

# BWR Channel Measurement Best Practices

2011 TECHNICAL REPORT



# BWR Channel Measurement Best Practices

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## Product Description

The EPRI BWR Channel Distortion Program has assembled an industry-wide database of channel distortion measurements. It is important that the data are consistent and of sufficient quality to be useful for improving the understanding of distortion mechanisms.

### **Background**

The Channel Distortion database consolidates operational performance data, poolside dimensional measurement data and hot cell examination results. This database has compiled channel distortion data and related information from 11 U.S. BWRs and 3 non-U.S. BWRs. Distortion measurement results from more than 1000 channels have been entered into this database. To ensure that the data is analyzed correctly, channel measurement practices and procedures must be consistent and complete.

### **Objective**

To populate the industry database with consistent BWR channel distortion data and to provide guidance for future channel measurement campaigns

### **Approach**

The Channel Distortion Team analyzed the existing database and worked with the three major fuel suppliers (AREVA NP, Global Nuclear Fuels, and Westinghouse Electric) to prepare this document.

### **Results**

Several best practices have been identified for future channel bow measurement campaigns.

### **Applications, Value, and Use**

Utilities and fuel suppliers participating in the Channel Distortion Program and/or considering additional channel measurement campaigns should consider the guidance contained in this document to ensure the data are consistent and complete.

**Keywords**

BWR Channel Bow

BWR Channel Bulge

Distortion Measurement

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## Section 1: Introduction

U.S. industry experience (discharge exposures > 40-45 GWd/MTU and cycle lengths of 18-24 months) has shown that anomalous distortion of Zircaloy-2 (Zr-2) channels may cause interference between channels and control blades. Channel interference is a multivariable problem that depends on factors such as core design, cycle length, channel design, materials and operating environment. International experience with shadow corrosion-induced channel distortion is very limited or non-existent since the predominant use of annual cycles precludes the need for early control of fresh fuel. However, for those planning to extend cycle lengths it is expected that some non-U.S. plants will experience channel interference problems. Figure 1-1 graphically illustrates the issue.

Some plant operators have switched back to Zircaloy-4 (Zr-4) channels due to its lower susceptibility to shadow corrosion-induced bow but additional data must still be gathered to validate acceptable fluence-gradient bow (differential irradiation growth) at high burnup in Zr-4. The long term solution is advanced materials with reduced sensitivities to shadow corrosion and irradiation growth. These advanced materials are currently deployed in several reactors as lead use channels in limited quantities and are expected to be licensed for full batch reloads in the next three-to-five year timeframe.

There are three primary types of channel distortion: bulge, bow and twist. Bulge is caused by irradiation creep of the channel due to the differential coolant pressure and is primarily manifest in the lower elevations of the channel. Bow is caused by a differential length change on opposite sides of the channel. Channel length can be principally increased by irradiation growth (due to an accumulation of microstructural defects) or by absorption of hydrogen during the corrosion process (either uniform corrosion or “shadow corrosion”). Shadow corrosion, which occurs in BWR conditions on zirconium alloys when in close proximity to a different alloy, is consistently observed on the surfaces of the channel sides that face an inserted stainless steel control blade or, potentially, instrumentation tubes. Twist results from small geometric differences in bulge and bow that impart a slight axially-varying rotation to the channel. All of these types of deformation add together to close the nominal control blade-channel gap as illustrated in Figure 1-2.

The EPRI BWR Channel Distortion Program has assembled an industry-wide database (“CDdb”) of channel distortion measurements. It is important that the data be consistent and of sufficient quality to be used to improve understanding of distortion mechanisms. The CDdb consolidates operational performance data,

poolside dimensional measurement data and hot cell examination results. This database has compiled channel distortion data and related information from 11 US BWRs and 3 non-US BWRs. Distortion measurement results from more than 1000 channels have been entered into the database. To ensure that the data is correctly analyzed, channel measurement practices and procedures must be consistent and complete.

