# Modelling Methodology for Subchannel Flow Redistribution Around End Plates in the Sub-channel Code ASSERT IV

**P. White, R.F. Dam, M.R. Soulard, N. Lee**
**AECL Sheridan Park**
**Mississauga, Ontairo**

## *Abstract*

*In general, pressure drop in a CANDU[1] fuel string is important because of its impact on equipment size and on its impact on thermalhydraulic behaviour for both normal and abnormal operating conditions. In sub-channel codes, such as ASSERT, characterising the frictional and form losses of the individual sub-channels is also important when modelling local flow void distribution in the fuel string. This in turn will impact on the prediction of phenomena such as critical heat flux.*

*A model has been previously developed, based on form loss equations found in Idelchik, to predict sub-channel form losses using the local geometry as input to the model. This model has exhibited good results. Recently, detailed pressure drop experiments have been carried out that help to better quantify the components of the overall pressure drop in a fuel string. These experimental results have been used to improve the existing model, and to develop a more comprehensive modelling methodology for use in ASSERT. The result is an integrated friction and form loss model that can reproduce the total fuel string pressure drop, and provide insight into the bundle average losses associated with each of the components for use in bundle average fuel string models.*

*This paper discusses the methodology used to integrate local form losses due to end plates into the new model and how the modelling envelope is defined.*

## 1.0 INTRODUCTION

Prediction of pressure drop and critical heat flux (CHF) in CANDU fuel strings has been a topic of interest for several years. This has lead to the development of several models used to predict dryout power on a bundle average basis. In addition, several experiments have been carried out to create a database that can be used to both develop prediction capabilities and validate existing models.

As existing fuel channels' age, greater attention is being paid to variances in geometry. These variations can result, for example, from pressure tube radial creep, end plate misalignment or nonconformity's in the bundle geometry. Even the possibilities of extraneous sources of blockage within the bundle have been considered [1].

The impact of these geometry variations must be considered from both a CHF and pressure drop perspective. The modelling of pressure drop and CHF are two aspects of thermalhydraulic performance of the fuel string which are integrally related. The focus of this paper is on the pressure drop prediction methodology.

To gain a more detailed understanding of the bundle thermalhydraulics, and to cater for the impact of geometry on pressure drop, the sub-channel code ASSERT-IV has been employed. The geometry based model [2], which calculates pressure drop due to form losses in the fuel string, is used to estimate the impact of endplates, spacers, and bearing pads on the pressure drop. The geometry based model treats local form losses as orifice-like contractions or expansions in the sub-channel. Samples

[1] CANDU is a registered trademark of Atomic Energy of Canada Limited

of the subchannel flow area reduction components of concern are shown in Figure 1. For example, the distribution of subchannel flow area reduction provided by uniformly-aligned end plates covers the range of 0-to-65%. The question that has arisen regards the appropriate modelling of local area reductions and downstream flow recovery.

# 2.0 METHODOLOGY

## 2.1 The ASSERT IV Code

ASSERT (Advanced Solution of Sub-channel Equations in Reactor Thermalhydraulics) is a computer code developed at Chalk River Laboratories to model transient single and two phase flow through fuel bundles. For this paper ASSERT IV V2R9 is used with the updates described by Soulard et al. [2] and Waddington et al.[3]. This geometry based model has been developed for ASSERT to model the flow area reductions arising from the endplates and spacers intruding into a subchannel.

### 2.1.1 Subchannel Flow Area Reduction Model

ASSERT models a subchannel flow area reduction as an orifice. Idelchick [4] provides a model for flow contraction based on theory and empirical evidence. The model is of the following form:

$$\frac{\Delta p}{\rho u_1^2 / 2} \approx \left(1 + \gamma \sqrt{1 - \frac{A_0}{A_1}} - \frac{A_0}{A_1}\right)^2 \left(\frac{A_1}{A_0}\right)^2 \quad (1)$$

Where: $\Delta p$ is the pressure drop

$A_0$ is the area of the subchannel with the area reduction

$A_1$ is the area of the subchannel

$u_1$ is the fluid velocity

$\rho$ is the density of the fluid

$\gamma$ is a constant

Figure 2 gives a graphic representation of the parameters used in equation one. As can be seen by this equation, as the area ratio of blockage area ($A_1$-$A_0$) to subchannel area ($A_1$) gets close to one, the form loss approaches infinity.

