FUELLING WITH FLOW AT BRUCE A

M.G.Gray

GE Canada

Nuclear Products

ABSTRACT

Fuelling with flow is the solution chosen by Bruce A to overcome the potential power pulse caused by a major inlet header failure. Fuelling with flow solves the problem by rearranging the core to place new fuel at the channel inlet and irradiated fuel at the channel outlet. The change has a significant impact on the Bruce A fuel handling system which was designed primarily to do on power fuelling in the against flow direction.

Mechanical changes to the fuelling machine include a modification to the existing ram head and the replacement of standard fuel carriers with new fuelling with flow fuel carriers having the capability of opening the channel latch.

Changes to the control system are more involved. A new set of operational sequences are required for both the upstream and downstream fuelling machines to achieve the fuel change. Steps based on sensitive ram push are added to reduce the risk of failing to close the latch at the correct position to properly support the fuel string. Changes are also required to the protective interlocks to allow fuelling with flow and reduce risk.

A new fuel string supporting shield plug was designed and tested to reduce the risk of endplate cracking that could occur on the irradiated bundle that would have been supported directly by the channel latch. Some operational changes have been incorporated to accommodate this new shield plug. Considerable testing has been carried out on all aspects of fuel handling where fuelling with flow differs from the reference fuelling against flow.

INTRODUCTION

Early in 1993 the potential for a power pulse accident on a Bruce or Darlington reactor was identified. Following a postulated inlet header failure the fuel in half the reactor core channels would shift toward the inlet end. Since the freshest fuel exists at the outlet end and approximately half of the most downstream bundle has never been irradiated, this fuel shift immediately causes a power spike. When this occurs on 240 channels simultaneously, an uncontrolled power pulse results.

Many potential solutions to the problem were put forth and following methodical evaluation, two solutions appeared most feasible: long fuel bundles and fuelling with flow. The long bundle concept solves the problem by minimizing the gap which exists between the most upstream bundle and the inlet shield plug, thereby limiting the potential fuel string shift. This is achieved by introducing fuel bundles that are longer than standard and continually monitoring the remaining gap. This may seem straightforward but one must appreciate that due to channel creep the combination of normal and long bundles becomes unique for every channel. The number and position of long bundles must always be tracked, the minimum gap size in any channel cannot be violated, the fuelling machines must be precisely loaded with the correct combination in the correct order in the correct magazine positions and there can be no deviation from the planned fuel changing mission once the machine is loaded. Much effort has gone into development of the long bundle program, the details of which are outside the scope of this paper. It has currently been implemented in limited form at Bruce B and Darlington.

Fuelling with flow solves the power pulse by reversing the core to place the freshest fuel at the inlet end and the irradiated fuel at the outlet end. The fuel string shift following an inlet header break then results in a decrease in reactivity as the most irradiated fuel enters the core and the freshest fuel leaves. This is the solution chosen by Bruce A. This paper discusses the changes required to the fuel handling system along with testing completed to support the fuelling with flow program.

BACKGROUND

Although the Bruce A reactors and fuel handling system were designed to be fuelled against the flow, there was always a requirement to be able to hold a latch open to allow fuel to pass back through. Initially this was intended to be done by manual operations with special tooling under shutdown conditions, but later evolved into the flow defuelling technique developed as part of the breakdown channel defuelling system. This technique has been used successfully at all stations with latch endfittings. Experience with flow defuelling contributed significantly to the fuelling with flow program at Bruce A.

Fuelling with flow does not result in any major changes to the fuel handling system. The new fuel is now inserted at the channel upstream end and the irradiated fuel discharged at the downstream end. New control system OPs and Sequences have been written to achieve this. Also a new fuelling with flow fuel carrier has been provided in the fuelling machines, and a new fuel string supporting shield plug has been installed at the channel outlet end. The new fuel mechanism ram stroke has been extended to accommodate the new fuel carriers. Changes to some protective interlocks have been provided and some changes have been made to control hardware. Testing of some critical fuelling with flow parameters was performed in the GE Canada lab and Chalk River Nuclear Labs. Full testing of fuelling machine sequences are being carried out at Bruce A.

MECHANICAL HARDWARE

Fuelling with flow requires inserting new fuel at the channel upstream end while discharging irradiated fuel at the downstream end. Although the original fuelling machine fuel carriers are capable of the new operations at the upstream end, they are unable to open the channel latch to allow passage of fuel out of the channel at the downstream end. New fuelling with flow fuel carriers were therefore designed and supplied. The new design is shown in Figure 1. For economic reasons the design reuses the original fuel carrier body, truncated, with the new nosepiece riveted on.

