Reuter-Stokes
a Baker Hughes business

Gamma traversing in-core probes

Gamma TIPs offer the opportunity for:

- Extended fuel life
- Increased operating margin
- Improved accuracy of TIP calibration

Investigations of boiling water reactor (BWR) core power levels have shown that thermal neutron traversing in-core probe (TIP) readings often indicate radial power asymmetries greater than actual.

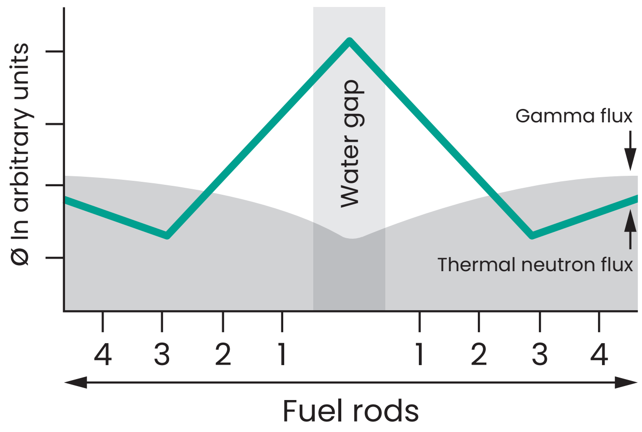
In some cases, these indicated asymmetries have led to unnecessarily conservative operating margins, reducing reactor operating flexibility and, in many plants, power output potential.

The Reuter-Stokes Gamma TIP answers the need for more accurate readings to calibrate the reactor's local power range monitors (LPRMs). The Gamma TIP, which senses gamma radiation, is less sensitive to water gap and LPRM positioning variables than a neutron measuring probe. Economics, particularly in BWRs experiencing core asymmetries, strongly favor conversion to the Gamma TIP. Benefit cost analyses performed on some BWRs have shown rations as high as three to one.

Even plants which have not yet exhibited core asymmetries may encounter such a condition in the future.

Rated against a benchmark gamma scan in an operating BWR, Baker Hughes Gamma TIP signals have demonstrated less than half the asymmetry variance, and therefore, twice the accuracy, of Neutron TIP signals. Moreover, the gamma signals require less correction to nodal powers than thermal neutron signals.

With the improved accuracy of Gamma TIPs, there is also the potential for extending time intervals between LPRM calibrations.



Less frequent usage can mean significantly longer service life and lower replacement rates when compared with thermal Neutron TIPs.

Experience gained at operating BWR plants which have installed Gamma TIPs verifies significant improvement in fuel bundle power readings.

Gamma TIP improvement over thermal neutron TIP

	Neutron TIP	Gamma TIP	Improvement
Asymmetry average	4.1%	2.3%	+56%
Minimum Critical Power Ratio (MCPR)	1.39%	1.46%	+5.1%
Maximum Fractional Limiting Power Density (MFLDP)	0.94%	0.9%	+3.7%
Maximum Average Planar Linear Heat Generation Rate (MAPLHGR)	0.93%	0.9%	+4.8%
TOTAL PEAKING FACTOR	2.278%	2.194%	+3.8%

NOTE: These are average values. Magnitudes of symmetry vary with each reactor and its operating history.

Peak nodal power in the bundle is a key thermal performance parameter because it determines the margin from the licensed Minimum Critical Power Ratio (MCPR) limit. The degree of uncertainty in power distribution resulting from Neutron TIP asymmetry reductions can lead to significant improvements in the MCPR. This permits safe operation of the reactor at levels closer to the true limits of operation.

BWR core symmetry analyses, which compared integral nodal TIP asymmetry, supported the factor of two asymmetry advantage of gamma versus thermal neutron signals. Following are averages of three data sets:

Indicated TIP asymmetries (deviations from actual)

	Thermal	Gamma
Integral	6.76%	2.54%
Nodal	8.21%	5.53%

Significant economic advantages

Conservative analysis of improved operating margins over a one year period show a potential benefit to cost ratio of greater than three to one for converting to the Gamma TIP system. Calculations indicated a two percent improvement in capacity factor resulting from a changeover to Gamma TIPs at an 850 MWe BWR plant. A two percent improvement in plant capacity factor translates to a benefit to cost ratio of three to one. Similar calculations for other BWRs would, of course, depend on the magnitude of indicated asymmetries and the particular replacement power costs associates with individual utility systems.