ASSERT calculates pressure drop using an fl/d + k model [2]. The pressure drop is a weighted-average of the form loss and friction over the length of the node. The code is able to capture the impact of node size on ΔP as the node length is changed. For small flow area reductions, the form loss and the friction will be of comparable size; so as the node length changes the friction component of the affected subchannel will increase or decrease along with the node size. However, as the flow area reduction increases the form loss starts to dominate and the frictional component in the pressure drop of the affected subchannel becomes independent of node size. The question that has to be asked is when does the dependence of friction with node size breakdown for a subchannel with a large flow area reduction. From an energy point of view, one can see a similar problem with mixing. As the node length changes, the amount of flow diverted out of the subchannel changes. This change in flow distribution affects the amount of energy that is transferred between the subchannels. To simulate the energy distribution correctly, mixing models have been developed which can account for turbulence and errors introduced through nodalization [5]. A similar approach has been adopted, as will be discussed below, to model the effects of flow area reductions on subchannel flow distribution and pressure drop.

## 2.2 Problem Definition

Modelling of subchannel flow area reductions is an important part of predicting the overall pressure drop and flow distribution. Given the geometry data, the geometry-based model is able to calculate the form loss associated with each subchannel [2]. The code then predicts the flow distribution given the distinct hydraulic characteristic of each subchannel.

The ASSERT model discretizes the fuel string into nodal lengths. Within a given node, the subchannel flow area reduction, say due to an end plate web, normally takes up only a fraction of the nodal length. Currently, typical ASSERT IV models use nodes in the 6 to 8 cm range, and this level of nodal refinement is converged for a uniform form loss applied in each subchannel of the bundle. However, when one applies a non-uniform loss to the bundle, the pressure drop will vary depending on the nodal length. The problem arises when the flow area reduction becomes significant when compared to the subchannel flow area. This change in pressure drop is due to the fact that there are flow recovery differences affecting the apparent frictional gradient. When the subchannel flow area reductions start to become significant (i.e. beyond 25% flow area reduction), there is a large lateral flow redistribution, and the flow cannot recover from this redistribution until the following node, which will be 6 to 8 cm downstream. Physically the flow will begin to recover immediately after the local area reduction. So while these 6 to 8 cm nodes can predict the average flow distribution correctly for small subchannel area reductions, it will have trouble as the flow area reduction increases.

The problem can be better illustrated by looking at the extreme case of a completely blocked subchannel. In this extreme case the entire flow is forced out of the subchannel and is unable to recover until the next node. In reality flow will start to return immediately after the local area reduction in the subchannel. This delay in flow recovery arising from the imposed nodalization scheme (i.e. 6-8 cm length nodes) can lead to an error in the overall pressure drop calculation. By increasing the length for the flow to recover, the apparent average friction factor for the new flow state is higher than it would be if allowed to recover quickly which in turn leads to a higher pressure drop being calculated.

To ensure that the geometry-based model is better able to capture the flow and pressure distribution of a known flow area reduction, a modelling methodology has been developed. This methodology defines the significant area reduction threshold and allows for an integrated approach to model any geometry (e.g. 37-element or 43-element bundles) and subchannel flow area variations (e.g. due to PT radial creep, end plate misalignment).

## 2.3 Modelling

The modelling of subchannel flow area reductions can be accommodated through the nodalization scheme. The node length is made equal to the length of the local flow disturbance allowing the fluid to recover when it is past the local area reduction. This method allows one to approximate the geometry of the system very closely. Unfortunately when modelling large structures like the CANDU fuel string, ASSERT IV has trouble converging when the nodal length gets below 4 cm. This limitation in ASSERT IV forces one to find a method of modelling these local area reductions while keeping the 6 to 8 cm nodes. Moreover, the larger 8 cm nodes provide for a shorter solution time.

A large node size can be accommodated by averaging the local form loss over the neighbouring subchannels while keeping the overall area reduction constant. This method of modelling subchannel flow area reduction is called **RE**alistic **B**lockage **A**rea **R**eallocation (REBAR). The idea behind REBAR is that at zero percent or no REBAR the local form loss corresponding to the subchannel flow area reduction is applied directly to the subchannel. At 100 percent REBAR the local form loss is shared such that the area reduction ratio is equal within all the neighbouring subchannels, but the total area reduction remains constant. All other levels of REBAR are just a linear interpolation between the zero and 100 percent points. The question then becomes one of when and to what extent the flow area reduction needs to be shared with the neighbouring subchannels.