The fuelling with flow fuel carrier has a protruding, thin walled nose which can open the channel latch and hold it open during the fuel change. The new carrier also has a flat shoulder machined on it, specifically to allow stalling against the shield plug lug in the end fitting. An operation stalling the carrier against the lug is carried out during the fuel accept sequence to verify the charge tube axial encoder prior to opening the latch. The new carrier incorporates inserts to operate the existing breakdown channel defuelling ram catch adapter. It is now unnecessary to replace the fuelling with flow fuel carriers with defuelling carriers when grappling is required.

Testing indicated a potential for bundle endplate cracking of irradiated fuel held by the channel latch. A new fuel string supporting shield plug (F3SP) has been designed and supplied, and is shown in Figures 2 and 3. This shield plug features a nosepiece which protrudes just through the channel latch and supports the fuel string off the latch fingers. Relative rotation can take place between the shield plug body and the nosepiece. In service the nosepiece is prevented from turning by the end fitting shield plug lug while the shield plug body rotates to lock or unlock from the end fitting. This ensures no relative rotation between the nosepiece and the fuel which otherwise might result in fuel damage.

The stroke of the new fuel mechanism's fuel transfer ram is too short to reliably push bundles past the lip of a defuelling carrier. Because of this shortfall, equipment was designed to retrofit the four mechanisms with different ram position detection components. The same retrofit allows the ram to provide sufficient additional stroke.

The chamfer has been increased on the four cruciform sections on the back end of the fuelling machine ram head. This improves the ability of the ram head to open the channel latch in the retract direction. Channel creep results in the need for the downstream ram to penetrate through the latch and any change in the orientation of the ram head during retract will result in contact between the ram head and the latch fingers. The ability to open the latch smoothly prevents the ram from hanging up or possibly causing damage.

OPS and SEQUENCES

New fuelling machine control operations and sequences had to be written to achieve fuelling with flow. The fuel change occurs while the channel latch is being held open by the fuel carrier at the downstream end. Any operations while the latch is open are critical since an incident could result in the fuel string passing uncontrolled through the latch. It is especially important that the fuel be held in the correct position while the carrier is withdrawn to close the latch to ensure that the latch fingers drop between bundles correctly to properly support the fuel string. Consequently the fuelling with flow ops and sequences contain more steps specifically added to verify correct position or operation.

New sequences were also written for installation and removal of the new fuel string supporting shield plug at the outlet endfitting. New Ops in the sequences check the type of channel end being visited to ensure that the appropriate sequence is being used.

PROTECTIVE INTERLOCKS and CONTROL

In the fuelling with flow mode of operation, the channel latch is opened to accept fuel into the fuelling machine on each fuel change. Holding the latch open with the fuelling with flow fuel carrier increases the hazard, since there is a greater period of time during which system failure, either due to power failure or system error, could lead to fuel being washed back through the open latch into the fuelling machine, leading to a difficult recovery process. For this reason, a number of interlock changes have been made to the system.

While the ram is supporting the fuel string, as the string is retracted to receive the irradiated fuel at the downstream channel end, at least one of the ram clutches must be engaged so that the ram is not pushed back freely by the fuel string. Hardwired interlocks prevent releasing the ram brakes at the downstream end unless one of the clutches has been engaged.

Similarly, while the charge tube has advanced to a position where the fuel carrier is holding the latch open, if the axial drive brake is released and the clutch is not engaged, the charge tube would be pushed backward by the fuel string, leaving fuel improperly positioned relative to the channel latch. Hardwired interlocks prevent releasing the charge tube axial brake unless the clutch is engaged.

A number of protective system interlocks have been changed to ensure that the fuel string is properly supported while the latch is open, and to ensure that the fuel will be left properly positioned after the latch is closed. Another set of changes prevents advancing the fuel string against a braked ram during the various sensitive ram push operations, and otherwise pinching the fuel string between two rams at high torque. Torque limitations on the fuel supporting shield plug required a limit on charge tube rotary torque while installing or removing the shield plug.