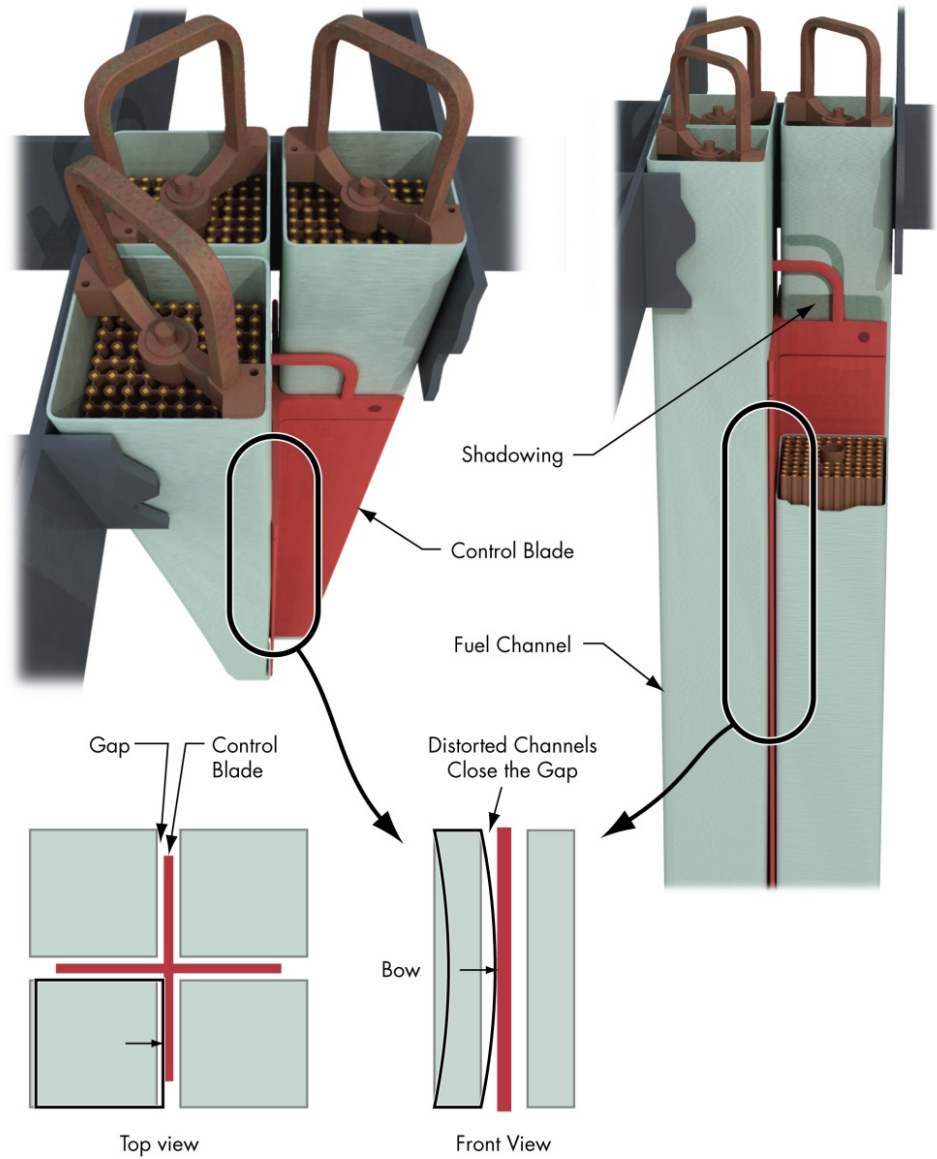


Figure 1-1  
Graphical illustration of BWR channel bow issue

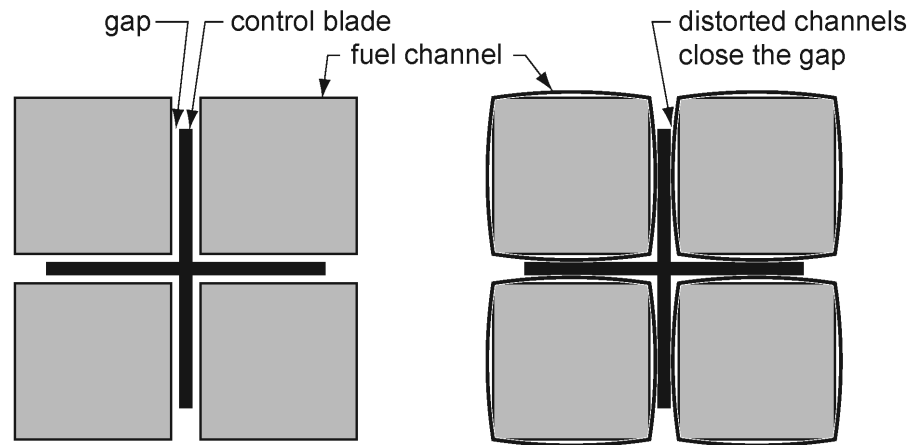
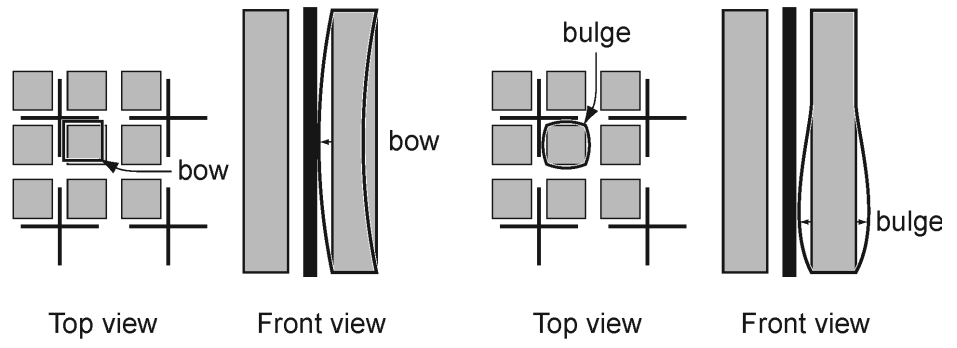


Figure 1-2  
Graphical illustration of channel bow and bulge





## Section 2: Discussion

It has been noted that there can be differences in the way channel dimensional characteristics are measured and reported that can lead to inconsistencies and misinterpretation when comparing channel dimensional measurement results from one fuel supplier to another. It is therefore considered that the issuance of an EPRI guidance report may be helpful to prevent such inconsistencies and misinterpretations, and further increase the utility of the information obtained from EPRI-sponsored channel dimensional measurement campaigns. The purpose of this document is to provide such guidance.

Some measurements may be performed using ultrasonic transducers or LVDTs. In some instances, the measured channel deflection may cause the measurement device to extend beyond its qualified or calibrated range. The measurement device qualified/calibrated range should be identified, along with an expected accuracy estimate.

- Best Practice: Identify those measurements that reflect the operation of a measurement device beyond its qualified/calibrated range, and suggest an appropriate disposition of those measurement results (can be used, must be discarded, etc.) with supporting justification.

Measurements provided to EPRI's database are assumed to be accurate and reliable. Erroneous measurement results, either for the Item 1 consideration or any other cause, should be identified by the fuel supplier, again with a recommended disposition of those measurement results.

