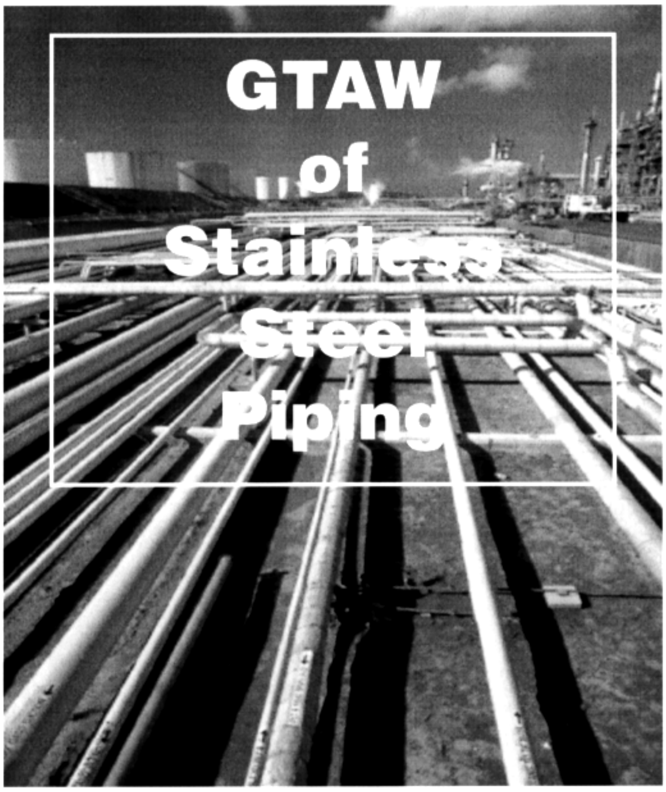


Process piping conveys fluid to and from a plant's various pieces of equipment such as furnaces, reactors, heat exchangers, distillation towers, boilers and turbines. It also connects one process unit with another, and may at times be assembled in long straight runs. Stainless steels — mainly austenitic types — are preferred for piping used at high or cryogenic temperatures, or in highly corrosive environments. The main grades of stainless steels for the process piping are shown in Table 1.

Table 1. The main austenitic stainless steel pipes for process piping (ASTM A 312-99)

ASTM grade	Main chemical composition (%)					
	C	Ni	Cr	Mo	Cb+Ta	Ti
TP304	0.08 max	8.00-11.00	18.0-20.0	—	—	—
TP304L	0.035 max	8.00-13.00	18.0-20.0	—	—	—
TP310S	0.08 max	19.0-22.0	24.0-26.0	—	—	—
TP316	0.08 max	11.0-14.0	16.0-18.0	2.00-3.00	—	—
TP316L	0.035 max	10.0-15.0	16.0-18.0	2.00-3.00	—	—
TP317L	0.035 max	11.0-15.0	18.0-20.0	3.00-4.00	—	—
TP347	0.08 max	9.00-13.0	17.0-20.0	—	4 x C-0.60	—
TP321	0.08 max	9.00-13.0	17.0-20.0	—	—	5 x C-0.70

Pipe welding procedures

Stainless steel process pipes are usually joined, depending on the diameter and wall thickness, by GTAW for both the root and filler passes, or by GTAW for the root pass and subsequently by shielded metal arc welding (SMAW) or gas metal arc welding (GMAW) for the filler passes. With solid filler rods, the root pass is usually welded from one side using argon gas as back shielding. By contrast, with flux-cored filler rods, the root pass can be completed from one side without back shielding because the flux fuses to become slag, thereby protecting the reverse side bead from the atmosphere. Table 2 shows a summary of pipe welding procedures used in GTAW, GTAW+SMAW and GTAW+GMAW. KOBELCO GTAW filler rods suitable for welding stainless steels are shown in Table 3. This article concentrates on GTAW root-pass welding of pipe joints.

