for deriving the number of cycles for fatigue analysis. Therefore the results should be applicable to all nuclear power plants sites in Canada.

In the current work particular attention is given to examining the input motion for the feeder seismic analysis. Two points of interest for seismic response motions are investigated. The first is the response of the headers where this constitutes the input seismic motion for one end of a typical feeder. The second is the Reactor fuel channel end fitting where the seismic input is applied to the other end of a typical feeder.

Three distinct studies are reported in this work. Firstly, the case of the secondary system supported directly by the ground and receiving the ground motion directly. Secondly, is the case of the secondary system supported by the structure (e.g., the header is supported by the boiler room floor). Thirdly, is the case where the secondary system is supported by the reactor end fitting and receiving its motion from this point.

5 FATIGUE EQUIVALENCE

The objective of this investigation is to determine, for each time-history response, the number of cycles at some specified reference acceleration amplitude that will have the same fatigue effect as the ensemble of acceleration peaks of varying amplitude. The manner chosen to determine such equivalence is essentially that described by as early as 1973 by Fischer and Wolff, which was developed for a linear log S - log N fatigue life relationship, in which S is the strain amplitude parameter and N is the number of cycles of fatigue life. Another way of expressing that same relationship is given by:

$$N = C S^{-\lambda} \quad (1)$$

in which C is a constant dependent upon the position of the curve (on the log S - log N diagram) and λ is a constant related to the slope of the curve. For this type of fatigue-life relationship, the equivalence rule can be stated as: N_i cycles at amplitude S_i is equivalent to N_j cycles at amplitude S_j , where N_i is given by:

$$N_i = N_j (S_j/S_i)^\lambda \quad (2)$$

The above equivalence rule is well established in the ASME pressure vessel and piping code appendices and is uniquely suited for low cycle seismic fatigue analysis. The parameter λ is inversely proportional to the slope of the fatigue-life curve and consequently, from (2), N_i will be largest for fatigue-life curves with the largest slope and therefore the lowest value of λ . The equivalence rule stated above is dependent upon the parameter λ and not on the actual position of the fatigue-life curve, which is governed by the constant C. It should be stressed that the ASME Code uses equation 2 for interpolation between tabulated points on the design curve. In the Code, the λ values are the local slope of the S-N curve at the interpolation point. The

use of the equation here extrapolates over a slightly wider range, but uses a bounding value for λ , which is conservative for this evaluation.

It is necessary to consider the parameter that would be analogous to the strain-amplitude parameter S referred to in the previous paragraphs. Since this is a generalized study and since, the acceleration amplitude is directly proportional to strain for linear-elastic systems, it is assumed that acceleration 'A' is the analogous parameter.

It is necessary to consider an appropriate value of the parameter λ . Examining typical fatigue-life curves for materials used in nuclear power plants yielded values of λ ranging from 3 to 5. Since the lowest value of λ is the most critical since it leads to a larger number of cycles, this study was done using $\lambda = 2.5$ which is significantly below the lower limit of 3 used by Duff and Heidebrecht. Even though these curves are not logarithmically linear over the total domain, close fitting straight-line approximations can be used over the domain of interest, i.e., $N < 1000$ cycles. The minimum exponents in the ASME Code curves is 2 for carbon steel UTS < 80 ksi, 2.55 for carbon steel 115-130 ksi, 2.14 for austenitics and 1.67 for bolting. The selected exponent of 2.5 is the exponent near about 10-100 cycles for carbon and austenitic steels, which is considered adequate. Bolting is not the issue here since it is typically designed conservatively.

If there are 'n' acceleration response peaks (positive and negative) during a seismic event each designated by A_i , then the total number of equivalent cycles N_{Max} , referenced to the maximum response acceleration A_{max} of that same time-history is obtained by summing applied to each acceleration response peak per equation 2, yielding:

$$N_{Max} = 1/2 \sum_{i=1}^n \left(A_i / A_{Max} \right)^\lambda \quad (3)$$

The factor $1/2$ is included because each response acceleration peak really represents only one-half cycle of response.

Nuclear power plants systems and equipment are typically designed conservatively for seismic conditions. From a stress point of view the design ensures that the stresses and deformations are below allowable even when the acceleration reaches the peak values A_{Max} . Equation 3 implies that if a higher value than A_{Max} is used to account for the conservatism inherent in the seismic design process, the number of equivalent cycles can be reduced even further. Even an increase of the A_{Max} by 20 % (minor conservatism in the seismic design process) would lead to a reduction in the number of equivalent cycles to approximately 63 % of the calculated values for a λ value of 2.5 [$(A_i / A_{Max})^\lambda = (1/1.2)^{2.5} = 0.633$]. Therefore the peak value to implement would also control the number of cycles developed.