### **Channel Bulge**

Channel bulge can be determined<sup>1</sup> either through measurement of the maximum channel width at a given channel elevation (channel bulge), or by measurement of the channel face deflection relative to the channel corners (face bulge). The measurement of channel face bulge neglects any possible channel corner movement relative to its original as-fabricated location, and can thereby introduce an inaccurate estimate of the closure of the channel-to-control blade gap due to channel bulge. The measurement method utilized (face bulge or width measurement) should be identified.

- Best Practice: Channel bulge should be determined from channel width measurements at the location equidistant from the channel corners (location of maximum bulge).

Channel bulge can be determined for an individual channel face (or pair of opposite channel faces with a width measurement), or multiple channel faces (or pairs). A comparison of the bulge values obtained from multiple face (or pair) measurements provides an independent check of the accuracy of the measurement (all faces should be relatively equal).

- Best Practice: Measure all channel faces (or pairs).

Channel bulge can be determined at a number of fixed axial elevations. The axial elevation of maximum channel bulge can vary with operating history and channel geometry. In some cases, the maximum measured channel bulge value may be reported (only). However, the maximum measured channel bulge value may not be the actual channel maximum bulge, if the maximum bulge occurs between measurement stations axially. The bulge axial profile, including the axial elevation of maximum bulge, is also useful for comparison to bulge model predictions.

- Best Practice: Provide the bulge measurements at each measured axial elevation to provide confirmation that the indicated profile does not suggest larger bulge than indicated by the individual measurements.
- Best Practice: Revisit the selected elevations of the measurement stations with new channel dimensional configurations and when indicated as non-optimal from measured axial profiles.