Table 2. A summary of pipe welding procedures by GTAW, GTAW+SMAW and GTAW+GMAW

Type of filler rod	Root pass		Filler pass
	Process	Back shielding	Process
Solid	GTAW	Required	GTAW
	GTAW	Required	SMAW, GMAW
Flux-cored	GTAW	Not required	GTAW with solid filler rod
	GTAW	Not required	SMAW, GMAW

Table 3. A quick guide to suitable GTAW filler rods for main austenitic stainless steels and dissimilar metals (1)

ASTM grade	Solid filler rod		Flux-cored filler rod	
	Brand	AWS (2)	Brand	AWS (3)
TP304	TGS-308	ER308	TGX-308L	R308LT1-5
TP304L	TGS-308L	ER308L	TGX-308L	R308LT1-5
TP310S	TGS-310	ER310	—	—
TP316	TGS-316	ER316	TGX-316L	R316LT1-5
TP316L	TGS-316L	ER316L	TGX-316L	R316LT1-5
TP317L	TGS-317L	ER317L	—	—
TP347	TGS-347	ER347	TGX-347	R347T1-5
TP321	TGS-347	ER347	TGX-347	R347T1-5
Dissimilar metals (4)	TGS-309 TGS-309L TGS-309MoL	ER309 ER309L ER309LMo	TGX-309L	R309LT1-5

Note:
(1) Available diameters (mmØ): 1.0, 1.2, 1.6, 2.0, 2.4 and 3.2 for TGS-308, 308L, 309, 309L, 316, 316L and 347; 1.2, 1.6, 2.0, 2.4 and 3.2 for TGS- 309MoL; 1.2, 1.6, 2.0 and 2.4 for TGS-317L; 2.2 for TGX series. Spooled filler wires are also available for TGS series for automated GTAW process.
(2) AWS A5.9-93
(3) AWS A5.22-95
(4) Carbon or low alloy steel to austenitic stainless steel dissimilar metal joints

Conventional GTAW root pass welding with solid filler rods

With solid filler rods, back shielding is required in GTAW root pass welding for stainless steel pipes, or the root pass weld cannot penetrate the back side of the joint properly. Poor weld penetration may be caused by oxidation due to the high chromium content of the weld. Therefore, back shielding with an inert gas — commonly argon (Ar) — is a must. Back shielding can be done by locally shielding the weld zone using jigs, or by surrounding the entire piping with shielding gas, as shown in Figure 1.

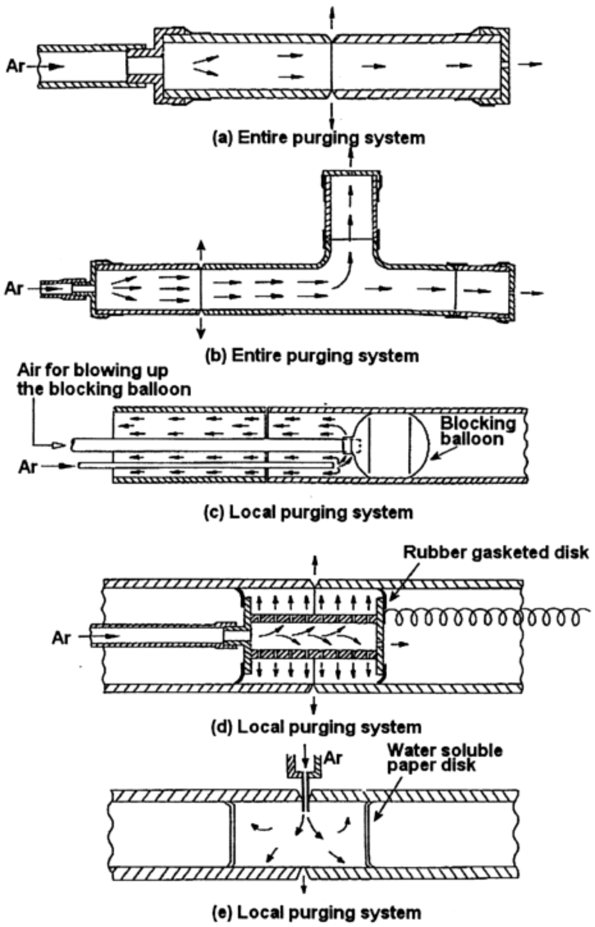


Figure 1. Typical gas purging systems for back shielding the root pass weld in piping

With either technique, a large volume of expensive argon gas and considerable time for setting jigs and purging gas are needed. Moreover, back shielding in this way can be risky because leaks in the gas passage of the system can allow air into the argon gas. Air contamination can cause insufficient fusion and penetration along with oxidized reverse surfaces of the root pass bead. Therefore, care must be taken to ensure back shielding is properly carried out.