To answer this question of when REBAR is required, we will have to return to the smaller node method first. Let's assume that the small node size gives us the best approximation of what is happening when the fluid encounters a local area reduction. This is a reasonable assumption as ASSERT IV has been tied to experiments for single phase pressure drops and has shown good agreement [3].

In using small nodes to model the effect of local area reduction, a few additional assumptions must be made. The first assumption is that modelling the subchannel area reduction in a node of the same length will give a better representation of flow recovery. The second assumption is that the effect of the area reduction is local, and does not impact beyond the adjacent subchannels, which is reasonable as a first order approximation.

## 2.4 Analysis

To allow a small node model to be built, a simplified three subchannel model was made. Here all three subchannels are of the same size, typical of a 37-element bundle, and are connected horizontally to remove the effects of gravity. The channel is 100 cm long with a 2 cm nodalization except for the local area reduction node. The local area reduction was placed 24 cm into the subchannel with the node at the local area reduction being equal to 0.5 cm. This reference model was used to predict the pressure drop and flow distribution caused by the local area reduction. A second model was then made of the same three subchannels, but using 8 cm nodes. Figure 3 shows a schematic of the three subchannel model.

Using the two models, the amount of REBAR required can then be determined by the amount of area reduction that needs to be shifted to the other subchannels to make the pressure and flow match. However, in a CANDU fuel bundle string, the flow is redistributed at regular intervals as it encounters end plates and spacer planes. This regular disturbance provides a set length over which the flow can recover. This leads to the defining of a characteristic length within which the flow and pressure should be matched after a local area reduction. For the purpose of this model, a 24 cm characteristic length was chosen consistent with the distance between end plate junctions and spacer planes in a typical CANDU fuel string and allowing for three 8 cm nodes.

### 2.5 Cases

All the cases simulated used the same temperature, pressure and flow. With the subchannels and characteristic length defined, both 2 and 8 cm models were used to generate pressure drop and flow profiles for flow area reductions ranging from 10 to 70 percent in the centre subchannel. The decision was made to only investigate up to 70 percent as the largest subchannel area reduction for a typical CANDU end plate is 64 percent with the majority being below 25 percent. REBAR was added to the 8 cm model for the blockage areas discussed, until the pressure drop over the characteristic length was matched. Using this approach allows the REBAR to be defined in a systematic and integrated way.

## 3.0 RESULTS and DISCUSSIONS

The results of the pressure drop of the 2 and 8 cm models are displayed in Figure 4. Figure 4 clearly shows that the pressure drop of the two models diverge as the amount of flow area reduction increases. This is because at low area reduction levels, the apparent friction increase is small for the flow distribution caused by the local area reduction. As the area reduction is increased more flow is diverted into the outer subchannels causing the 8 cm nodes to have a larger apparent frictional pressure drop than the 2 cm nodes. The reason for this smaller drop in 2 cm nodes is the flow can recover sooner than the 8 cm model.

Comparing the flow distribution, Figure 5, one can see that in Figure 5a the flow for the 8 cm case is disturbed more than that of the 2 cm case. By applying REBAR, Figure 5b, the flow of the 8 cm model is now in agreement with the 2 cm model. With the use of REBAR we are able to match the pressure drop of the characteristic length by keeping the form loss and the frictional losses the same for both the 8 and 2 cm cases.

Using the data obtained about REBAR from the 8 cm sub-channel model a graph of percentage REBAR verse percentage area reduction was made and is displayed in Figure 6. Looking at Figure 6, one notices that a straight line can be fit to the data points. This graph shows that for area reductions below 25 percent no REBAR is required This implies that most of the subchannels disturbed by a uniformly-aligned 37-element end plate need no REBAR. Also from the graph in Figure 6 one notes that the REBAR for 30 percent blockage is about 4 percent. As a check of the linearity of the data, this 4 percent REBAR was used to bring the pressure drop of the 8 cm model with 30 percent blockage in line with 2 cm model. The results are displayed in Figure 7, and shows that the 30% area reduction case for the 8 cm node model is now in agreement with Figure 4

The results from this work shows the concept to be workable. However, there are limitations to keep in mind. The 3 subchannel geometry was very simple (i.e., all the same size subchannels). Also, only one mass flow rate was used. The next step to be taken with subchannel flow area reduction methodology is to establish the variances that may exist in REBAR for other flow conditions and for different combinations of adjacent subchannel area reductions. The methodology for use with a 37-element 12-bundle fuel string can be developed based upon this analysis.