Channel bulge is expected to be similar for similar channel designs operated similarly. Therefore, a confirmation of expected behavior, or identification of true performance variability, as well as an additional check on measurement accuracy, is provided by measurement of symmetrically operated same channel designs.

- Best Practice: Include symmetrically operated channels in channel measurement campaigns.

## **Channel Bow**

Channel bow determination requires the definition of a reference (zero deflection) location. Ideally, this reference location should be taken at the channel ends. The uppermost or lowermost measurement stations may not represent adequate reference positions if located too far from the channel ends. Additionally, for thin channels especially where finger-springs are included at the interface with the lower tie plate, the lowermost channel edge at the channel mid-width position can deflect significantly (bulge) and should therefore not be used as a reference for the bow measurement. The method to correct the axial distribution of deflection measurements to obtain the true maximum channel bow should be described. All reported bow measurement results should reflect this bow correction procedure, and be clearly identified as including this bow correction. This bow correction should preserve the location of maximum channel bow indicated by the channel deflection measurements (bow is not necessarily adequately represented by an assumed fixed axially-symmetric sinusoidal shape).

Measurements are performed at various axial elevations to determine channel bow. The axial elevation of maximum channel bow can vary with operating history. In some cases, the maximum measured channel bow value may be reported (only). However, the maximum measured channel bow value may not be the actual maximum bow, if the maximum value occurs between fixed measurement stations axially. Additionally, the bow profile, including the axial elevation of maximum channel bow, is useful for comparison to bow model predictions. This bow profile should reflect the bow correction identified above.

- Best Practice: Provide the bow measurements at each measured axial elevation to provide confirmation that the indicated profile does not suggest larger bow than indicated by the individual measurements.

Channel bow can vary significantly from one pair of opposite channel faces to the other pair of opposite channel faces. Channel bow measurements should be routinely performed for both pairs of opposite channel faces.

Channel bow is expected to be similar for similar channel designs operated similarly. Therefore, a confirmation of expected behavior (or quantification of real performance variations) as well as an additional check on measurement accuracy is recommended by also measuring symmetrically-operated same-channel designs.

- Best Practice: Include symmetrically operated channels in channel measurement campaigns.

## **Channel Length**

Channel length measurements enable a characterization of irradiation growth behavior. Length measurements of channel faces adjacent to the control blade can include the effects of shadow corrosion-induced hydrogen pickup in addition to conventional irradiation-induced growth. Length measurements of channel faces away from the control blade will provide a better measure of true irradiation induced growth (although some lower level of hydrogen-induced growth can be expected). Channel length measurements of opposite channel faces can also be used as an independent check of the channel bow measurement.

- Best Practice: Include length measurements of all four channel faces over the spectrum of conditions covered by the channel measurement campaign.

## **Supporting Information**

Channel dimensional performance is determined by the channel operating history. The channel operating history includes the fast flux/fluence history, channel wall pressure drop history, and control blade insertion history. For each measured channel, the axial distribution of channel face fast fluence (e.g.,  $E > 1$  MeV) should be provided for each of the four channel faces. Additionally, the control blade insertion history should also be provided for each measured channel. For channel bulge behavior understanding, the time history of the axial distribution of channel fast flux and channel wall pressure drop should be reported.





## Section 3: Conclusions

It has been noted that there can be differences in the way channel dimensional characteristics are measured and reported that can lead to inconsistencies and misinterpretation when comparing channel dimensional measurement results from one fuel supplier to another. It is therefore considered that the issuance of this EPRI guidance report may be helpful to prevent such inconsistencies and misinterpretations, and further increase the utility of the information obtained from EPRI-sponsored channel dimensional measurement campaigns.

The following best practices have been identified:

- Identify those measurements that reflect the operation of a measurement device beyond its qualified/calibrated range, and suggest an appropriate disposition of those measurement results (can be used, must be discarded, etc.) with supporting justification.
- Channel bulge should be determined from channel width measurements at the location equidistant from the channel corners (location of maximum bulge).
- Measure all channel faces (or pairs)
- Provide the bulge measurements at each measured axial elevation to provide confirmation that the indicated profile does not suggest larger bulge than indicated by the individual measurements.
- Revisit the selected elevations of the measurement stations with new channel dimensional configurations and when indicated as non-optimal from measured axial profiles.
- Include symmetrically operated channels in channel measurement campaigns.
- Provide the bow measurements at each measured axial elevation to provide confirmation that the indicated profile does not suggest larger bow than indicated by the individual measurements.
- Include symmetrically operated channels in channel measurement campaigns.
- Include length measurements of all four channel faces over the spectrum of conditions covered by the channel measurement campaign.