In a typical energy replacement calculation, the annual benefit of two percent capacity in a currently operating 850 MWe plant is 126,600 MWhr (850 MWe x 876 hr/yr x 0.02 x 0.85 plant availability = 126,582 MWhr), and the annual dollar saving over replacement by coal fired generation is more than $750,000.* Based on this analysis in the plant considered, conversion to Gamma TIPs paid for itself in approximately 120 days.

You are encouraged to calculate your own economic improvement by applying plan specific variables.

Three additional Gamma TIP benefits are also important and worthy of consideration: 1) improved fuel utilization resulting from more even fuel depletion, 2) reduced starting time due to improvements during peaking factor calculations and 3) simplified inventory storage and the potential for longer life, since the Gamma TIP contains no fissile material.

**Based on assumed replacement energy cost of $10.00 per MWhr and nuclear costs of $4.00 per MWhr.*

Gamma TIP system sales to BWRs

Gamma TIP systems are used in many BWRs throughout the world.

Gamma TIP plant listing as of January, 1989

Plant	Year of Gamma Tip installation
Hatch I	1978
Duane Arnold	1980
KKM	1980
Vermont Yankee	1981
Hatch 2	1983
Nine Mile Point 1	1984
Leibstadt (KKL)	1984
Confrentes	1984
FitzPatrick	1985
Nuclenor	1985
Caorso	1986
TVO 1, 2	1986
Hope Creek	1986
Perry	1987
Brunswick 1, 2	1988
Browns Ferry 1, 2, 3	1988
Cooper	1988*
Forsmark	1988*
Peach Bottom 2, 3	1988*
Limerick 1, 2	1988*

**On order, or delivered*

Changeover to Gamma TIPs

Changes required to drive

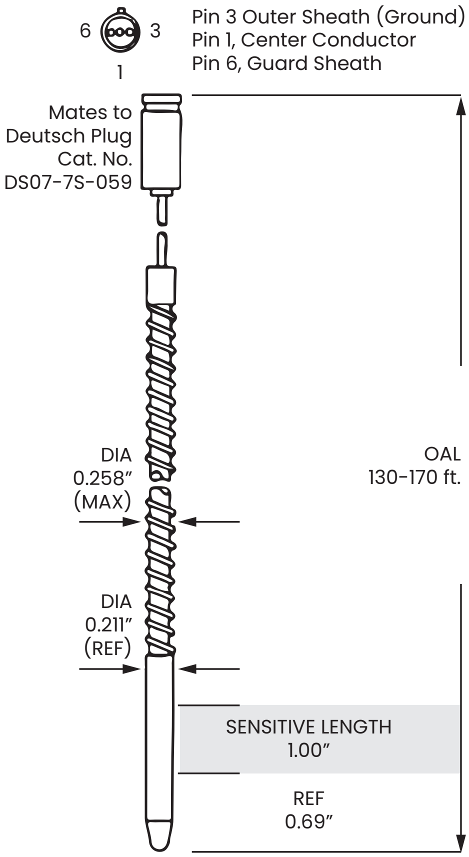
None. The Gamma TIP is similar to the Neutron TIP, but is sensitive to gamma flux rather than neutron flux. Both TIPs use the same drive cable, and they are mechanically interchangeable. Early design Gamma TIPs were constructed of materials containing a significant amount of cobalt, resulting in radiation rates after usage which were greater than Neutron TIPs. However, the Gamma TIP design has been changed to incorporate low cobalt materials, resulting in radiation rates from activation which are actually lower than activation Neutron TIPs.

Gamma signal processing

The Gamma TIP output signal current in lower than the corresponding Neutron TIP current. For this reason, a triaxial cable with guard sheath is used for the Gamma TIP to reduce spurious noise currents which would interfere with the signal current. This continues to permit location of all signal processing electronics in the control room for ease of calibration and maintenance. The Gamma TIP cable is terminated with a Deutsch quick connect electrical connector, whereas the Neutron TIP is terminated with an SMA connector. A short adaptor cable is supplied with each TIP, and is installed between the TIP connector and Gleason reel cable connector.

