



The Printer Working Group

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Working Draft

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## PWG Safe G-Code Subset for 3D Printing v1.0

Status: Stable

Abstract: This Best Practice document defines a "safe" subset of G-code for use in 3D printing with IPP along with the capabilities and parameters needed to allow a client to generate G-code compatible with the printer.

This is a PWG Working Draft. For a definition of a "PWG Working Draft", see:

<https://ftp.pwg.org/pub/pwg/general/pwg-process30.pdf>

This white paper is available electronically at:

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20190114.docx>

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20190114.pdf>

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25 Title: *PWG Safe G-Code Subset for 3D Printing v1.0*

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## 77 **1. Introduction**

78 G-Code [ISO6893-1] [RS274D] [RS274NGC] [REPRAP] is a commonly-used format for 3D  
79 printing with so-called Fused Deposition Modeling (FDM) printers. Besides the commands  
80 used to move the print head and/or platform and to extrude material, G-Code includes a  
81 variety of device control (e.g., set extruder temperature) and hardware access (e.g., write  
82 file to SD card) commands that pose serious safety and security concerns. To make matters  
83 worse, such commands are often printer-specific or have printer-specific variations in syntax,  
84 requiring the equivalent of printer driver software to produce G-Code suitable for a particular  
85 model or firmware version. Finally, differences in filament and extruder nozzle diameters  
86 mean that G-Code created for one print job may not work on the same printer due to changes  
87 to the material or extruder.

88 The IPP 3D Printing Extensions v1.0 [PWG5100.21] define the model and semantics for  
89 networked 3D printing, along with a required high-level 3D file format. However, the  
90 processing requirements of such a format require either improved printer controllers with  
91 greater memory, storage, and CPU capacity or the use of Cloud services to offload that  
92 processing.

93 The IPP Shared Infrastructure Extensions (INFRA) [PWG5100.18] define the model and  
94 semantics for Cloud printing, however it does not specify an intermediate format suitable for  
95 3D printing.

96 This document defines a "safe" subset of G-Code that can be used for direct and Cloud  
97 printing configurations, along with a description of the capabilities and parameters that will  
98 be needed to generate suitable layers for printing to the target printer.

99 The goal of this document is to enable the use of IPP with existing entry-level FDM printers  
100 that are not able to perform their own slicing and to enable generic Cloud and local  
101 infrastructure services to provide slicing services to existing FDM printers. Support for other  
102 kinds of 3D printers will likely require an intermediate format such as the 3MF Slice Extension  
103 [3MF-SLICE].

104

## 105 **2. Terminology**

### 106 **2.1 Terms Used in This Document**

107 *Cloud*: the environment supporting services such as Cloud Computing.

108 *Cloud Computing*: "... a model for enabling ubiquitous, convenient, on demand network  
109 access to a shared pool of configurable computing resources (e.g., networks, servers,  
110 storage, applications, and services) that can be rapidly provisioned and released with  
111 minimal management effort or service provider interaction." The NIST Definition of Cloud  
112 Computing [NISTSP800-145].

113 *Fused Deposition Modeling*: A 3D printing process that extrudes a molten material to draw  
114 layers, sometimes also called material extrusion.

### 115 **2.2 Acronyms and Organizations**

116 *IANA*: Internet Assigned Numbers Authority, <https://www.iana.org/>

117 *IETF*: Internet Engineering Task Force, <https://www.ietf.org/>

118 *ISO*: International Organization for Standardization, <https://www.iso.org/>

119 *PWG*: Printer Working Group, <https://www.pwg.org/>

120

### 121 **3. PWG Safe G-Code Subset**

122 This document defines a safe G-Code subset with the MIME Media Type  
123 "application/vnd.pwg-safe-gcode". Safe G-Code files consist solely of the following  
124 commands which represent the common subset of commands supported by most FDM  
125 printers:

126 G0: Rapid Linear Move

127 G1: Controlled Linear Move

128 G4: Dwell

129 G21: Set Units to Millimeters

130 G28: Move to Origin (Home)

131 G90: Set Absolute Positioning

132 G91: Set Relative Positioning

133 G92: Set Position

134 M82: Set Absolute Extrusion

135 M83: Set Relative Extrusion

136 Tnnn: Set Tool

137 Most machine ("M") commands are not allowed since they directly control or access the  
138 machine hardware. Temperature control and other machine settings are the responsibility  
139 of the IPP Printer, which will likely use the IPP Job Template attribute values to send the  
140 corresponding printer-specific G-code commands to a lower-level controller.