# Appendix A: Channel Bow Correction

## Introduction

An important part of the channel bow measurement is the assumed reference (zero deflection) axial elevations. Briefly, a straight line is drawn between two reference elevations and the bow of the channel is defined by the measured horizontal displacement of the channel surface from that reference line. The axial elevation of those reference locations can vary by fuel supplier and for different inspection campaigns by the same fuel supplier. The further the reference elevations are away from the ends of the channel, the smaller the measured bow will be relative to the true bow of a given channel. The purpose of this appendix is to outline the procedure that should be applied to the measured channel bow values to determine the actual channel bow. With the indicated corrections, the bow from one fuel supplier campaign can be fairly compared to the bow obtained from another fuel supplier campaign.

## Discussion

The basic bow correction process is defined below:

1. Generate a theoretical bow profile. Actual bow profiles are typically relatively sinusoidal in shape with the peak measured bow occurring near the channel mid-height elevation. Usually, a transducer is placed at/near the channel mid-height elevation for the specific purpose of capturing this peak deflection. For the calculations presented here, the theoretical bow profile is taken as a sine curve with a peak magnitude of 428 mils. The actual magnitude of the peak bow deflection is not important as the determination of the relative error (%) will apply to all assumed bow magnitudes with a sinusoidal profile.
2. Determine the reference elevations for the specific application. In some cases, the reference elevations may be the channel ends, in which case the bow correction is zero. In the other cases, the reference elevations are the locations of the uppermost and lowermost transducers.
3. On a plot of the theoretical bow as a function of axial elevation, draw a vertical line from the x-axis to the bow profile at each reference elevation. Then, draw a straight line connecting these two points. This line represents the reference condition corresponding to zero measured bow.

4. At each transducer elevation, determine the vertical (y-axis) distance from the reference line to the theoretical bow profile. This vertical deviation between the reference line and the theoretical bow profile is the amount of bow that would have been measured by the specific measurement system being evaluated.
5. Compare the peak bow measured by the measurement system to the peak actual bow of the theoretical bow profile (428 mils in this case). The relative error is defined as

$$\text{Error (\%)} = \frac{(\text{theoretical peak bow}) - (\text{measured peak bow})}{\text{measured peak bow}} \quad \text{Equation A-1}$$

6. The error determined above should then be used to correct the reported measured peak bow values from each fuel supplier for each measurement campaign. For example, if the error is determined to be 13%, then each reported measured peak bow value should be multiplied by 1.13 to obtain the corrected (actual) peak bow value.

An example application is presented below.

For a hypothetical example channel measurement system, fixed elevation transducers are utilized. The uppermost and lowermost transducers measure the distance from the fixture position to the channel, and those distances are defined as the reference (zero bow) locations. With this configuration, the greater distance the upper and lower transducers are away from the channel ends, the greater the bow measurement error will be.

Consider the following arbitrarily assumed transducer configuration for measurement of a channel of assumed length of 166.91 in. The transducer elevations are listed below (relative to the bottom of the channel):

3962 mm	155.98 in.
3073 mm	120.98 in.
2057 mm	80.98 in.
1346 mm	52.99 in.
1041 mm	40.98 in.
737 mm	29.02 in.
25 mm	0.98 in.

Figure A-1 presents the assumed theoretical actual bow profile. Figure A-1 also includes the assumed transducer positions, and resulting reference (zero bow) line. It is observed from Figure A-1 that the bow measurements will underestimate the true bow by 8-87 mils in this case, depending on the axial elevation of interest.

Figure A-2 presents the bow profile as it would have been measured by the hypothetical example channel measurement system, as compared to the true bow profile. The error in maximum bow is determined to be 13.1%.

