Technical Justification for Strain Approach

Introduction

Heavy Load movement was the subject of industry evaluations initiated in the early 1980s in response to Generic Letter (GL) 80-113, as modified by GL 81-07, which required interim actions as well as six month and nine month responses, referred to as Phase I and Phase II, respectively, showing compliance with the NUREG-0612 guidelines. Both phases required responses to various issues, including the results of analytical evaluations. Phase II required, among other issues, evaluation of reactor vessel head drops and consequence analysis. (No acceptance criteria were identified for these analyses.) The NRC reviewed all of the Phase I responses and performed a high level sampling of Phase II responses. That review concluded in GL 85-11 that the improvement in heavy loads handling obtained from the implementation of Phase I reduced the risks associated with the handling of heavy loads and that further action associated with Phase II was not needed.

More recently NRC inspection and enforcement activities imposed new interpretations of the generic communications on this issue as they relate to reactor vessel head load drop and consequence analyses. In several cases regulatory actions that specifically involved reactor head replacement were imposed while the licensees were engaged in refueling outages. Unique, region-based, and uncoordinated interpretations of old generic communications were creating confusion in the industry and obvious inconsistency in regulatory oversight.

On September 14, 2007, industry approved a formal initiative that specified actions each plant will take to ensure that heavy load lifts continue to be conducted safely and that plant licensing bases accurately reflect plant practices. A task force was established to provide guidelines to implement the initiative. One subgroup of the task force was assigned the task of developing guidelines for load drop analyses and included nationwide specialists in load drop evaluations from licensees as well as Architect/ Engineering and other specialty firms that have supported the industry from the time the initial NUREG-0612 guidelines were issued. The initiative realistic (best estimate) guidelines are included in NEI 08-05.

Discussion

Industry in its initiative, and NRC in its Enforcement Guidance Memorandum, both stated that the load drop analysis can be “based on realistic (i.e., best estimate) calculations.” This is appropriate since reactor head load drop is not a design basis event.

Reactor vessel head lifts have been carried out according to very detailed, tightly controlled procedures that result in a highly orchestrated process to assure safety, far greater than lifts performed by other industries. As a result, there have not been any breaches of safety on reactor head lifts that would have remotely led to load failure. The objective of the initiative is to ensure that the core remains covered and that the ability remains to cool the core. It is important to note that while the vessel, piping or support structure may be permanently damaged in a load drop event, the sole objective is to ensure the core remains covered and cooled. Therefore, there are inherently greater safety margins available than those which apply to design basis events, such as LOCA.

A major goal in developing the guidelines was to select an analytical methodology that best meets the stated objective of the load drop analysis. One possibility was ASME Section III, Division 1,

Appendix F (referred hereafter as the ASME Code) which identifies Service Loadings with Level D Service Limits to evaluate design basis events. However, since the reactor head load drop is not a design basis event, the ASME code or similar structural codes do not provide adequate criteria to address the level of material damage expected to occur from such an event. In fact, the ASME Code does not specifically address the physics associated with head load drop. The industry believes analytical methods that best define the physics (mechanics) of the event are important for accurate evaluation and for that reason proposed the methods included in NEI 08-05. The ASME Code is based on loading conditions (such as gravity, pressure, seismic, etc.) that are not expected to be influenced by the dynamic response of the structure (e.g., the codes were intended to address situations where there is a direct correlation between load and stress). Therefore the success of the design event is measured only by comparing computed to allowable stress levels throughout the structure. Success is measured in terms of allowable stress in the ASME Code, and strain is only a secondary consideration that is not the basis for acceptance. If the load is sustained for even short periods of time and the stress exceeds the stress capacity, catastrophic failure is assumed to occur under design basis events.

However, the impact from a reactor vessel head drop causes the target structure (the reactor vessel and its support system) to behave differently than the assumptions on which the ASME Code is based. The stress level of the structure due to load drop is determined by the target structure behavior, not a computed load as is the assumption of the ASME Code.

All competent structural codes, including ASME, require the use of ductile materials. The materials typically are required to have large extended strain (deformation) regions at relatively constant stress levels after the linear (elastic) initial portion of stress-strain relationship is exceeded. Thus reactor vessels and their support systems use materials which are ductile and have stress-strain relationships allowing significant strain beyond the allowable stress. Additionally the ASME Code requires fabrication and inspection methods which maintain the ductility of the material in the constructed component. This means that the structure is typically capable of significant deformation, beyond the ASME Code “equivalent strain” limits, before failure. As discussed here, equivalent strain is the strain associated with the ASME Code stress limits.

During the postulated head load drop significant permanent deformation of the target structure (reactor and support system) is expected, and preferred. As the structure (vessel and support system) deforms, the product of the stress (determined by the stress-strain behavior or the structure’s material) distributed through the structural assembly and the associated strain produces strain energy that absorbs the kinetic energy of the impacting head. The greater the deformation, the greater amount of strain energy the structure absorbs. If the ability to absorb structural energy exceeds the energy of the dropped head at impact, the vessel and support structure successfully arrest the motion of the head. For the load drop application, strain (deformation) plays the key role in these events, so margins of safety for load drop considerations need to be measured against strain limits, not stress limits as required by the ASME Code. By evaluating strain, rather than stress, it becomes apparent that significant margins may exist that are not properly identified by imposing the ASME Code requirements.

The ASME Code’s primary emphasis is control of over-pressurization of the vessel in design basis events -- and significant strain is understandably limited. The ASME Code, Appendix F addresses all faulted (Level D) events, including those resulting from imposed “force” based events and therefore, provides conservative criteria which does not accurately account for the large margins of strain potentially available in these structures. This shortcoming is recognized by the ASME Code and efforts are currently underway to develop strain based criteria similar to the criteria proposed in this initiative.

Reactor head load drop evaluation techniques are more appropriately addressed by impact considerations using strain allowance, similar to NRC approved pipe whip evaluations, rather than design basis over-pressurization considerations. For this reason the industry initiative proposed strain limits more closely related with those identified in ANSI/ANS 58.2-1988, Sections 6.5 and 6.6 on the basis that these provide for a more realistic evaluation rather than the very limited strain allowance associated with stress limits in the ASME Code. These criteria have been approved by the NRC (in their May 16 letter to NEI) for use in support structures but not the pressure vessel materials. This position is not logical since the pressure vessel components receive better inspection and fabrication controls than the structural supports, providing confidence they can adequately sustain the strain limits proposed in this criteria.

However, based on our extensive discussions with NRC staff who insisted that the ASME Section III, Division 1, Appendix F code be included as an approach to load drop acceptance criteria, we have included it as an alternative in NEI 08-05. As described above, we believe this approach is technically inappropriate and unnecessarily conservative for an analysis which is meant to be realistic.

Conclusion

The industry proposed load drop analysis and strain based acceptance criteria address the concerns raised by industry and NRC that a realistic (best estimate) analysis provide reasonable assurance that the core remain covered and cooled in the very unlikely event of a reactor vessel head drop. Applying design basis ASME Code stress limits are unnecessarily conservative for analyzing the event in question and their required use could impose operational limitations on head lift operations which do not benefit overall safety. Since there are no codes in existence which appropriately and realistically address the load drop analysis, the industry has provided an approach which addresses this unique event with margins similar to, and in some cases larger, than the margins accepted by the NRC for design basis faulted events using ASME Code stress criteria.