The ASME Code Level 'C' stress limits are applied for assessment of DBE conditions. These level C limits are typically from 1.2 for vessels to 1.5 for piping times those that are permitted under normal plant operating conditions. Applying the lower limit of 1.2 to A_{max} in (3) gives, as explained above, a ratio of 0.633. This provides a measure of the increase in allowable fatigue cycles corresponding to a 20% change in allowable stress. To maintain consistent margin for level C allowable, the level 'C' allowable number of cycles can be increased by a factor of $1/0.633 = 1.58$.

6 TIME HISTORY ANALYSIS RESULTS

Analysis was performed for a suite of earthquakes given in Table 1. These earthquakes represent a wide variety of ground motions used for CANDU plants. For comparison with real earthquakes another suite of historical earthquakes was added and this included the El Centro and Alaska earthquakes. The earthquake ground motions were applied to a CANDU 6 three-dimensional Reactor Building. The well-established STARDYNE program was used in all analyses. The program is well established and verified and is at revision 5.11 at present. The equivalent numbers of cycles for the input ground motions have been calculated and the results are given in Table 2. A post processor program to the STARDYNE system was used to develop the number of cycles. This post processor was tested against hand calculations and several test cases. The time history motions for the reactor building are calculated and the equivalent numbers of cycles have been developed.

The results for building motions are given in Table 2. By subjecting the three-dimensional model of the reactor to the building motions the equivalent numbers of cycles for the end fitting response are obtained and are given in Table 2. This would illustrate the application of the previously developed fatigue equivalence equation. It should be stressed that the equivalent number of cycles depends on a number of factors. It depends on the frequency content that is governed by both the input motion and the dynamic characteristics of the system. It also depends on the peak or the maximum amplitude achieved during the response. The number of equivalent cycles grows with the number of structural systems in cascade. The lowest number observed is associated with the ground motions.

Considering Table 2, it can be seen that the largest value of N_{Max} is 13.3. Using this as a basis for establishing fatigue equivalence would be conservative since it does not allow for a consideration of the amplitude level which is being used with this number of cycles. As discussed before the seismic amplitude levels are determined conservatively. Nevertheless this calculated maximum value observed in the current study is below the 15 cycles of CSA N289.3.

Considering Table 2, the maximum number of cycles reported is 22.68 cycles. If one assumes that the design of secondary level equipment would be based on broadened conservative floor response spectra using amplification factors that would envelope those obtained from actual earthquake response studies, then a realistic reference level, at each frequency, would be the maximum response acceleration. Even 20 % conservatism in the amplitude would lead to a reduction of 37 % in the number of cycles. Notwithstanding this the number of cycles is below the 25 cycles called for by CSA N289.3.

Finally a simple overall summary of the time history analysis results is that Table 2 validates the CSA N289.3 value of 15 cycles for ground supported systems and the value of 25 cycles for floor supported systems.

7 DISCUSSION

The foregoing results clearly indicate that there are upper limits to the fatigue effect induced in secondary level equipment due to seismic response. It is useful to consider the implication of the study on fatigue evaluation in actual design situations. The current study has implemented realistic multi-degree-of-freedom three-dimensional systems for the reactor building and also for the reactor. It has implemented the design time-histories that were used for CANDU plants. Real earthquakes have also been used to investigate the impact of these on the results obtained. The objective of the investigation is to confirm what has been implemented already in CSA N289.3 standard.

The maximum amplitude of inertial response of a multi-degree-of-freedom system represents the combined effects of all modes of vibration of both primary and secondary systems. It is reasonable to base the total fatigue effect on this maximum amplitude. Where frequency is a consideration in fatigue analysis, the frequency of the dominant mode of vibration of the secondary system can be used. Where anchor point movements (e.g., two ends of a pipe) are the source of the fatigue effect under consideration, the frequency of the dominant mode of the anchor points (e.g., building floor) can be used. As the frequency of the dominant mode of response of the secondary system is frequently the same as or higher than that of the floor on which it is located, the combined alternating stress amplitude from both inertia and anchor point movements of the secondary system can be used for assessing the overall fatigue effect, using the higher frequency.

There has been concern expressed that a number of smaller seismic events could produce more fatigue damage than one DBE. In the US this concern has been expressed by requiring a fatigue evaluation for five Operating Basis Earthquakes (OBE); each having one-half the peak acceleration of the DBE. It can be seen, from Equation 3, that an amplitude reduction by one-half would yield, for $\lambda = 3$, one-eighth of the fatigue damage. Consequently, it would require at least eight OBE events to produce the fatigue effect of one DBE. Using $\lambda = 2.5$ will yield 5.6 OBE events to produce the same fatigue effects as one DBE. Therefore, it is not considered necessary to require fatigue damage evaluation at the OBE level. It should be mentioned that the OBE is typically combined with stress levels A and B when taking ranges for fatigue assessments, while fatigue due to DBE is evaluated for the earthquake in isolation.