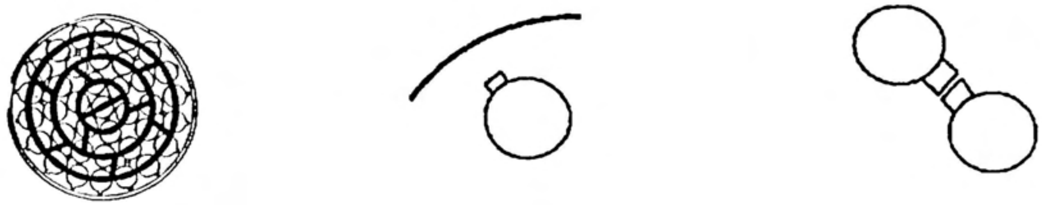
## 4.0 CONCLUSIONS

The need for a consistent way to model large subchannel flow area reductions is clearly evident by the resulting pressure drop change among the 8 and 2 cm node cases. It has been shown that by redistributing the local area reduction among the adjacent subchannels both the flow and pressure drop can be modelled by the two nodalization schemes. By developing a methodology for REBAR, one can come up with an integrated and consistent representation of large subchannel flow area reductions. For local area reductions beyond 70%, the form loss grows exponentially. This implies that the linear relationship for REBAR found here most likely does not apply at area reductions near 100 percent. For local area reductions above 70 percent, the process outlined here would have to be extended. Also the sensitivity of REBAR to other parameters such as flow rate, subchannel size, combinations of adjacent subchannel area reductions, etc need to be examined in future work.

## 5.0 REFERENCES


1. G.D. Harvel et al., "Investigation of Flow Blockages in a Fuel Channel with the ASSERT Sub-channel Code", Annual CNS Conference, Fredericton, 1996.
2. M.R. Soulard et al, "Investigation into the Modelling of the Effects of Pressure Tube Creep on CHF, Dryout Power and Pressure Drop', Annual CNS Conference, Saskatoon, 1995.
3. G.M. Waddington, J.C. Kiteley and M.B. Carver, "ASSERT Validation Against the Stern Laboratories' Single Phase Pressure Drop Tests", CNS Simulation Symposium, 1995.
4. I.E. Idelchik, "Handbook of Hydraulic Resistances", CRC Press Inc., 3rd Edition, 1994.
5. J.T. Rogers R.G. Rosehart, "Mixing by Turbulent Interchange in Fuel Bundles", ASME 72-HT-53, 1972.