Flux-cored filler rods eliminate gas purging through back shielding

To improve traditional GTAW root pass welding, the TGX series of flux-cored stainless steel filler rods have been developed to provide an easy-to-use and economical welding method that produces sound welds without using back shielding.

A TGX filler rod contains a particular flux inside a tubular rod of stainless steel as shown in Figure 2. When fused by the arc heat, the flux becomes molten slag. This molten slag can flow smoothly to the reverse side of the root to cover uniformly the penetration bead extruded inside the pipe. This molten slag protects the molten weld metal and red heated bead from the adverse effects of nitrogen and oxygen in the atmosphere. When the weld cools down the slag solidifies to become thin, fragile slag, which can be removed easily by lightly hitting the face of the joint with a chipping hammer. Then a glossy bead will appear on the face and reverse sides of the root with a smooth, uniform ripple without oxidation as shown in Figure 3. TGX filler rods provide regular penetration through the entire part of the pipe in all positions as shown in Figure 4.

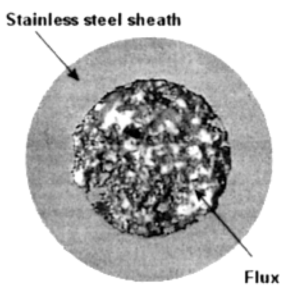


Figure 2. A cross-sectional view of a TGX flux-core filler rod

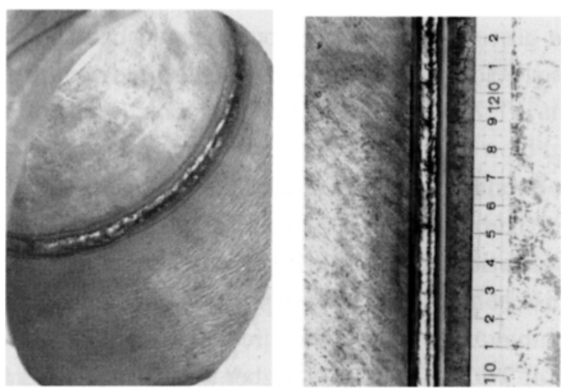


Figure 3. Glossy, regular bead appearance of the root pass weld of a 304-type stainless steel pipe welded with TGX-308L without back shielding

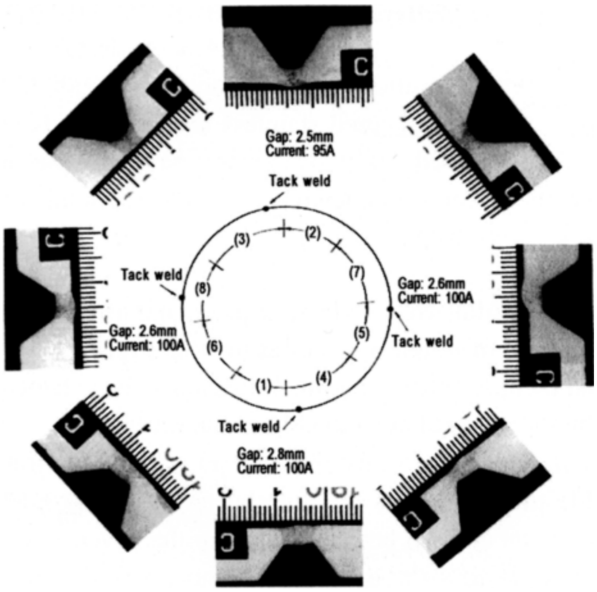


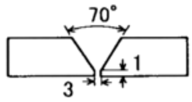
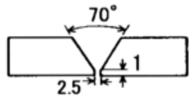
Figure 4. Macrostructure of TGX-308L weld made on a 304-type stainless steel pipe (12 X150 <*t*) in horizontally fixed position.

How TGX filler rods can cut costs for gas purging and back shielding

As discussed above, the use of a conventional solid filler rod requires back shielding normally with argon gas. Though the amount of argon gas and time for purging the inside of the pipe vary depending on the inside diameter and the length of the pipe to be purged, they markedly raise the total welding cost. Table 4 compares how using usual solid filler rods and TGX filler rods affects the factors associated with the costs of root pass Welding a pipe with an inside diameter of 305 mm. It is obvious that the using a TGX filler rod can noticeably reduce labor (total work time) by 23-74% because no downtime for setting the back shielding jig and pre-purging is needed. It can also reduce the consumption of shielding gas by 55-91% because no argon gas is needed for pre-purging and back shielding during welding, as compared with a typical solid filler rod.