8 CONCLUSIONS

The current Canadian CSA practice requires a seismic fatigue evaluation under ASME Level C conditions. Fatigue analysis requirements are decided based on the seismic primary plus secondary stress intensity range. If this exceeds $3S_m$ a seismic fatigue analysis is required.

Based on the current investigation, the validity of the number of cycles in CSA seismic fatigue analysis is established. The following recommendations can be made for determining the earthquake fatigue effects on systems and components.

- If a seismic fatigue evaluation is to be performed, for primary systems (i.e., resting directly on the ground), the application of 15 cycles as a minimum at the maximum response level is conservative.
- If a seismic fatigue evaluation is to be performed, for secondary systems (i.e., floor-supported equipment including piping systems), the application of 25 cycles at the maximum response level is conservative. The current practice of using 200 cycles for fatigue analysis of piping is excessive.
- Artificial time histories, as used in the seismic analysis of nuclear power plants systems, that are generated based on spectrum compatibility can exhibit fatigue characteristics that are more severe than those of real severe earthquakes. Special care should be exercised when using these time histories in time history fatigue analysis.

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Table 1. Earthquakes Records used in the Study

Earthquake Record Component Designation	Description of Records	Max. Acceleration (g)	Comments
A-1 A-2 A-3	Spectrum-Compatible time histories as used for CANDU 6 Reactor Building Site A.	.20 g [.201 g] .133 g [.135 g] .20 g [.22 g]	3 components of ground motions (X,Y,Z) Stiff Rock Site conditions. Delta t = .01 s, 2000 points, 20 Seconds.
B-1 B-2	Spectrum-Compatible time histories as used for Site B	.05 g [0.068 g] .033 g [0.053 g]	2 components of ground motions for the horizontal and the vertical directions. Horizontal components are assumed the same. Delta t = .01 s, 3000 points, 30 Seconds.
C-1 C-2	Spectrum-Compatible time histories as used for Site C	.08 g [0.11 g] .053 g [0.067 g]	2 components of ground motions for the horizontal and vertical directions. Horizontal components are assumed the same. Delta t = .01 s, 3000 points, 30 Seconds.
EQ-1	1940 EL CENTRO (HORIZONTAL, N-S).	.327 g	Delta t = .01 s, 2500 points, 25 Seconds.
EQ-2	1940 EL CENTRO (HORIZONTAL, E-W).	.310 g	Delta t = .01 s, 2500 points, 25 Seconds.
EQ-3	1940 EL CENTRO (VERTICAL)	.261 g	Delta t = .01 s, 2500 points, 25 Seconds.
EQ-4	ALASKA (E-W)	.341 g	Delta t = .03 s, 832 points, 25 Seconds.
EQ-5	ALASKA (VERTICAL)	.358 g	Delta t = .03 s, 832 points, 25 Seconds.
EQ-6	ALASKA (N-S)	.364 g	Delta t = .03 s, 832 points, 25 Seconds.

[Values in brackets are peak acceleration values obtained from the actual design time histories that are slightly higher than the DBE acceleration values]

Table 2. Number of Equivalent Fatigue Cycles Calculated for different Response Motions

Earthquake Record Component Designation	Description of Records	Vault Floor Motions		Boiler Room Floor and PHTS headers Motions		Reactor End Fitting Motions	
		Max. Acceleration (g)	Number of Equivalent Fatigue Cycles (Calculated for each direction)	Max. Floor Acceleration (g)	Number of Equivalent Fatigue Cycles (Calculated)	Max. Acceleration (g)	Number of Equivalent Fatigue Cycles (Calculated)
A-1 A-2 A-3	Spectrum- Compatible time histories as used for CANDU 6 Reactor Building-Site A	.201 g .135 g .220 g	10.15 9.99 11.3 RMS=10.5	.488 g .186 g .409 g	8.8 27.35 21.47 RMS = 20.7	.324 g .165 g .453 g	15.76 27.02 23.08 RMS=22.68
B-1 B-2	Spectrum- Compatible time histories as used for Site B	0.068 g 0.055 g 0.070 g	10.3 13.32 10.88 RMS=11.57	.146 g .081 g .139 g	13.84 15.04 10.21 RMS=13.20	.104 g .087 g .168 g	13.63 18.77 9.96 RMS=14.57
C-1 C-2	Spectrum- Compatible time histories as used for Site C	0.110 g 0.067 g 0.120 g	7.46 8.37 6.82 RMS=7.58	.249 g .083 g .240 g	9.35 10.9 6.20 RMS=9.03	.158 g .099 g .247 g	9.89 27.03 7.93 RMS=17.24
EQ-1	1940 ELCENTRO (HORIZONTAL, N-S).	.327 g	6.75	.703 g	6.96	.531 g	5.43
EQ-2	1940 EL CENTRO (HORIZONTAL, E-W).	.334 g	10.34	.606 g	8.81	.661 g	8.72
EQ-3	1940 ELCENTRO (VERTICAL)	.261 g	7.25	.461 g	10.34	.436 g	7.52
EQ-4	ALASKA (EAST-WEST)	.341 g	10.73	.648 g	17.2	.399 g	10.62
EQ-5	ALASKA (VERTICAL)	.358 g	6.70	.379 g	7.61	.38 g	6.07
EQ-6	ALASKA (N-S)	.364 g	9.94	.792 g	9.26	.584 g	12.78