141 The line number command ("N") and checksum ("\*") are similarly not allowed because they  
142 are used for direct communications with the controller - IPP provides the necessary  
143 infrastructure for reliable communication of the G-Code file to the IPP Printer.

144 Comments starting with the ";" character are allowed and continue to the end of the current  
145 line.

146 For simplicity, safe G-Code always uses millimeters for the units (the default).

#### 147 **3.1 G0 and G1: (Rapid/Controlled) Linear Move**

148 These commands move the current tool (extruder) and/or extrude material for printing.  
149 Parameters for this command are:

- 150 Xnnn: Set X position in millimeters
- 151 Ynnn: Set Y position in millimeters
- 152 Znnn: Set Z position in millimeters
- 153 Ennn: Extrude the specified number of millimeters of material
- 154 Fnnn: Set the feed rate in millimeters/minute
- 155 Note: The "S" parameter is not allowed in safe G-Code.

### 156 **3.2 G4: Dwell**

- 157 This command pauses printing for a specifies amount of time. The "Pnnn" parameter  
158 specifies the time interval in milliseconds.

### 159 **3.3 G21: Set Units to Millimeters**

- 160 This command explicitly specifies that coordinates are in millimeters (the default).
- 161 Note: This command is only provided for completeness - there is no support in safe G-Code  
162 for any other units.

### 163 **3.4 G28: Move to Origin (Home)**

- 164 This command moves the current tool to the home position (end stops). The "X", "Y", and  
165 "Z" parameters may optionally be specified to move the tool on the specified axes - if not  
166 supplied the tool is moved on all axes.

### 167 **3.5 G90: Set Absolute Positioning**

- 168 This command specifies that all coordinates are relative to the origin of the machine.

### 169 **3.6 G91: Set Relative Positioning**

- 170 This command specifies that all coordinates are relative to the current position of the tool.

### 171 **3.7 G92: Set Position**

- 172 This command sets the current tool positions without moving or extruding material.  
173 Parameters for this command are:

- 174 Xnnn: Set X position in millimeters

175            Ynnn: Set Y position in millimeters

176            Znnn: Set Z position in millimeters

177            Ennn: Set extrusion to the specified number of millimeters of material

178 All positions are set to 0 if no parameters are specified.

### 179    **3.8 M82: Set Absolute Extrusion**

180 This command specifies that the extrusion ("E") coordinates in move commands are  
181 absolute.

### 182    **3.9 M83: Set Relative Extrusion**

183 This command specifies that the extrusion ("E") coordinates in move commands are relative.

### 184    **3.10 Tnnn: Set Tool**

185 This command sets the current tool (extruder) to use, starting at 0. Tool numbers correspond  
186 to the index within the "materials-col" Job Template attribute.

187



## 188 4. Generating Safe G-Code

189 IPP Clients [STD92] and Infrastructure Printers [PWG5100.18] can generate safe G-Code  
 190 using the values of Printer Description attributes reported by the IPP Printer or Proxy. Table  
 191 1 shows the information that is needed to generate safe G-Code for a printer. The "materials-  
 192 col" values are obtained from the "materials-col-database" and/or "materials-col-ready"  
 193 Printer Description attributes which provide a list of all possible materials and those that are  
 194 loaded in the Printer, respectively.