**Figure 1: Typical Components Causing Subchannel Flow Area Reductions**

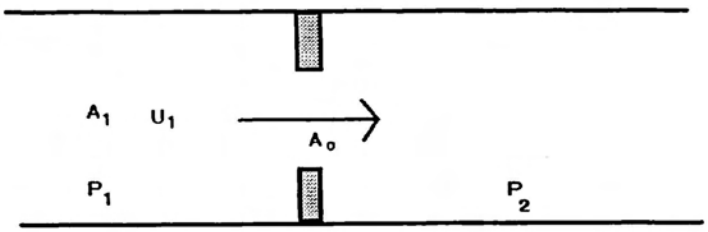


End Plate

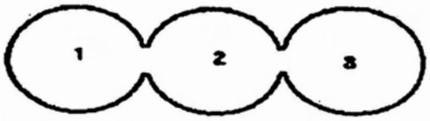
Spacers

Bearing pad

**Figure 2: Flow Area Reduction Modelled by Equation 1**



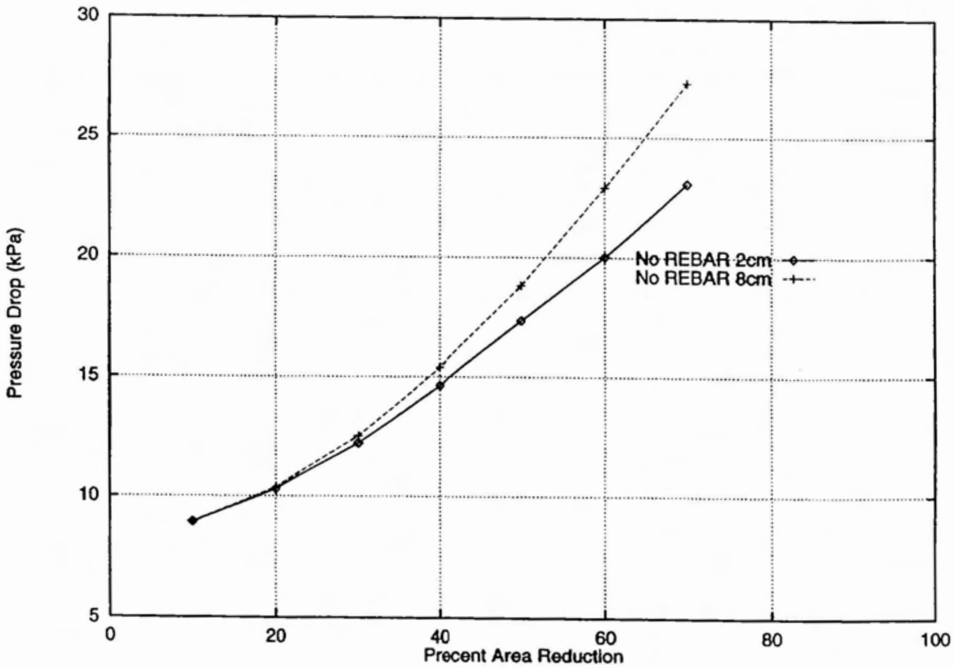
## Figure 3: Subchannel Model




3 subchannels no area reduction

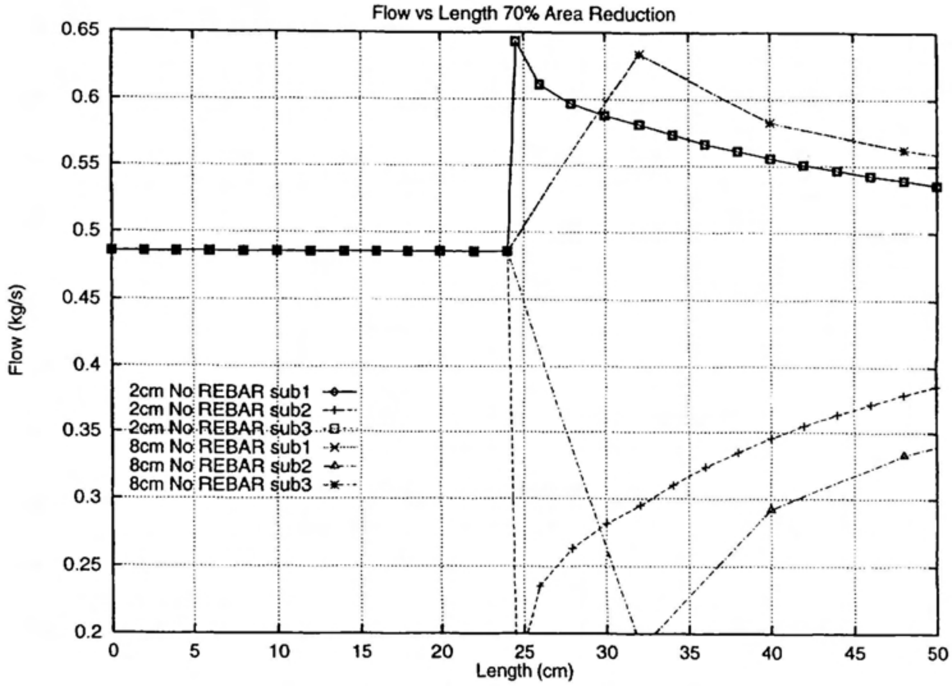

3 subchannels with area reduction

## Figure 4: Pressure vs Percent Area Reduction For A Characteristic Length of 24 cm



## Figure 5: Flow vs Length with and without REBAR

(a)




(b)