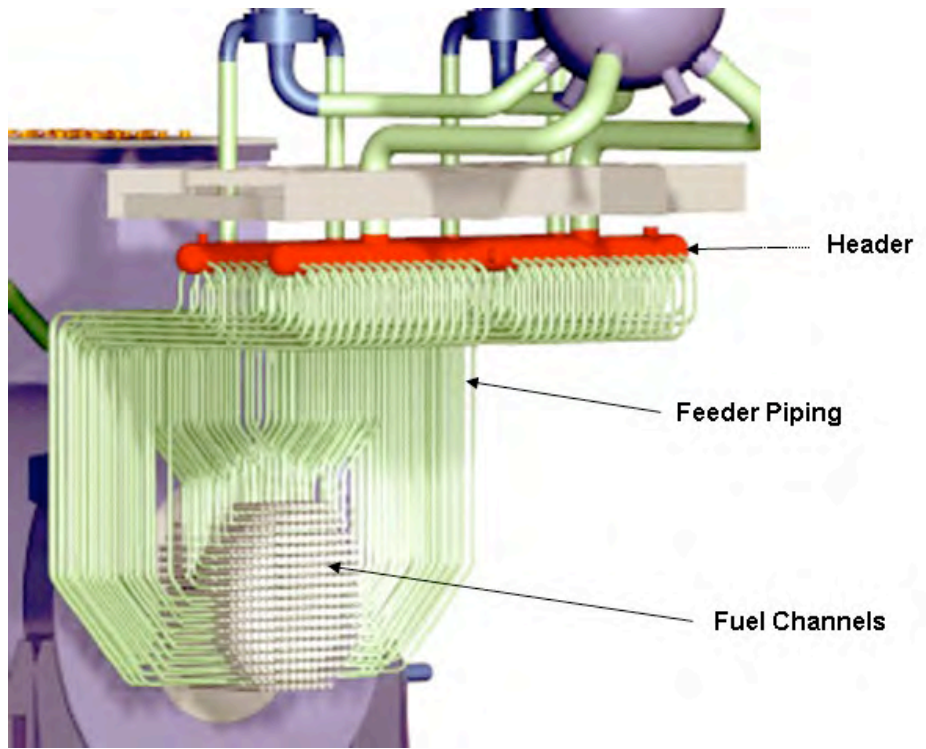


Figure 1 Typical Feeder General Arrangement.

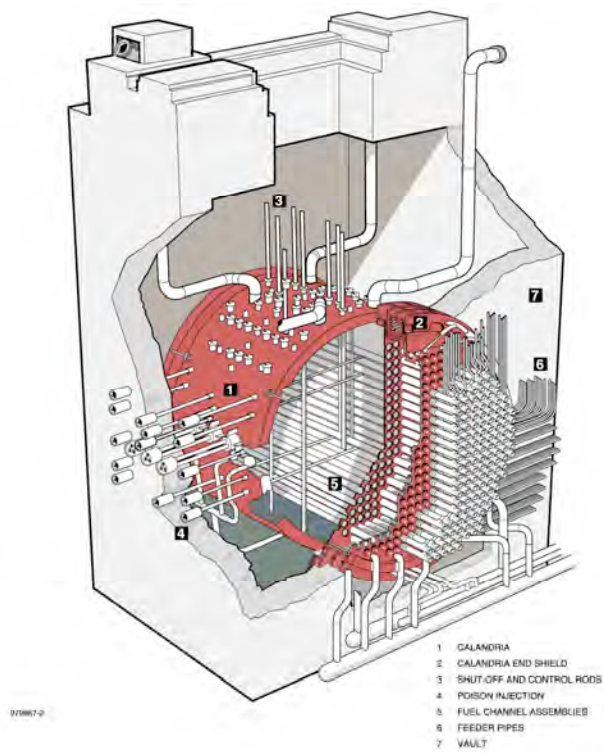


Figure 2 CANDU 6 Reactor Assembly