Interlock changes are incorporated to both ram and charge tube axial drives to ensure proper positioning of fuel relative to the latch. For the ram drive interlocks, one change specific to ram motion applies. When retracting the fuel string into the downstream fuel carrier while it is holding the latch open, the ram can be retracted only to the position where the bearing pad at the upstream end of the second bundle is over the channel latch line, so that as the latch is closed it cannot catch the bearing pad. At this point, the third bundle is still upstream of the latch, and there is no danger of it coming through the latch as the fuel carrier is withdrawn. The charge tube axial interlocks are mainly related to ensuring that the fuel is properly positioned before the fuel carrier can be retracted to close the latch. Compensated axial motion is used when closing the latch such that the charge tube and fuel carrier are retracted while the ram is driven forward relative to the charge tube to hold the fuel string stationary with respect to the latch. This forward motion of the ram inside a fuel carrier in a lip down orientation was previously prevented due to the possibility of damaging a bundle against the lip, but is now allowed over specific defined ranges.

To ensure that the forces on the fuel string are kept low enough to prevent fuel damage, a number of new protective interlocks have been applied. Signals are generated from the upstream fuelling machine to indicate that both of the ram brakes and clutches have been released, and therefore the ram is 'floating'. This condition is required during ram position sensing operations which are done more often during fuelling with flow. While discharging fuel from the upstream fuel carrier, the ram must be advanced behind the fuel to move it along within the carrier until it reaches the area of channel flow and is carried by the flow into the channel. Since there is the possibility of advancing this ram to pinch the fuel string between the two ram heads or against the latch at the downstream end, the speed and torque for this ram advance motion are limited to lower values than when advancing the ram within a fuel carrier at the downstream end.

Controller program functions have been added to accommodate the fuelling with flow mode of operation. The new functions ensure that fuelling with flow is being carried out at appropriate channels and each fuelling machine is executing the right sequence for the end at which it is operating. There is capability of monitoring the motion of the rams of the two fuelling machines to ensure that they are properly synchronized during the fuel transfer. As the downstream ram retracts to accept fuel bundles into the carrier, the upstream ram advances to move fuel along so that it is carried into the channel by the flow. The upstream ram follows along behind the fuel to ensure that it continues moving into the channel. Maintaining a gap between the ram and the fuel ensures that the fuel string is not pinched between the two fuelling machine rams, while minimizing the gap reduces the impact as each bundle is swept by the flow into the slowly moving fuel string. This synchronization is achieved by having ram encoder feedback from both fuelling machines monitored by each controller simultaneously. The ram encoder signal is connected directly as an input to the controller of the other fuelling machine on the same trolley, thereby avoiding delays inherent in communicating the data over the interprocessor communication links.

During the changeover from fuelling against flow to fuelling with flow, it is important to keep track of the fuel ordering in each channel since both types of fuelling will be in service until the changeover is complete. A channel information data file, CHANN.TD, has been created to store the characteristics of each channel of each reactor so that the control system can determine whether the proper fuelling approach has been selected for the channel. Other pertinent data stored for each channel include: channel data updated, channel quarantined, shield plug not installed, channel defuelled, long bundle(s) in channel, flow restricting outlet shield plug installed, and F3SP installed.

The operation of all of the fuelling machine brakes has been changed to a 'command to release' from the previous 'command to engage'. In this way, on loss of computer control, the brakes revert to the braked state, holding the machine components in their current positions.

For additional reliability, Class II power has been provided to both of the brake circuits for the fuelling machine ram, charge tube axial and rotary drives. The Class II power is switched within the fuel handling power distribution cabinet so that as long as the normal Class III supply is available, it is used and the Class II is standby. If the Class III is lost, Class II is immediately switched in with only a momentary delay in the supply to the brakes. This change will prevent the fuel string passing through the latch uncontrolled in the event of a loss of power during the fuel change while the latch is being held open.

TESTING

A series of tests were performed in the GE Canada lab to demonstrate the feasibility of fuelling with flow at Bruce A and establish the key flow rate parameters. These tests are summarized as follows:

1. Check the release of fuel bundles past the lip of the upstream fuel carrier at normal full flow conditions.
2. Establish the maximum flow at which fuel bundles will successfully move past the lip of the upstream carrier.
3. Determine the effect of a bundle impacting the fuel string over a distance of 45 inches under full flow conditions.
4. Establish how far the fuel carrier can retract from full forward stall in the latch before a bundle no longer passes through.
5. At full flow conditions establish the point of relative movement during rotation of the upstream carrier when the new fuel is in contact with the fuel string.
6. Establish the minimum flow requirements to consistently wash two bundles past the lip of the downstream fuel carrier.