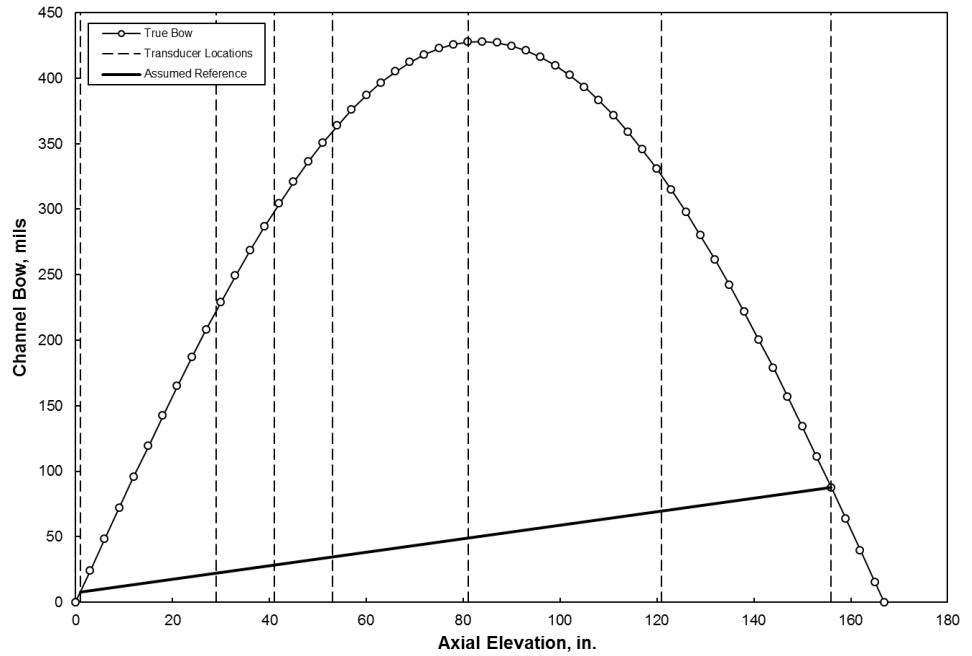


Figure A-1  
Example Transducer Positions and Reference Line

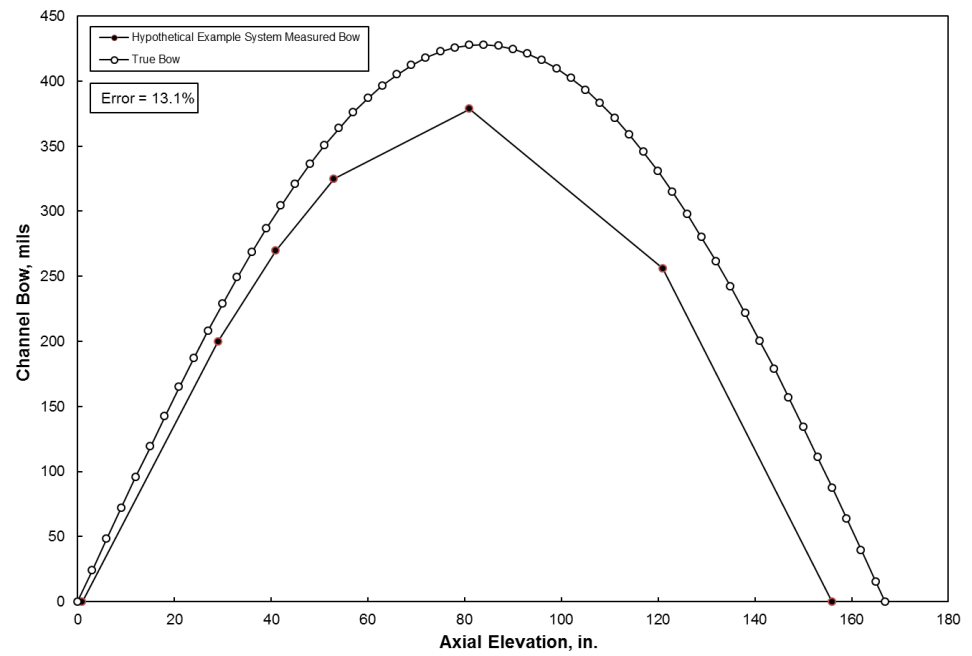


Figure A-2  
Comparison of Example System Measured Bow and True Bow





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