



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-pwgsafegcode10-20180604.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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## 74 **1. Introduction**

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

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

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

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

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

101

## 102 **2. Terminology**

### 103 **2.1 Terms Used in This Document**

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

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

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

### 112 **2.2 Acronyms and Organizations**

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

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

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

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

117

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

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

123 G0: Rapid Linear Move

124 G1: Controlled Linear Move

125 G4: Dwell

126 G21: Set Units to Millimeters

127 G28: Move to Origin (Home)

128 G90: Set Absolute Positioning

129 G91: Set Relative Positioning

130 G92: Set Position

131 M82: Set Absolute Extrusion

132 M83: Set Relative Extrusion

133 Tnnn: Set Tool

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

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

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

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

#### 144 **3.1 G0 and G1: (Rapid/Controlled) Linear Move**

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

147 Xnnn: Set X position in millimeters

148 Ynnn: Set Y position in millimeters

149 Znnn: Set Z position in millimeters

150 Ennn: Extrude the specified number of millimeters of material

151 Fnnn: Set the feed rate in millimeters/minute

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

### 153 **3.2 G4: Dwell**

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

### 156 **3.3 G21: Set Units to Millimeters**

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

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

### 160 **3.4 G28: Move to Origin (Home)**

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

### 164 **3.5 G90: Set Absolute Positioning**

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

### 166 **3.6 G91: Set Relative Positioning**

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

### 168 **3.7 G92: Set Position**

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

171 Xnnn: Set X position in millimeters

172 Ynnn: Set Y position in millimeters

173 Znnn: Set Z position in millimeters

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

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

### 176 **3.8 M82: Set Absolute Extrusion**

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

### 179 **3.9 M83: Set Relative Extrusion**

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

### 181 **3.10 Tnnn: Set Tool**

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

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

184



## 185 4. Generating Safe G-Code

186 IPP Clients [RFC8011] and Infrastructure Printers [PWG5100.18] can generate safe G-Code  
 187 using the values of Printer Description attributes reported by the IPP Printer or Proxy. Table  
 188 1 shows the information that is needed to generate safe G-Code for a printer. The "materials-  
 189 col" values are obtained from the "materials-col-database" and/or "materials-col-ready"  
 190 Printer Description attributes which provide a list of all possible materials and those that are  
 191 loaded in the Printer, respectively.

192 **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>

### 193 4.1 Material Extrusion Parameters

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

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

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

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

### 206 4.2 Support for Additional "Safe" G-Code Commands

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

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

## 214 5. Printing Safe G-Code

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

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

### 221 5.1 Adding Printer-Specific Machine Commands

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

225 **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	

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

**230 5.2 Printer-Specific Attributes and Values**

231 IPP allows implementors to add printer-specific attributes and values as defined in section 7  
232 of [RFC8011]. However, printers cannot depend on IPP Clients or Infrastructure Printers to  
233 support such attributes or values, particularly for generation of safe G-Code. Default values  
234 should be used as a backup when necessary.

## 235 6. IANA Considerations

### 236 6.1 Attribute Registrations

237 The attributes defined in this white paper will be published by IANA according to the  
238 procedures in IPP/1.1 Model and Semantics [RFC8011] section 7.2 in the following file:

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

240 The registry entries will contain the following information:

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

### 252 6.2 MIME Media Type Registration

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

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

257 The registry will contain the following information:

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

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

## 301 7. References

- 302 [3MF-SLICE] "3MF Slice Extension Specification and Reference Guide", August  
303 2016, <https://3mf.io/specification/>
- 304 [BCP13] N. Freed, J. Klensin, T. Hansen, "Media Type Specifications and  
305 Registration Procedures", BCP 13, RFC 6838, January 2013,  
306 <https://tools.ietf.org/html/rfc6838>
- 307 [ISO6983-1] "Automation systems and integration -- Numerical control of machines  
308 -- Program format and definitions of address words -- Part 1: Data  
309 format for positioning, line motion and contouring control systems",  
310 ISO 6983-1:2009
- 311 [NISTSP800-145] P. Mell, T. Grance, "The NIST Definition of Cloud Computing",  
312 September 2011,  
313 <http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf>
- 314 [REPRAP] "G-code - RepRapWiki", <http://reprap.org/wiki/G-code>
- 315 [RS274D] "Interchangeable Variable Block Data Format for Positioning,  
316 Contouring, and Contouring/Positioning Numerically Controlled  
317 Machines", EIA Standard RS-274-D, February 1979
- 318 [RS274NGC] "The NIST RS274NGC Interpreter - Version 3", NIST Standard RS-  
319 274-NGC, August 2000, [https://www.nist.gov/publications/nist-  
320 rs274ngc-interpreter-version-3](https://www.nist.gov/publications/nist-rs274ngc-interpreter-version-3)
- 321 [PWG5100.18] M. Sweet, I. McDonald, "IPP Shared Infrastructure Extensions  
322 (INFRA)", PWG 5100.18-2015, June 2015,  
323 [https://ftp.pwg.org/pub/pwg/candidates/cs-ippinfra10-20150619-  
324 5100.18.pdf](https://ftp.pwg.org/pub/pwg/candidates/cs-ippinfra10-20150619-5100.18.pdf)
- 325 [PWG5100.21] M. Sweet, "IPP 3D Printing Extensions v1.0 (3D)", PWG 5100.21-  
326 2017, February 2017,  
327 [https://ftp.pwg.org/pub/pwg/candidates/cs-ipp3d10-20170210-  
328 5100.21.pdf](https://ftp.pwg.org/pub/pwg/candidates/cs-ipp3d10-20170210-5100.21.pdf)
- 329 [RFC8011] M. Sweet, I. McDonald, "Internet Printing Protocol/1.1: Model and  
330 Semantics", RFC 8011, January 2017,  
331 <https://tools.ietf.org/html/rfc8011>  
332

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342 white paper:

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## 344 **9. Change History**

### 345 **9.1 June 4, 2018**

- 346 1. Status: Prototype
- 347 2. Type: Best Practice
- 348 3. Section 3: Reword M command prohibition.
- 349 4. Changed registered extension to ".pwggc".
- 350 5. Added RS274NGC reference.

### 351 **9.2 April 26, 2018**

- 352 1. Made a PWG Best Practice working draft.
- 353 2. Added reference to RepRapWiki for G-Code
- 354 3. Added reference to ISO 6983-1 for current official G-Code specification
- 355 4. Section 4: Mention materials-col-database and materials-col-ready
- 356 5. Section 4.1: Retitle as "Material Extrusion Parameters"

### 357 **9.3 April 16, 2018**

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

### 367 **9.4 April 12, 2018**

368 Initial revision.