The results indicated no reportable damage to any of the fuel bundles, fuel carriers or channel components during any of the tests. The minimum flow rate to successfully receive two bundles over the lip of the downstream carrier was established to be 20.9 Kg/s at 300°C. The series of tests showed that pursuing fuelling with flow at Bruce A would be a viable option.

Testing at CRNL indicated a possible problem with cracking of endplates of irradiated bundles supported on the latch. This concern led to the design and implementation of the fuel string supporting shield plugs in the outlet endfittings.

Testing of the new Ops and Sequences, and the new fuel handling protective programs are being performed at Bruce A by Ontario Hydro with support from GE Canada Fuel Handling personnel.

CONCLUSIONS

With appropriate changes to the fuel handling equipment and control system, the reactors at Bruce A can be refuelled in the fuelling with flow direction. The current test program together with previous flow defuelling experience established confidence in this fuelling method. The replacement of outlet shield plugs with the new fuel string supporting shield plugs will eliminate the risk of bundle endplate cracking at the latch.

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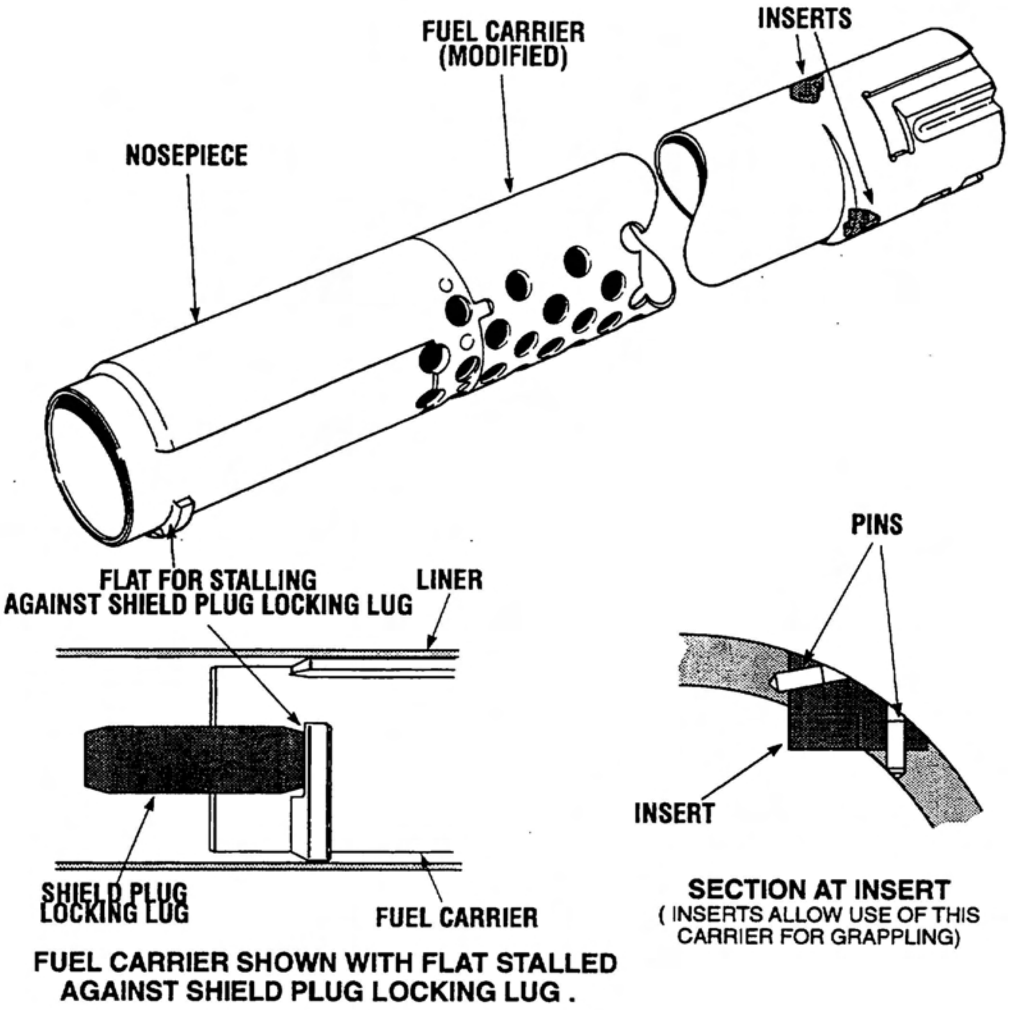
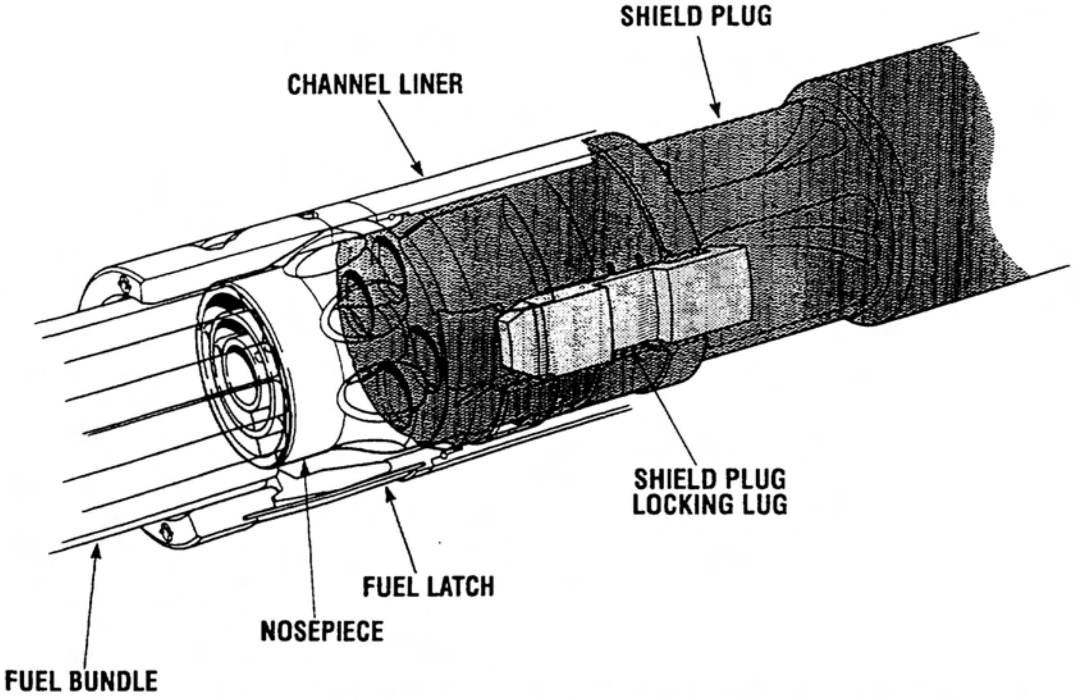