If not already installed, the Gamma TIP requires triaxial cable having the following characteristics from the sensor to the signal processing electronics:

a. Voltage	1,000V Rms (maximum)
b. Cable capacitance between center conductor to inner shield. (Maximum length cable is 500 ft.)	21 pf/ft (nominal)
c. Minimum insulation resistance between center conductor to inner shield	10^{12} ohms @ 23°C
d. Minimum insulation resistance between inner shield and outer shield.	10^{10} ohms @ 23°C



Changes to electronic readout

The Gamma TIP requires a Flux Probe Monitor with higher gain than the Neutron TIP because of its lower output signal. This higher gain, together with other advanced circuitry, is offered in the Gamma TIP Flux Probe Monitor.

The Monitor is a standard electronics drawer designed for inputs from up to six (6) TIPs. It is directly interchangeable with the existing Neutron TIP drawer.

Components used in the Gamma TIP drawer are readily available on world markets. Specific characteristics include:

Flux probe monitor specifications	
Power	120 VAC, 60 Hz, 50 watts
Signal inputs (1 to 6)	
Current (adjustable)	0-200 microamps full scale
Detector bias supply (1 to 6)	
Voltage	75 to 200 VDC
Current (total)	2 milliamps
Record outputs	
Voltage	0-10 VDC
Impedance	1.5 k in parallel with 390 microfarads
Response time	600 microseconds
Computer outputs	
Voltage	1-160 millivolts
Impedance	211, 961, or 1,098 ohms
Response time	0.9 microseconds (for full scale)

Software modifications

In order to convert to Gamma TIP, it is necessary to have GEXL +15 software.

In applications where Reuter-Stokes fuel is installed, necessary software modifications and data bank inputs are supplied directly. The price is included with each offering with initial conversion to Gamma TIP.

In those installations where Reuter-Stokes fuel and/or software is not being used, Reuter-Stokes provides, at, no charge, data on Gamma TIP sensitivity and energy response for data bank inputs to other programs.

Since the Gamma TIP signal does not respond to neutron flux repressions caused by fuel rod spacer or LPRM's as well as thermal Neutron TIP, a special procedure must be used for TIP axial alignment. This procedure is very similar to Neutron TIP alignment and requires no special tooling. It does require more care in locating spacers, in setting core top and bottom limits, and in calibrating the TIP position indicator. Complete instructions are supplied with each initial conversion from Neutron to Gamma TIP.

Gamma TIP

Material

Chamber	
Outer shell	Stainless steel
Inner electrodes	Titanium
Insulation	$A1_20_3$
Cable	
Outer sheath	Stainless steel
Guard sheath	Stainless steel
Center conductor	Stainless steel
Insulation:	
Outer to guard sheath	Mg0
Guard sheath to inner sheath	Mg0
Drive cable	Carbon steel
Fill gas	Argon

Maximum ratings

Voltage between electrodes	
Center conductor to guard sheath	100 volts
Guard sheath to outer sheath	400 volts
Temperature	
Sensor	608°F (320°C)
Connector	302°F (150°C)
Gamma flux	2.8 x 10^9R/hr
Guide tube travel	600,000 ft
Force on drive cable helix	100 lbs.

Gamma TIP

Impedance

Resistance	
@ 25°C with 100 volts applied:	
Center conductor to guard sheath	1 x 10^9 ohms (min.)
Guard sheath to outer sheath	2 x 10^9 ohms (min.)
With connectors plus 10 ft. cable @ 25°C and sensor element and remainder of cable @ 320°C with 100 volts applied:	
Center conductor to guard sheath	1 x 10^8 ohms (min.)
Guard sheath to outer sheath	2 x 10^8 ohms (min.)

Typical operating characteristics

Voltage	100 volts
Range	10-100% power
Gamma sensitivity (Note 1)	3x10^{-14} amp/R/hr±25%
Linearity over operating flux range	Better than 1% full scale

NOTE 1: In Cobalt 60 with 100 volts applied.

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