On the other hand, because a TGX filler rod is a flux-cored rod, both the filler rod and power source consumption will slightly increase during welding because of slightly lower deposition efficiency (approx. 90%) than with a solid filler rod. Furthermore, the unit price of TGX filler rods is higher than that of solid filler rods. However, calculating the total welding cost by multiplying the unit price of each factor will show that the TGX series filler rods can lead to overall savings.

Table 4. A comparison between TGX and solid filler rods on work time, argon gas consumption, filler rod consumption and power source consumption in root pass welding of a pipe

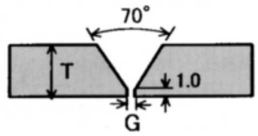
Filler rod	TGX filler rod	Solid filler rod	
Groove preparation			
Back shielding length of pipe	Without back shielding	300 mm for local shielding	6000 mm for entire shielding
Pre-purging [1] Setting jigs Welding [2] Arc time rate	Not required Not required 35 min 50%	5.2 min 10 min 30 min 50%	104 min Not required 30 min 50%
Total work time	**35 min**	**45.2 min**	**134 min**
Total filler rod consumption	**120 g**	**100 g**	**100g**
Pre-purging [1] Welding [2] Back shield [3]	Not required 263 liter Not required	122.2 liter 225 liter 240 liter	2444 liter 225 liter 240 liter
Total Ar gas consumption	**263 liter**	**587.2 liter**	**2909 liter**
Total power source consumption	**0.405 kwh**	**0.358 kwh**	**0.358 kwh**

Note:
(1) The pre-purging condition is per AWS D10.11-7X (Guide for Root Pass Welding and Gas Purging)
(2) Torch shielding gas flow rate for welding: 15 liter/min
Welding condition: 110 Amp. x 13 Volt
(3) Shielding gas flow rate for back shielding: 8 liter/min.

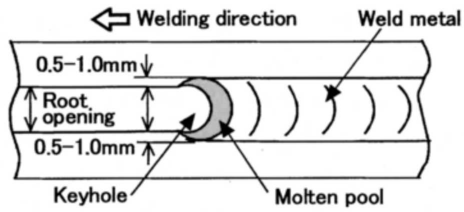
Welding procedure with TGX filler rods

TGX filler rods can be used in almost the same way as solid filler rods. The following are the specific techniques to be used for root pass welding with a TGX filler rod.

(1) PROPER ROOT OPENING to assure a sound penetration bead.

Groove preparation			
Plate thickness (T)	4 mm	6 mm	10 mm min
Root opening (G)	2.0 mm	2.5 mm	3.0 mm

(2) PROPER KEYHOLE TECHNIQUE to help the molten slag flow to the backside of the root.

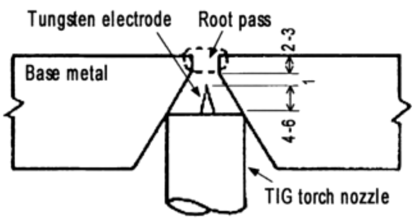


(3) HIGHER FEEDING PITCH with careful wire feeding than with a solid filler rod to ensure adequate fusion of the rod and sound penetration beads. This technique is to compensate for the slightly lower deposition efficiency (about 90%) of TGX filler rods.

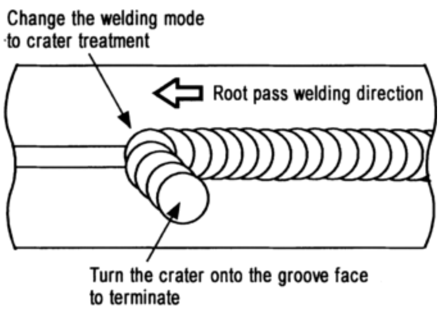
(4) PROPER WELDING CURRENT to ensure regular fusion and penetration.

Plate thickness	3-5 mm	6-9 mm	10 mm min
Amperage	80-90 A	90-105 A	90-110 A

(5) SHORT ARC LENGTH to ensure stable crater formation and regular slag flow by keeping the nozzle contact with the groove fusion faces, with a proper extension of tungsten electrode.