FUEL CARRIER SHOWN WITH FLAT STALLED AGAINST SHIELD PLUG LOCKING LUG .

SECTION AT INSERT
(INSERTS ALLOW USE OF THIS CARRIER FOR GRAPPLING)

Figure1 - Fuelling With Flow Fuel Carrier



FUEL STRING SUPPORTING SHIELD PLUG ADVANCED INTO LINER

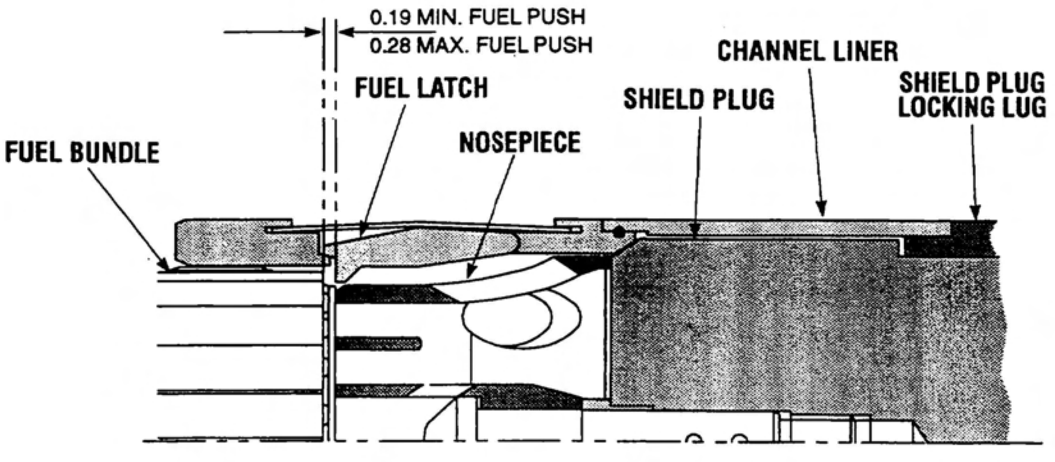


Figure 2 - Fuel String Supporting Shield Plug - Unlocked

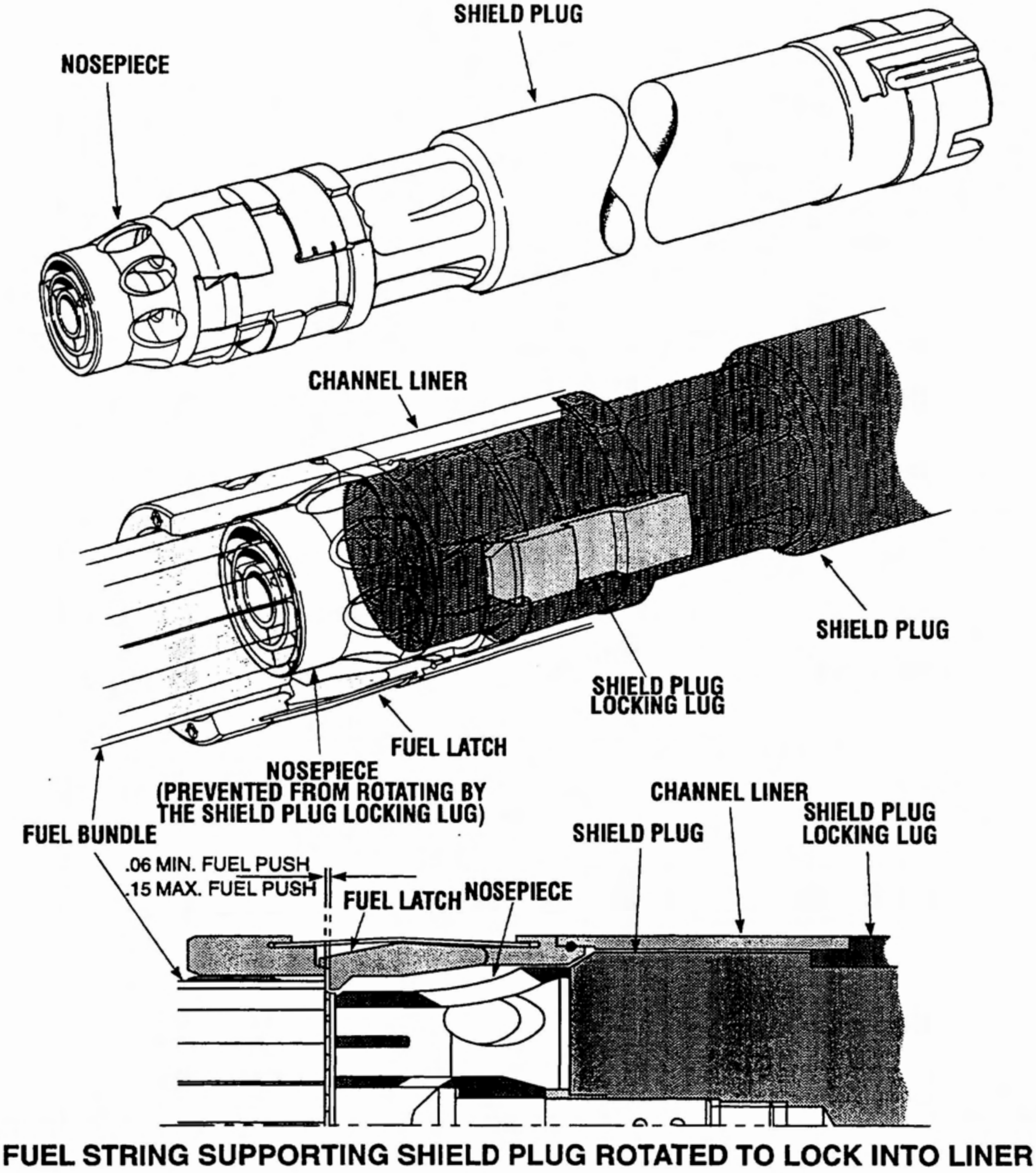


Figure 3 - Fuel String Supporting Shield Plug - Locked