195 **Table 1 - Information Needed to Generate Safe G-Code**

Description	Current IPP Attribute
Accuracy limits/minimum layer height	print-accuracy-supported (collection)
Build platform dimensions	printer-volume-supported (collection)
Build platform shape	platform-shape (type2 keyword)
Extruder nozzle size/maximum layer height	See section <b>Error! Reference source not found.</b>
Filament diameter	materials-col.material-diameter (integer)
Retraction support	See section <b>Error! Reference source not found.</b>

### 196 4.1 Material Extrusion Parameters

197 IPP 3D v1.0 [PWG5100.21] does not define attributes or values for the extruder nozzle size,  
 198 nor does it define a way to specify whether retraction is used. These can be added to the  
 199 "materials-col" collection as:

200 "material-nozzle-diameter (integer(0:MAX))": Specifies the required extruder  
 201 diameter in nanometers, with the value 0 indicating the nozzle diameter is less than  
 202 1 nanometer.

203 "material-retraction (boolean)": Specifies whether retraction should be used with the  
 204 material.

205 A corresponding "material-nozzle-diameter-supported (1setOf (integer(0:MAX) |  
 206 rangeOfInteger(0:MAX)))" Printer Description attribute can provide the supported nozzle  
 207 diameter values. The presence of 'material-retraction' in the "materials-col-supported"  
 208 Printer Description attribute indicates that the Printer supports material retraction.

### 209 4.2 Support for Additional "Safe" G-Code Commands

210 In addition to the common subset of G-Code commands listed in the previous sections,  
 211 newer FDM printers support additional "safe" commands such as mixing of extruded material  
 212 ("M163", "M164", and "M165"), controlled arc ("G2" and "G3") and Bézier cubic spline ("G5").  
 213 In order for a generic slicer to support these commands, a printer needs to advertise its  
 214 support for them. The usual method employed for IPP is a PDL-specific capability attribute,

215 such as "safe-gcode-supported (1setOf text(MAX))" with each value corresponding to a  
216 named command.

## 217 5. Printing Safe G-Code

218 Printers that support safe G-Code can largely pass the print file to the controller - typically  
219 all that is required is to add printer-specific commands to initialize the printer to set  
220 temperatures and other machine settings, send the print file, and then add printer-specific  
221 commands to return the printer to an idle state.

222 Status information returned by the printer can be used to set the values of the various IPP  
223 Printer Status attributes.

### 224 5.1 Adding Printer-Specific Machine Commands

225 IPP Job Template attributes provide the values for extruder and build platform temperatures,  
226 as well as the list of materials used in the print job. Table 2 lists the standard attributes a  
227 FDM printer can use to configure the machine prior to printing.

228 **Table 2 - IPP Job Template Attributes**

Description	IPP Attribute(s)	Typical G-Code
Build platform temperature	platform-temperature	M140/M190
Chamber humidity	printer-volume-humidity	M146
Chamber temperature	printer-volume-temperature	M141/M191
Extruder nozzle size	materials-col/material-nozzle-diameter	
Extruder temperature	materials-col/material-temperature	M104/M109
Filament color	materials-col/material-color	
Filament diameter	materials-col/material-diameter materials-col/material-diameter-tolerance	M200
Filament type	materials-col/material-type	
Flow rate	materials-col/material-rate materials-col/material-rate-units	M203
Job Name	job-name	M531
Print accuracy	print-accuracy	M201/M202/ M222/M223
Print quality/speed	print-quality	

229 When an IPP Client does not specify one or more of these attributes, the corresponding  
230 default attribute values are used - "materials-col-default", "platform-temperature-default",  
231 "print-accuracy-default", "print-quality-default", "printer-volume-humidity-default", and  
232 "printer-volume-temperature-default" for the attributes in Table 2.

## 233 **5.2 Printer-Specific Attributes and Values**

234 IPP allows implementors to add printer-specific attributes and values as defined in section 7  
235 of [STD92]. However, printers cannot depend on IPP Clients or Infrastructure Printers to  
236 support such attributes or values, particularly for generation of safe G-Code. Default values  
237 should be used as a backup when necessary.

## 238 **5.3 Canceling Jobs**

239 When a Job is canceled, Printers SHOULD stop sending G-Code commands as soon as  
240 possible and then send printer-specific commands to the controller to return the printer to an  
241 idle state.