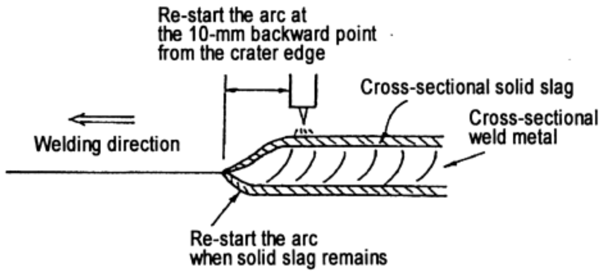


(6) PROPER CRATER TREATMENT by turning the crater onto the groove face to prevent crater cracking and shrinkage cavities in the crater.

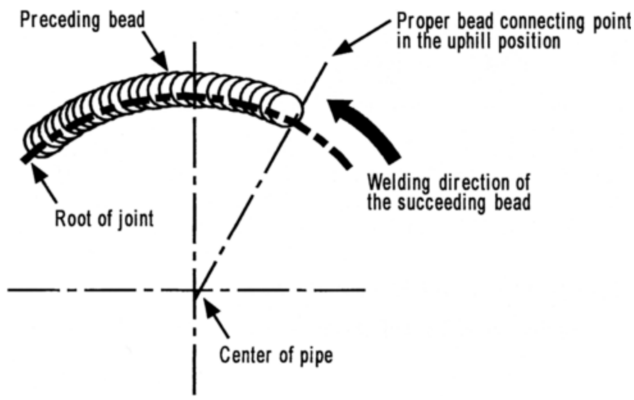


(7) PROPER BEAD CONNECTION to prevent oxidation in the penetration bead and to obtain normal penetration bead contour.

Maintain solid slag both on the crater and on the bead on the reverse side when re-starting an arc to join a preceding bead. The re-arcing point should be placed back from the edge of the crater by approximately 10 mm.



In 5G position welding, the termination of the succeeding bead onto the crater of the preceding bead should be done in the uphill positions to control the molten slag and thereby to help create the keyhole.



(8) ONLY ROOT PASS welding is suitable.
TGX filler rods are designed so that enough slag can be generated to cover both the surfaces of the face and reverse sides of the root pass bead; therefore, if a TGX filler rod is used in filler passes, all of the slag may cover the face side of the bead, thereby causing slag inclusions and lack of fusion.

Chemical, mechanical and microscopic properties of root pass welds

Chemical and mechanical properties of root pass welds are summarized in Table 5 for individual TGX filler rods. As shown in this table, every TGX filler rod exhibits low nitrogen in the bulk of root pass weld metal. Electron Probe Micro-Analysis (EPMA) of the vicinity of the reverse surface area has verified that no microscopic condensation of nitrogen can be observed. Still more, microstructure testing has revealed that the distribution of ferrite precipitation in the austenite matrix is uniform throughout the root pass weld. Low nitrogen content, together with the glossy bead appearance mentioned above, is evidence of the effectiveness of the shielding effect of the slag of TGX filler rod.

Table 5. Chemical and mechanical properties of single-V groove one-sided weld joints with TGX filler rods for root pass, TGS filler rods and DW flux-cored wires for filler pass

Filler rod for root pass (1)		TGX-308L (2.2Ø)	TGX-316L (2.2Ø)	TGX-309L (2.2Ø)	TGX-347 (2.2Ø)
Filler rod and wire for filler pass (2)		TGS-308 (2.4 Ø)	TGS-316L (2.4 Ø)	DW-309L (1.2Ø)	DW-347 (1.2Ø)
Type of base metal (Thickness, mm)		304 (9)	316L (9)	Mild steel / 316 (19)	321 (20)
Welding position		Flat	Flat	Flat	Flat
Welding current (DCEN for GTAW, DCEP for GMAW)		Root pass: 105A Filler pass: 150-180 A	Root pass: 105A Filler pass: 150-180 A	Root pass: 105A Filler pass: 180A	Root pass: 105A Filler pass: 180A
Chemical composition and ferrite content of root pass weld metal (%)	**C**	0.040	0.018	0.047	0.028
	Si	0.55	0.64	0.56	0.65
	Mn	1.11	1.48	1.36	1.78
	Ni	9.72	12.34	9.99	10.35
	Cr	18.89	18.93	19.47	18.67
	Mo	—	2.17	0.35	—
	Nb	—	—	—	0.44
	Ti	—	—	—	0.07
	N	0.044	0.041	0.038	0.044
	FS, FN	4.6-5.7	7.1-7.6	6.9-8.5	4.4-6.2
	SD, F%	7	7.5	7	6
	DD, FN	5.5	8	8	5
X-ray test per JIS		1st grade	1st grade	1st grade	1st grade
Joint tension test (Fracture position)		593 N/mm^2 (Base metal)	551 N/mm^2 (Base metal)	—	634 N/mm^2 (Weld metal)
2T-radius side and root bend test		No defect	No defect	No defect	No defect