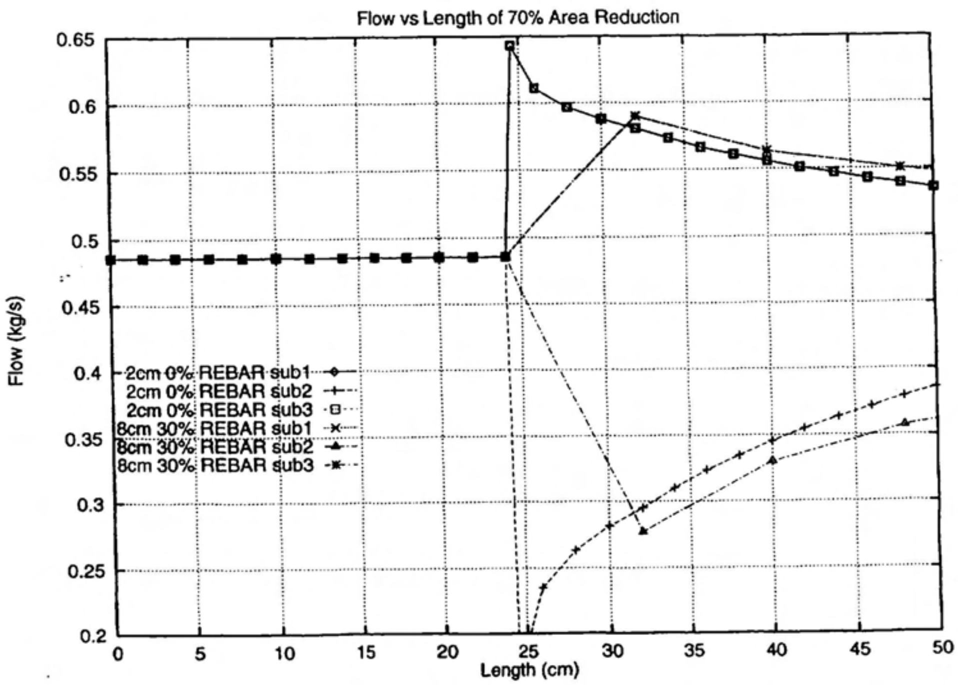


**Figure 6: Percent REBAR vs Percent Area Reduction**

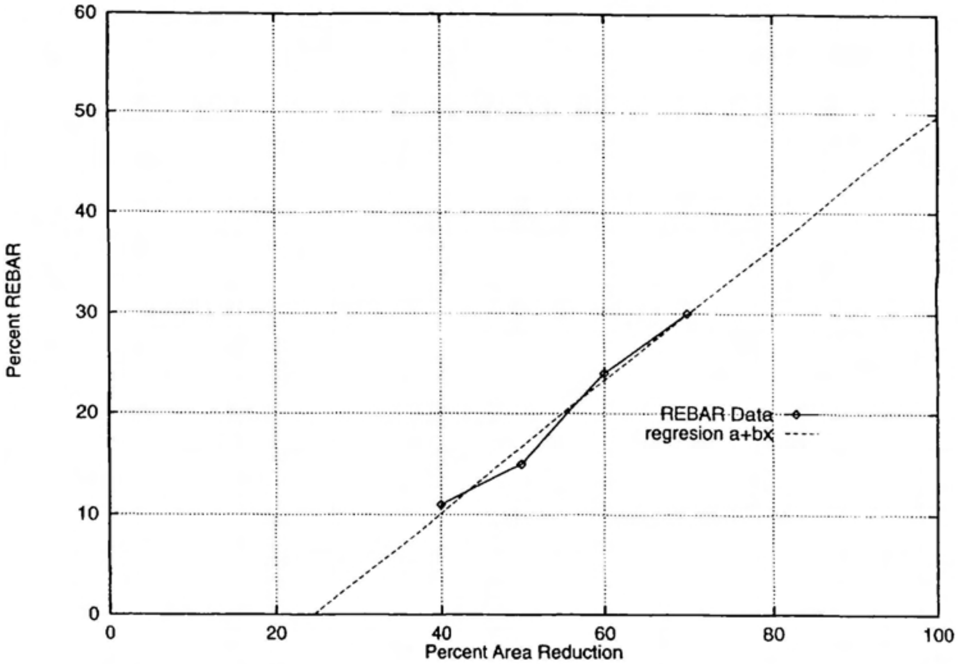



**Figure 7: Pressure vs Percent Area Reduction For A Characteristic Length of 24 cm**