242

## 243 6. IANA Considerations

### 244 6.1 Attribute Registrations

245 The attributes defined in this white paper will be published by IANA according to the  
246 procedures in IPP/1.1 Model and Semantics [STD92] section 7.2 in the following file:

247 <https://www.iana.org/assignments/ipp-registrations>

248 The registry entries will contain the following information:

249	Job Template attributes:	Reference
250	-----	-----
251	materials-col (1setOf collection)	[PWG5100.21]
252	material-extruder-diameter (integer(0:MAX))	[SAFEGCODE]
253	material-retraction (boolean)	[SAFEGCODE]
254		
255	Printer Description attributes:	Reference
256	-----	-----
257	material-extruder-diameter-supported (1setOf (integer(0:MAX)	
258	rangeOfInteger(0:MAX))	[SAFEGCODE]
259	safe-gcode-supported (1setOf text(MAX))	[SAFEGCODE]

### 260 6.2 MIME Media Type Registration

261 The MIME media type defined in this white paper will be published by IANA according to the  
262 procedures in the Media Type Specifications and Registration Procedures [BCP13] in the  
263 following file:

264 <https://www.iana.org/assignments/media-types>

265 The registry will contain the following information:

266	Type name: application
267	
268	Subtype name: vnd.pwg-safe-gcode
269	
270	Required parameters: N/A
271	
272	Optional parameters: N/A
273	
274	Encoding considerations: US ASCII
275	
276	Security considerations: Safe G-code prohibits machine control commands,
277	however it is up to the consumer to verify that such commands are not part
278	of the print file.
279	
280	Interoperability considerations: While the format is interoperable, the
281	contents of each file are still specific to the combination of material
282	parameters and printer capabilities used for the G-code.
283	

284 Published specification: [this white paper]  
285  
286 Applications that use this media type: IPP 3D  
287  
288 Fragment identifier considerations: N/A  
289  
290 Additional information:  
291  
292     Deprecated alias names for this type: N/A  
293     Magic number(s): N/A  
294     File extension(s): pwggc  
295     Macintosh file type code(s): N/A  
296  
297 Person & email address to contact for further information: Michael Sweet,  
298 msweet@apple.com  
299  
300 Intended usage: COMMON  
301  
302 Restrictions on usage: N/A  
303  
304 Author/Change controller: The Printer Working Group, c/o The IEEE Industry  
305 Standards and Technology Organization, 445 Hoes Lane, Piscataway, NJ  
306 08854, USA  
307  
308 Provisional registration? (standards tree only): No

## 309 7. References

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338 8011, January 2017, <https://tools.ietf.org/html/std92>  
339

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349 white paper:

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## 351 **9. Change History**

### 352 **9.1 January 14, 2019**

- 353 • Updated status to stable
- 354 • Added version number to title
- 355 • Section 3.10: Tool number corresponds to the materials-col index.
- 356 • Section 5: Added subsection on canceling jobs.
- 357 • Section 7: Fixed reference link for STD92.

### 358 **9.2 July 4, 2018**

- 359 • Removed old comments.
- 360 • RFC 8011 is now STD 92.

### 361 **9.3 June 4, 2018**

- 362 • Status: Prototype
- 363 • Type: Best Practice
- 364 • Section 3: Reword M command prohibition.
- 365 • Changed registered extension to ".pwggc".
- 366 • Added RS274NGC reference.

### 367 **9.4 April 26, 2018**

- 368 • Made a PWG Best Practice working draft.
- 369 • Added reference to RepRapWiki for G-Code
- 370 • Added reference to ISO 6983-1 for current official G-Code specification
- 371 • Section 4: Mention materials-col-database and materials-col-ready
- 372 • Section 4.1: Retitle as "Material Extrusion Parameters"

### 373 **9.5 April 16, 2018**

- 374 • Status: Interim
- 375 • Introduction: Added discussion of nozzle and filament diameter influencing
- 376 portability of G-code, and why we want this.
- 377 • Added G21, M82, and M83 commands, and hooks for other printer-specific
- 378 commands (safe-gcode-supported)



- 379       • Updated T command (set tool) to use 0 as the first index.
- 380       • Added sections on generating and printing safe G-code
- 381       • Added IANA registration of new attributes and the MIME media type
- 382       • Added references to 3MF slicing and RFC 8011.

383    **9.6 April 12, 2018**

384    Initial revision.