Note:
(1) Torch shielding gas: Ar (without back shielding)
(2) Torch shielding gas: Ar for GTAW; CO_2 for GMAW
(3) FS: Ferrite scope; SD: Schaeffler diagram;
DD: Delong diagram

Corrosion resistance of root-pass welds

TGX filler rod root pass beads have to be followed by ordinary GTAW or GMAW filler pass beads to complete the weld joint. Accordingly, the root pass bead is reheated by subsequent beads. The surface of the root pass bead formed by a TGX filler rod without back shielding can therefore become oxidized. By contrast, the root pass bead formed by ordinary solid GTAW with back shielding will not become oxidized if the back shield is maintained until welding of the second or third passes is complete.

The effect of this oxide film on the corrosion resistance of the root pass weld has been examined, using specimens that include the reverse side surfaces affected by the presence or absence of back shielding. The results of a stress corrosion cracking (SCC) test (JIS G 0576: 42% magnesium chloride test), a pitting corrosion test (JIS G 0578: Ferric chloride test) and an intergranular corrosion test (JIS G 0575: Sulphuric acid-copper sulphate) are shown in Tables 6 thru 8, respectively.

Table 6. Results of SCC test (1)

Type of base metal	Filler rod		Ar back shield for root and 2nd pass	Threshold period of macrocrack (h)	
	Root pass	2nd pass		C-type specimen	L-type specimen
304	TGS-308L	TGS-308L	Used	1-2	15-20 (2)
	TGX-308L		Not used	1-2	15-20 (2)
304L	TGS-308L	TGS-308L	Used	1-2	—
	TGX-308L		Not used	1-2	—

Note:
(1) Two types of specimens:
(2) Crack occurred for 1-2 h in the base metal

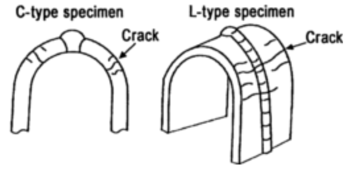
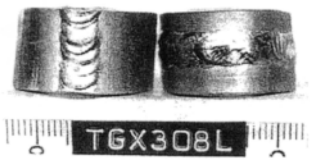


Table 7. Results of pitting corrosion test

Type of base metal	Filler rod		Ar back shield for root and 2nd pass	Corrosion weight loss ($g/m^2/h$)		
	Root pass	2nd pass		1	2	Av.
304	TGS-308L	TGS-308L	Used	14.77	14.12	14.45
	TGX-308L		Not used	17.67	12.61	15.14
316L	TGS-316L	TGS-316L	Used	5.03	3.91	4.47
	TGX-316L		Not used	4.49	5.89	5.19

Table 8. Results of intergranular corrosion test

Type of base metal	Filler rod	Ar back shield for root and 2nd pass	Root pass specimen after corrosion and bend test
304L	Root pass: TGX-308L 2nd pass: TGS-308L	Not used	
316L	Root pass: TGX-316L 2nd pass: TGS-316L	Not used	

In the SCC test, cracks occurred in the base metal within a short time (1-2 h), whether or not back shielding was present. As for the weld metal, there was no significant difference between TGS and TGX specimens. In the pitting corrosion test, TGS and TGX specimens exhibited almost the same results. In the intergranular corrosion test, TGX specimens showed no intergranular corrosion cracking on either the weld metal or the heat-affected zone of the base metal.

From the above, it can be concluded that, though the reverse surface of TGX root pass beads can become oxidized when welding the subsequent passes without back shielding, its corrosion resistance remains almost the same as that of traditional TGS root pass beads with back shielding.