



The Printer Working Group

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Working Draft

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## PWG Safe G-Code Subset for 3D Printing

Status: Prototype

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-pwgsafegcode10-20180704.docx>

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20180604.pdf>

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

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## 75 **1. Introduction**

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

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

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

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

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

102

## 103 **2. Terminology**

### 104 **2.1 Terms Used in This Document**

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

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

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

### 113 **2.2 Acronyms and Organizations**

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

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

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

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

118

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

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

124 G0: Rapid Linear Move

125 G1: Controlled Linear Move

126 G4: Dwell

127 G21: Set Units to Millimeters

128 G28: Move to Origin (Home)

129 G90: Set Absolute Positioning

130 G91: Set Relative Positioning

131 G92: Set Position

132 M82: Set Absolute Extrusion

133 M83: Set Relative Extrusion

134 Tnnn: Set Tool

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

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

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

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

#### 145 **3.1 G0 and G1: (Rapid/Controlled) Linear Move**

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

148 Xnnn: Set X position in millimeters

149 Ynnn: Set Y position in millimeters

150 Znnn: Set Z position in millimeters

151 Ennn: Extrude the specified number of millimeters of material

152 Fnnn: Set the feed rate in millimeters/minute

153 Note: The "S" parameter is not allowed in safe G-Code.

### 154 **3.2 G4: Dwell**

155 This command pauses printing for a specifies amount of time. The "Pnnn" parameter  
156 specifies the time interval in milliseconds.

### 157 **3.3 G21: Set Units to Millimeters**

158 This command explicitly specifies that coordinates are in millimeters (the default).

159 Note: This command is only provided for completeness - there is no support in safe G-Code  
160 for any other units.

### 161 **3.4 G28: Move to Origin (Home)**

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

### 165 **3.5 G90: Set Absolute Positioning**

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

### 167 **3.6 G91: Set Relative Positioning**

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

### 169 **3.7 G92: Set Position**

170 This command sets the current tool positions without moving or extruding material.  
171 Parameters for this command are:

172 Xnnn: Set X position in millimeters

173 Ynnn: Set Y position in millimeters

174 Znnn: Set Z position in millimeters

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

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

### 177 **3.8 M82: Set Absolute Extrusion**

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

### 180 **3.9 M83: Set Relative Extrusion**

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

### 182 **3.10 Tnnn: Set Tool**

183 This command sets the current tool (extruder) to use, starting at 0.

184 **Editor's Note: Discuss how client maps tool numbers to materials.**

185



## 186 4. Generating Safe G-Code

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

193 **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>

### 194 4.1 Material Extrusion Parameters

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

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

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

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

### 207 4.2 Support for Additional "Safe" G-Code Commands

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

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

## 215 5. Printing Safe G-Code

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

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

### 222 5.1 Adding Printer-Specific Machine Commands

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

226 **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	

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

**231 5.2 Printer-Specific Attributes and Values**

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

## 236 6. IANA Considerations

### 237 6.1 Attribute Registrations

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

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

241 The registry entries will contain the following information:

242	Job Template attributes:	Reference
243	-----	-----
244	materials-col (1setOf collection)	[PWG5100.21]
245	material-extruder-diameter (integer(0:MAX))	[SAFEPCODE]
246	material-retraction (boolean)	[SAFEPCODE]
247		
248	Printer Description attributes:	Reference
249	-----	-----
250	material-extruder-diameter-supported (1setOf (integer(0:MAX)	
251	rangeOfInteger(0:MAX))	[SAFEPCODE]
252	safe-gcode-supported (1setOf text(MAX))	[SAFEPCODE]

### 253 6.2 MIME Media Type Registration

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

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

258 The registry will contain the following information:

259     Type name: application  
260  
261     Subtype name: vnd.pwg-safe-gcode  
262  
263     Required parameters: N/A  
264  
265     Optional parameters: N/A  
266  
267     Encoding considerations: US ASCII  
268  
269     Security considerations: Safe G-code prohibits machine control commands,  
270     however it is up to the consumer to verify that such commands are not part  
271     of the print file.  
272  
273     Interoperability considerations: While the format is interoperable, the  
274     contents of each file are still specific to the combination of material  
275     parameters and printer capabilities used for the G-code.  
276

277 Published specification: [this white paper]  
278  
279 Applications that use this media type: IPP 3D  
280  
281 Fragment identifier considerations: N/A  
282  
283 Additional information:  
284  
285     Deprecated alias names for this type: N/A  
286     Magic number(s): N/A  
287     File extension(s): pwggc  
288     Macintosh file type code(s): N/A  
289  
290 Person & email address to contact for further information: Michael Sweet,  
291 msweet@apple.com  
292  
293 Intended usage: COMMON  
294  
295 Restrictions on usage: N/A  
296  
297 Author/Change controller: The Printer Working Group, c/o The IEEE Industry  
298 Standards and Technology Organization, 445 Hoes Lane, Piscataway, NJ  
299 08854, USA  
300  
301 Provisional registration? (standards tree only): No

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333

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343 white paper:

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## 345 **9. Change History**

### 346 **9.1 July 4, 2018**

- 347 • Removed old comments.
- 348 • RFC 8011 is now STD 92.

### 349 **9.2 June 4, 2018**

- 350 • Status: Prototype
- 351 • Type: Best Practice
- 352 • Section 3: Reword M command prohibition.
- 353 • Changed registered extension to ".pwggc".
- 354 • Added RS274NGC reference.

### 355 **9.3 April 26, 2018**

- 356 • Made a PWG Best Practice working draft.
- 357 • Added reference to RepRapWiki for G-Code
- 358 • Added reference to ISO 6983-1 for current official G-Code specification
- 359 • Section 4: Mention materials-col-database and materials-col-ready
- 360 • Section 4.1: Retitle as "Material Extrusion Parameters"

### 361 **9.4 April 16, 2018**

- 362 • Status: Interim
- 363 • Introduction: Added discussion of nozzle and filament diameter influencing
- 364 portability of G-code, and why we want this.
- 365 • Added G21, M82, and M83 commands, and hooks for other printer-specific
- 366 commands (safe-gcode-supported)
- 367 • Updated T command (set tool) to use 0 as the first index.
- 368 • Added sections on generating and printing safe G-code
- 369 • Added IANA registration of new attributes and the MIME media type
- 370 • Added references to 3MF slicing and RFC 8011.

### 371 **9.5 April 12, 2018**

372 Initial revision.